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ARTICLE

Efficiency of Agricultural Production in India: An Analysis using Non-Parametric Approach

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ABSTRACT

The study estimates the technical efficiency (TE) in agricultural production in India and decomposes it into its constituents- pure technical efficiency (PTE) and scale efficiency (SE). The analysis is undertaken using a non-parametric approach- data envelopment analysis. The districts are considered as the decision making units (DMUs). The study also identifies major determinants that influence the TE by regressing the estimates of efficiency yielded in the first step on plausible causative variables. A total of 409 districts are included in the analysis. The district level per-hectare value of crop output is the output variable considered in the analysis. The input variables included are fertiliser application, rainfall, extent of degraded land, irrigation, availability of workers per hectare of net cropped area. The overall mean level of TE is reported as 42 per cent. The PTE is about 54 per cent and SE is about 78 per cent, pointing to presence of large level of inefficiencies. The study reveals large variation of efficiency over agro-ecologies. The highest level of TE is exhibited by the hill and mountainous region, and the lowest by the rainfed region. The rainfed and irrigated regions posts comparable level of PTE, highlighting the possibility for improving the productivity through manipulation of conditions that enable efficiency. The study identifies significant and positive effect of infrastructure, education, and capital assets in enhancing the TE. One highlight of the study is the usage of a variable depicting health of agro-ecosystem, captured using the extent of degraded land as a determinant of TE. This variable exhibited significant and negative effect calling for accelerated efforts to conserve the natural resource base.

Key words: Education, land degradation, Infrastructure, Sustainable intensification, Technical efficiency.

JEL: C14, Q15, Q16, Q18

I

INTRODUCTION

Ensuring food and nutritional security and thereby improving the quality of life have remained the most important development goal of nation states. The two most important strategies for achieving food and nutritional security are accelerated technology generation and its adoption and improving the efficiency of production. This has been demonstrated very emphatically during the green revolution period in some of the countries. In India, National Agricultural Research System (NARS) with a wide network has been established under the public sector to facilitate technology generation. In order to facilitate faster technology diffusion, establishment of extension network has been undertaken. While technology generation is of paramount

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importance, the efficiency component also assumes great significance in a country like India for two reasons. One, the natural resources like water, land and biodiversity face serious strain. Producing more output for all the units of inputs remains the only means to maintain positive output growth without challenging the natural resource health. Two, a check on food prices going high is crucial for sustaining food security in the country. Again, efficient growth is the only means to raise food output without increase in the average cost of production and hence prices. Some researchers have observed that farmers in the developing countries fall short of achieving the full potential of a technology (Kalirajan, 1991; Trans *et al*., 1993; Parikh *et al.*, 1995). Such a phenomenon can be attributed to two factors: one is put forward by T.W. Schultz (1964) in his "poor but efficient hypothesis" where he delineates the traditional agricultural system as one which lacks the ability and/or willingness to adjust the levels of input as per the new technology, but efficiently allocates the resources in the conventional technological frame. This is essentially micro in approach. The second factor lies with the larger issues of cultural and institutional constraints as noted by Ghatak and Ingerset (1984). Researchers suggest that efficiency improvement holds promising prospects for productivity enhancement in case of many crops and regions, and thereby for ensuring food and nutritional security. This situation becomes more glaring in the context of the limited scope for expansion of land frontier under cultivation (Bhende and Kalirajan, 2007), as is the case of India.

Two important dimensions of the concept of efficiency are technical efficiency (TE) and allocative efficiency (AE). While TE focuses on the firm's ability to produce maximum possible output for a certain input level given a technology, AE refers to the efficiency in resource allocation at optimal proportions given the respective prices. The present study focuses on TE of crop sector in India. It estimates the TE considering districts as production units/decision making units (DMUs). Many authors have studied technical efficiency of individual farmers/production units. Most of these studies have identified some factors at the farmer level including the level of illiteracy and lack of access to inputs and information etc. as the major factors responsible for the inefficiency (Thiam *et al*., 2001). Another set of studies has focused on the inefficiency of the system as the major factor that affects the production. Such studies are essentially macro in approach. These studies have also identified the changes in efficiency as a major factor responsible behind the changes in total factor productivity (TFP) as well. In this approach, larger geographical areas, including countries, states etc. are considered as a production entity and focuses on the factors behind the system level inefficiency (Coelli and Rao, 2003; O'Donnell, 2010). This study also considers a larger geographical area, viz., districts as the production units, identifies the major factors that determine of TE and decomposes it into pure and scale efficiencies.

