Agricultural Economics Research Review
Vol. 22 July-December 2009 pp 215-224

Technical Efficiency and its Determinants in Tomato Production in Karnataka, India: Data Envelopment Analysis (DEA) Approach

D. Sreenivasa Murthy*, M. Sudha, M.R. Hegde and V. Dakshinamoorthy
Division of Extension and Training, Indian Institute of Horticultural Research,
Hessaraghatta Lake Post, Bangalore-560 089, Karnataka

Abstract

Low productivity in agriculture is mainly due to the inability of the farmers to exploit the available technologies fully, resulting in lower efficiencies of production. The present study has estimated the technical and scale efficiencies of tomato-producing farms in Karnataka, considering different production levels and has identified the determining factors of their technical efficiency. The study is based on the data collected from the major tomato-producing regions of Karnataka, viz. Kolar and Bangalore rural districts of Karnataka, under three-production situations, viz. small, medium and large farms. Data Envelopment analysis (DEA) and log linear regression models have been used for estimating the technical efficiency and its determining factors, respectively. The study has indicated that most of the farms irrespective of size of holding have shown technical inefficiency problems. The medium farmers have been observed with best measures of technical efficiency, which has been explained by factors such as the land and labour productivity and education. Though medium farmers have been found efficient, with higher yields, it is the small farmers who have emerged as price-efficient producers in terms of lower cost on production (Rs 1.72/kg compared to Rs 2.01 in medium farms and Rs 1.85 in large farms) and higher unit profit. Most of the farms have been observed to have potential to expand production and productivity, increasing technical efficiency as majority have been performing with increasing returns to scale.

Introduction

One of the main reasons for low productivity in agriculture all over the world, including India is the inability of farmers to fully exploit the available technologies, resulting in lower efficiencies of production. This fact has been emphasized in many studies, particularly on cereals and pulses (Kalirajan, 1981; 1982; Bagi, 1982; Battese, 1992; Battese and Coelli, 1988; 1992; Anjana *et al*., 1996; Sharif and Dar, 1996; Battese and Broca, 1997; Villano and Fleming, 2006; Mehmet and Ceyhan, 2007). The situation of horticultural crops in India, which is the second largest producer of fruits and vegetables in the world, is not different. The productivity in most of the crops is relatively low