The present study adds to the existing body of literature on the topic in three different ways. One, there have been limited attempts to analyse the efficiency of crop production in India[1] considering aggregate level entities as DMUs. The present study estimates the TE at district level and derives the distribution of TE estimate across all the agro-ecologies. Second, studies that estimate TE using non-parametric methods are very few; those where DMUs are aggregate spatial units like districts are fewer. By using DEA, the technical efficiencies are estimated and decomposed it into its components. Third, the study identifies health of agro-ecosystem as an important factor influencing efficiency. Empirical evidence for the linkage of agro-ecology health affecting the agricultural production through efficiency pathway is scarce.

II

DATA AND METHODOLOGY

Approach for Estimating TE Using DEA

The TE can be estimated by using both parametric and non-parametric methods. Each method holds distinct advantages and disadvantages over the other. The parametric method warrants explicit assumptions regarding the functional form of the technical relationship between the inputs and outputs and distribution of the error term (Jondrow *et al*., 1982). Under this method statistical techniques are used to estimate parameters of the specified function. On the other hand, the non-parametric methods in general, and DEA in particular, constructs piecewise linear function, using mathematical programming based on empirical observations of inputs and outputs without the assumption of a functional relationship *a priori* between them. Moreover, under DEA framework, output and input variables can assume different units of measurement without the requirement of any *a priori* trade-offs. Also avoided is the requirement for having information on prices of inputs and outputs. However, the DEA estimator also has the lacuna that it, being deterministic than stochastic, is sensitive to measurement errors and outliers. A comprehensive review on the two approaches is available in Charnes *et al.,* (1994) and Kalirajan and Shand, (1999). In this paper, the DEA approach has been adopted, as mentioned earlier.

The TE is conceptualised by Farrell (1957) as the ability of the firm to use minimum feasible amounts of inputs to produce a specified level of output or to produce the maximum output feasible from specified level of inputs. Usually, they are called input oriented and output oriented measures, respectively (Coelli *et al*., 2002). The choice between the two methods is subjective. However, this study uses input oriented model, as this reflects more efficient use of resources (Rodriguez Diaz *et al.,* 2004). The TE itself can be further decomposed into pure technical efficiency (PTE) and scale efficiency (SE). The SE refers to the most efficient scale of operation in the sense of maximising the average productivity. And, separation of the scale effect from TE yields PTE (Coelli, 1996).

The application of linear programming as a technique to estimate the efficiency is associated with Charnes *et al.* (1978), wherein he assumed constant returns to scale

(CRS). The CRS model is appropriate only when the firm is functioning at optimal scale (Coelli, 1996). However, institutional constraints, imperfect competition, market interventions etc. may cause a DMU or a firm to operate at less than optimal scale. Many subsequent papers have considered alternative sets of assumptions like variable returns to scale (VRS) that permit calculation of TE without the effect of scale effects (Banker *et al.*, 1984). This DEA estimation under VRS assumption is more flexible. Further, it envelops the data more tightly than DEA under CRS assumption.

The model is presented here for a case where there is data on K inputs and M outputs for each of the N districts. Input and output vectors are represented by the column vectors x_i and y_i, for the i-th district. The K by N input matrix, X, and M by N output matrix, Y, represent the data for all the N districts in the sample. The model to calculate CRS technical efficiency under input orientation can be specified as:

$\text{Min}_{\theta\lambda}\theta,$

Subjected to

$-y_i + Y\lambda \geq 0,$

$\theta x_i - X\lambda \geq 0,$

$N1'\lambda = 1,$

$\lambda \geq 0,$

where, θ indicates a scalar, N1 indicates a vector of ones, whereas λ indicates a vector of constants. For every DMU, the model is solved once using variable λ and θ, exploring for the highest level of radial contraction of the input vector x_i with the given technology set. The TE score for i-th DMU is the value of θ corresponding with this contraction. It has a value $0 \leq \theta \leq 1$. If the θ value is one, indicating the DMU considered is on the frontier, the vector λ is an NT X 1 vector of weights which defines the linear combination of the peers of the i-thDMU. In the above equation the first constraint depicts that the output produced by the i-thDMU is smaller than that on the frontier. On the otherhand, the second constraint limits the proportional decrease in input use, when θ is minimised to the input use achieved with the best technology. Constraint three is the convexity constraint that creates a VRS specification without which it specifies a CRS model.

The SE of the i-th DMUs is derived as

$$\text{SEi} = \frac{\text{TEi}(\text{under CRS assumption})}{\text{TEi}(\text{under VRS assumption})}$$

SE = 1 implies scale efficiency and a value less than one reflects scale inefficiency. The scale inefficiency can be due to either increasing or decreasing returns to scale. This can be ascertained by undertaking one more DEA with imposition of non-increasing returns to scale (NIRS) constraint (Coelli, 1996). The TE scores in the present paper are estimated by using a program DEAP version 2.1 Coelli (1996).

Determinants of TE Using Tobit model

Identification of the determinants of TE helps in delineating policy directions to improve the efficiency. Once the district level efficiencies are estimated, their determinants are identified by analysing the second-stage relationship of the efficiency estimates with suspected correlates of efficiency. To undertake this, the efficiency measures obtained from the DEA analysis are regressed on the explanatory variables. As the efficiency values are censored- ranging from zero to one- a Tobit model (Tobin, 1958) is employed.

Model and Data

The efficiency is estimated by employing one aggregate output and four inputs. The output variable is the average value of district level crop productivity per hectare of net cropped area for the year 2003-04 and 2004-05, derived by using CSO estimates of value of crop output, as estimated by Chand *et al*., (2009). Here, the value of output has been used to aggregate the district level crop production, considering the price as the single term for aggregation. While using the value of output for estimating the efficiency, some important theoretical apprehension has to be addressed, the major one being the suitability of values as a basis for estimating efficiency. This is particularly so in the context of existence of different kinds of production systems- cash crops, subsistence crops, and crops that arenot traded etc. Nevertheless of this diversity, price remains the most important aggregator. Literature provide evidence for using “value of output”, which is the product of the prices and yield per unit area, for measuring the efficiency, both as a part of estimating the TFP and decomposing to its constituent components, i.e., technical change and efficiency change. For example, Coelli and Rao (2003) has estimated the efficiency changes of agricultural sector in 93 countries, which accounts for 97 per cent of total agricultural production, with a coverage of 185 agricultural commodities for a 20 year period of 1980-2000. The value of outputs derived by multiplying the quantity of production (provided by Food and Agricultural Organisation) with the (international) prices has been used as a dependent variable. In case of India, the district level value of output as the output variable for estimating efficiency has been used by Shanmugam and Venkataramani (2006). The single most advantage of using the aggregate values happens to be combining different kinds of agricultural outputs into a single unit. The input variables used in the estimation are rainfall, use of chemical fertilisers (nutrients), labour availability represented by number of workers per hectare and area under irrigation as a percentage to net sown area, corresponding to the same time period. The analysis is carried using data of 409 districts, and the estimated TE scores are post-classified across all agro-ecosystems.

While estimating the Tobit regression, it is hypothesised that the efficiency of crop production might be influenced by factors falling mainly under three dimensions- capital, driver and agro-ecological endowments. The capital dimension is further separated into three, namely natural capital, man-made capital and human capital. The natural capital dimension is captured through three set of variables. They are average size of holding representing operational size, livestock intensity representing crop-livestock integration and extent of land degradation capturing the agro-ecosystem health. The issue of relationship of farm size with agricultural productivity and efficiency has been intensively debated in India. Many studies have suggested an inverse relationship (Sen, 1962, Bardhan, 1973). However, some studies have also reported that the inverse relationship has weakened over a period of time (Chadha, 1978; Bhalla and Roy, 1988). However, Chand *et al.,* (2011) has noted that the observed inverse relationship has not disappeared over time. Due to the divergent conclusions, this review of literature does not help to form a definite expectation regarding its impact on efficiency.

Based on literature, it is expected that the land degradation would impact the TE negatively (Wadud and White, 2000; Heath and Binswanger, 1996). The crop livestock-integration has been identified as a pertinent aspect of sustainability of agricultural system due to its role in strengthening ecosystem services (Erenstein and Thorpe, 2010).[2] On the basis of the availability of the data, two variables are considered for capturing the man-made capital- road density as a proxy for infrastructure and tractor density representing durable capital assets, and positive sign is *a priori* assumed for both. The linkages between infrastructure and durable capital assets on sustainable agricultural growth in India and elsewhere are well established (Antle, 1984 and Bhatia, 1999). The human capital variable has been captured through literacy rate. Positive role of education in productivity growth is widely recognised (Datt and Ravallion, 1998; Jamison and Lau (1982), based on a survey of 31 studies has noted that four years of education has increased agricultural production by about 8.7 per cent. They also report that the marginal effects of education on output is greater in rural than in urban areas. In this study, the literacy rate of rural women is used as a variable representing human capital, based on a few considerations, the foremost among them being the extensive contribution of women in Indian agriculture in varying roles, from managers to landless labourers. The report of National Commission on Farmers by Government of India (2006) has noted that in the overall farm production, women’s average contribution in total labour ranges between 55 and 66 per cent. Their share is much higher in certain regions. However, among the agricultural workforce, the female literacy rate at 34.1 per cent forms only half of the male literacy rate (Government of India, 2008); and the average years of education of a female worker is only 1.9 years compared to 4.5 years in case of male self-employed worker in the agricultural sector. Also, evidences suggest that the marginal effect of educating females is more than that of men in contributing to agricultural productivity, through improvement in efficiency of input use (Moock, 1976; Saito *et al*., 1994).

The study considered markets as the major driver variable. This dimension is captured by percentage area under high value crops like fruits and vegetables. The agro-ecological variation has been taken into account through dummy variables denoting four agro-ecologies. There have been many attempts to classify India into various zones based on agro-climates/agro-ecology. For example, Planning Commission, during the VII plan period (1985-1990) has classified India into 15 agro-climatic zones, on the basis of climate and physiography. The National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), an establishment under the Indian Council of Agricultural Research (ICAR) in 1994 divided the country into agro-ecological sub-regions (AESRs) (60 in number) by considering soils, climate and length of growing period (LGP) and several other related parameters. These classifications have been pioneer in their attempts; however, they have a limitation that since they provide a large number of zones, they are not easily amenable for statistical/econometric treatments. The National Agricultural Technology Project (NATP) of ICAR has also undertaken a classification of the country into different agro-ecosystems, viz., arid, coastal, rainfed, irrigated and hill and mountain. The classification of NBSS & LUP is based primarily on agro-climate, whereas socio-economic variables are also incorporated in other studies. Saxena *et al*., (2001) have combined the elements of the previous approach in the NATP classification, with slight modifications, and classified the districts into various agro-ecosystems. The present study has used this classification for incorporating in our econometric model. The regression used four dummy variables, keeping the arid region as the base dummy. The model used for estimation of determinants of efficiency is as follows:

Efficiency (VRS/CRS/ Scale) = f (average size of land holding, percentage area under land degradation, livestock intensity, road density, tractor density, rural female literacy rate, percentage area under high value crops, agro-ecology dummies).

III

RESULTS AND DISCUSSION

The mean and standard deviations of the major variables considered in the analysis, distributed across agro-ecological regions are provided in Table 1. The values of mean and standard deviations are arrived at by using weighted averages for each agro-ecological region. The significance of variation across the agro-ecological zone has been tested by using one way ANOVA (F test). The analysis indicates that agro-ecological zones have significant impact on all the variables. It can be observed that the mean productivity (for the year 2003-04 and 2004-05) to be roughly Rs. 28.2 thousand per ha, the highest in hill and mountainous and the lowest in the arid regions respectively. The overall average rainfall is 967 mm and it ranges between 353 mm in arid region to 2012 mm in hill and mountainous region. Usage of inputs like fertiliser and irrigation remained the highest in the irrigated region as expected, while the hill and mountainous region topped the list for 'availability of workers'. The use of all the three inputs is found lowest in the arid region. The hill and mountainous region are endowed with the highest number of livestock per hectare of net sown area. Conservation of the health of the natural resource base is a serious concern to ensure the sustainability of agricultural production. It is observed that at the national level about one-third of the land is severely degraded. Almost half of total land is degraded in the arid region mainly on account of its exposure to severe soil erosion. While the coastal region is characterised by the smallest land holding size, it is far ahead of other regions in terms of road density and rural female literacy rate. Except for farm size, the arid region has been at the lowest rung in case of many variables considered in efficiency determination like livestock intensity, road density and share of area under fruits and vegetables.

TABLE 1. DESCRIPTIVE STATISTICS ON MAJOR VARIABLES BYAGRO-ECOLOGICAL REGIONS

Variable (1)	Arid (2)	Coastal (3)	Hill and mountainous (4)	Irrigated (5)	Rainfed (6)	Overall (7)
Productivity ('000 Rs./ha)	12.8	43.7	57.70	40.9	22.6	28.2
	(10.8)	(14.7)	(27.0)	(17.2)	(12.0)	(17.2)
Rainfall (mm)	353	1614	2012	895	986	967
	(107)	(864)	(996)	(353)	(400)	(517)
Fertiliser (NPK, kg/ha)	34.35	176.29	165.05	222.16	95.82	128.76
	(39.2)	(119.8)	(151.9)	(117.8)	(60.7)	(104.1)
Workers (No./ha)	0.62	2.22	2.42	2.02	1.48	1.61
	(0.27)	(0.75)	(1.06)	(1.08)	(0.68)	(0.89)
Net area irrigated (per cent)	21.03	44.00	37.05	78.03	31.19	43.01
	(13.7)	(25.4)	(25.39)	(19.49)	(18.34)	(28.09)
Average size of holding size	5.96	0.83	0.96	1.61	1.79	2.02
(ha)	(2.96)	(0.32)	(0.29)	(1.69)	(0.58)	(1.78)
Land degradation (per cent)	49.52	20.48	18.61	35.55	32.54	33.00
	(24.00)	(18.02)	(15.69)	(28.22)	(23.54)	(24.80)
Livestock intensity (No./ha)	1.32	2.71	5.22	2.93	2.40	2.48
	(0.78)	(1.20)	(2.12)	(1.15)	(1.32)	(1.35)
Road density (km/'000 ha)	2.29	9.48	5.38	6.76	5.44	5.84
	(0.90)	(5.82)	(2.05)	(5.06)	(3.91)	(4.55)
Tractor density (No./'000	12.16	4.65	12.05	42.31	10.44	18.15
ha)	(5.52)	(5.30)	(17.23)	(28.61)	(10.86)	(21.85)
Rural female literacy rate	45.60	67.19	58.57	45.62	52.75	51.75
(per cent)	(11.49)	(14.60)	(10.35)	(12.94)	(12.55)	(14.55)
Area under fruits and	1.06	12.63	20.99	4.81	8.92	7.65
vegetables (per cent)	(1.30)	(8.84)	(13.54)	(55.02)	(44.25)	(34.08)

Source: Estimated by the author.

Table 2 summarises the DEA results, post-classified across agro-ecological regions (indicating mean and standard deviation, SD). The overall TE with CRS assumption has been estimated at 42 per cent. The overall average SE is 78 per cent and PTE is 54 per cent, pointing to existence of substantial level of inefficiencies among the districts. In a naïve technical perspective, it indicates that with the current level of technology, there is considerable scope to reduce the input use, still produce same output by eliminating pure technical inefficiency. But in practice, due weightage need to be accorded to factors like agro-ecological characteristics, resource endowments and cropping pattern while generalising the results. One of the major reasons for the large variation between the CRS and VRS technical efficiencies is because of many districts operating at inefficient scale. Interestingly, close to 90 per cent of districts has been observed to be operating at increasing returns to scale. The presence of large level of variation in TE across agro-ecologies is another significant observation. The hill and mountainous region has the highest CRS technical efficiency and rainfed region has the lowest. However, if the scale effects are removed, the arid region (followed by hill and mountainous region) emerges with highest PTE and the irrigated region the lowest. One of the most striking observations is the contrast in performance of arid and irrigated region with respect to input use and technical efficiency. Though irrigated region is generally well endowed with resources, it operates with lower efficiency, whereas arid region, with lowest input use operates with higher efficiency.

TABLE 2. SUMMARY STATISTICS ON EFFICIENCY ESTIMATES

	VRS		CRS		Scale	
Agro-ecology	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Arid	0.75	0.23	0.44	0.26	0.58	0.24
Coastal	0.57	0.24	0.52	0.26	0.89	0.11
Hill and mountainous	0.74	0.24	0.64	0.28	0.87	0.20
Irrigated	0.50	0.24	0.45	0.26	0.85	0.13
Rainfed	0.52	0.16	0.37	0.16	0.71	0.17
Overall	0.54	0.21	0.42	0.23	0.78	0.18

The methodology for efficiency estimation involves consideration of the efficient envelope generated for the 409 districts, irrespective of the agro-ecological variations. However, to get the efficiency values for each agro-ecology separately, the DEA analysis is carried out independently taking into consideration the districts under them alone, and the results are provided in Table 3. The efficiency figures are generally higher when independently estimated. The highest TE (under CRS) is observed in arid region and the lowest in rainfed region. The hill and mountainous regions registered highest PTE.

TABLE 3. THE VRS, CRS AND SCALE EFFICIENCY RESULTS AS PER SEPARATE DEA

Agro-ecologic regions (1)	VRS (2)	CRS (3)	Scale (4)
Arid	0.87	0.80	0.92
Coastal	0.89	0.71	0.79
Hill and mountainous	0.93	0.67	0.72
Irrigated	0.73	0.63	0.85
Rainfed	0.72	0.54	0.75

The frequency distribution of all the efficiency estimates –VRS, CRS and Scale, at a class interval of 0.10 efficiency points is provided in Table 4. In case of both VRS and CRS technical efficiencies, roughly 60-70 per cent of the districts fell in the TE category of 20 to 60 per cent. The overall TE above 80 per cent is noted only in 10 per cent of the districts in case of CRS assumption and it improved to about 15 per cent in case of VRS assumption. More than half of the districts operated with more than 80 per cent SE.

TABLE 4. PERFORMANCE COMPARISON ACROSS EFFICIENCY CATEGORIES

Efficiency category (1)	VRS (2)	CRS (3)	Scale (4)
Below 0.10	0	0	0
0.10- 0.20	0	11.3	0
0.20-0.30	11.3	23.7	0.7
0.30-0.40	17.8	22.7	2.6
0.40-0.50	24.9	14.9	7.3
0.50-0.60	14.4	8.1	7.3
0.60-0.70	11.2	6.1	10.6
0.70-0.80	5.7	3.2	18.8
0.80-0.90	5.1	3.9	24.0
Above 0.90	9.6	6.1	28.7
No. of observations	409	409	409

The distribution of TE across agro-ecological regions is summarised in Table 5. TE above 90 per cent was the highest in hill and mountainous regions (29 per cent) whereas the rainfed region registered the lowest level (0.5 per cent). This could be probably due to multitudes of constraints faced in rainfed farming situations.

The Determinants of Efficiency

Prior to the Tobit regression analysis, bivariate correlation among the explanatory variables is examined (Appendix I). It indicated that the farm size is negatively correlated with all the explanatory variables, except for tractor density. The area under high value crops are positively correlated with road density, livestock density and literacy; and negatively with variables like farm size and tractor density. Another significant observation is the negative correlation between livestock density (per hectare of land) and farm size, highlighting the role of livestock in the livelihood of low land holders. The positive correlation of tractor density with rural road density

TABLE 5. PERFORMANCE COMPARISON ACROSS AGRO-ECOLOGIES

Efficiency category (1)	Arid (2)	Coastal (3)	Hill and mountainous (4)	Irrigated (5)	Rainfed (6)	Overall (7)
Below 0.10	0	0	0	0	0	0
0.10- 0.20	0	7.3	0	16.2	10.8	11.2
0.20-0.30	46.2	14.6	9.5	23.8	25.5	23.7
0.30-0.40	23.1	17.1	9.5	13.1	31.4	22.7
0.40-0.50	0	14.6	23.8	11.5	17.2	14.9
0.50-0.60	7.7	17.1	9.5	7.7	6.4	8.1
0.60-0.70	7.7	9.8	9.5	7.7	3.9	6.1
0.70-0.80	0	0	4.8	4.6	2.9	3.2
0.80-0.90	0	2.4	4.8	8.5	1.5	3.9
Above 0.90	15.4	17.1	28.6	6.9	0.5	6.1
No of observations	13	41	21	130	204	409

and farm size is also noteworthy. The negative relationship of land degradation with literacy could be probably due to better awareness of environmental concerns and sustainable landmanagement. The lower farm size promotes higher level degradation, probably due to intensive production practices. The determinants of the TE are identified using Tobit regression analysis and the results are provided in Table 6.

TABLE 6. TOBIT ESTIMATES OF DETERMINANTS OF EFFICIENCY

	VRS		CRS		Scale	
Variables (1)	Coefficient (2)	SE (3)	Coefficient (4)	SE (5)	Coefficient (6)	SE (7)
Constant	0.69799***	0.06725	0.33811***	0.06478	0.53002***	0.05206
Average size of holding (ha)	0.00001	0.00019	-0.00002	0.00018	0.00001	0.00015
Land degradation (per cent)	-0.00246***	0.00038	-0.00263***	0.00037	-0.00098**	0.00029
Livestock per hectare of net sown area	0.00021	0.00019	0.00022	0.00019	0.00009	0.00015
Road density	-0.00001	0.00003	0.00006*	0.00003	0.00010***	0.00003
Tractor density (no.)	0.00076	0.00055	0.00197***	0.00054	0.00218***	0.00004
Rural female literacy (per cent)	0.00397***	0.00080	0.00416***	0.00078	0.00151**	0.00063
Area under high value crops (per cent)	0.00023	0.00016	0.00026*	0.00016	0.00008	0.00013
Agro-ecology dummies						
Coastal	-0.35570***	0.06400	-0.06012	-0.06122	0.27199***	0.04921
Hill and mountainous	-0.12699*	0.06974	0.11658*	0.06673	0.28888***	0.05398
Irrigated	-0.29034***	0.05932	-0.03419	-0.05670	0.22469***	0.04555
Rainfed	-0.30763***	0.05530	-0.11325**	-0.05254	0.11373***	0.04218
No. of observations	409		409		409	
Log-likelihood function	66.62		91.84		54.63	

***, ** and * indicate probabilities at 1, 5 and 10 per cent levels, respectively.

Out of the three natural capital variables considered in the analysis, the average size of holding did not have any significant influence on VRS, CRS, or scale efficiencies.

This could be probably due to the fact that rather than the average size of holding in a district, the nature of distribution of the holdings among different farm categories might be more important variable that may influence the efficiency of production at the aggregate level. However, due to the data limitation, this aspect like usage of median instead of mean is not included in the analysis. Another important variable is the land degradation reflecting eco-system health. In our analysis, the variable indicates land degradation of the severe type including salinity, sodicity and erosion is used. It turns out that land degradation affects all the efficiency parameters negatively. One plausible reason may be that the degraded land behaves differently compared to the normal land in the realms of nutrient dynamics, soil properties and its interaction with biological entities. Further, such soils warrant different management strategies like chemical treatments, soil and water conservation efforts, etc., requiring greater capital investment and specialised knowledge. Another important natural capital variable is livestock intensity, which captures the crop-livestock integration. It is hypothesised that the higher number of livestock units per unit of cultivated land, would promote soil fertility. However, this variable has not turned out to be significant. One possible reason may be that higher livestock intensity requires more area under fodder crops which have lower productivity (in economic terms) compared to the non-fodder crops. Another reason for this can be that the integration of crop-livestock system is gradually getting weak. This happens in the context of increased use of the chemical fertilisers, rather than manures of livestock origin to replenish the nutrient loss. Another area of integration is the use of livestock for draft purpose, a domain which is increasingly being carried out through mechanised means.

Road density and tractor density are the major man-made capital considered in the analysis. Researchers suggest that rural road facilitates diffusion of agricultural technologies, enhance more efficient allocation of resources, reduce transaction costs and strengthen linkages in agriculture (Narayanamoorthy and Hanjra, 2006). Both the variables reflect a common pattern in their influence on the TE- significant and positive influence on CRS TE, but not on PTE. In contrast, these variables have significant and positive effect on the SE pointing to the situation that the effect of these variables on TE may be through its effect on the SE, rather than through PTE.

The TE is affected positively by the human capital dimension through its significant and positive influence on both PTE and SE. The positive role of the literacy factor on efficiency enhancement in Indian agriculture through promotion of better management practices is well documented (Reddy and Sen, 2004, Shanmugam and Venkataramani, 2006; Bhende and Kalirajan, 2007). Considering the widespread role of women in various agricultural operations with both the managerial and labour service activities, enhancing their education level would promote the efficiency of production. The driver variable considered in the analysis is markets, captured through area under high value crops. The results reveal that the higher the area under the high value crops, the higher would be the technical efficiency.

The agro-ecologies have significant impact on technical efficiency. In general, it can be observed that, compared to the base dummy (arid region) CRS technical efficiency is significantly higher in hill and mountainous region, and significantly lower in rainfed region. All the regions have registered significantly lower PTE compared to the arid region. On the other hand, SE has shown significantly higher values for all the agro-ecologies compared to the base, the highest being in hill and mountainous region, revealing scope for their improvement. The arid region in general applies less of all the inputs per unit of cultivated land, but uses it more efficiently. As noted earlier, the analysis reveals prevalence of increasing returns to scale operating in many districts. This indicates that there is scope for further input intensification. Sustainable intensification can turn out to be a strategy to increase the agricultural production.

IV

SUMMARY AND CONCLUSION

This study estimates the TE of production considering districts as the DMUs, and further decomposes the TE using DEA approach. The study reveals existence of large extent of inefficiencies at district level, exhibiting wide inter-district variations. The hill and mountainous region posted the highest level of technical efficiency, whereas the lowest was noted in arid and rainfed regions. But, once the scale effect is negated, the highest pure technical efficiency turned out to be in arid region. It is also noteworthy that the irrigated and rainfed regions operate at very close pure technical efficiency levels. The results clearly indicate that notwithstanding the agro-ecological differences, the efficiency can be improved through manipulating the enabling conditions.

The study provides some important suggestions for policy. First, the study provides evidence for positive role of the education influencing the crop production through efficiency improvement. This could be through improvement in the awareness of the cultivators on improved farming practices, resource management etc. In this context, it would be of importance to introduce various activities for improving the information flow and awareness of the cultivators. Steps to improve the agricultural extension carry significant role in this direction. Second, improving the ecosystem health is significant in attaining higher production efficiency. Steps to prevent further degradation of the land and to ameliorate the already degraded land, are important directions in this regard. It needs greater investment on soil water conservation efforts. Third, infrastructure would help in capitalising the scale effect and promote the technical efficiency. The paper has considered road density as the variable for representing the infrastructure. Rural roads help farmers to easier access to inputs as well as easier disposal of outputs, thereby improving the efficiency. Investments in rural roads and steps to promote acquisition of durable assets like agricultural machinery would be the key steps in improving the efficiency. Literature suggests that augmenting rural credit has greater role in boosting the demand for farm machineries. Fourth, the increasing returns to scale conditions prevailing in Indian agriculture could be due to the sub-optimal application of inputs. This points to the need for sustainable intensification of agriculture. Fifth, the study shows that agro-ecologies influence technical efficiency, signalling the need to develop region-specific strategies to improve efficiency. Development of region specific agro-ecologic plans could be a useful step in this direction.

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NOTES

1. One such study is that of Shanmugam and Venkataramani (2006) wherein they estimate the TE for 248 districts of India using stochastic frontier framework.
2. The number of livestock was measured in terms of adult cattle units.

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APPENDIX 1. BIVARIATE CORRELATION AMONG MAJOR VARIABLES

Variable (1)	Farm size (2)	Area under high value crops (3)	Land degradation (4)	Livestock intensity (5)	Road density (6)	Tractor density (7)	Female literacy (8)
Farm size	1.00	-0.30***	-0.01	-0.34***	-0.23***	0.14***	-0.09*
Area under high value crops		1.00	-0.23***	0.22***	0.21***	-0.24***	0.27***
Land degradation			1.00	-0.02	-0.22***	0.14***	-0.27***
Livestock intensity				1.00	0.09*	0.01	-0.10*
Road density					1.00	0.11**	0.38***
Tractor density						1.00	0.01
Female literacy							1.00

***, **, and * indicates statistical significance at 1, 5 and 10 per cent, respectively.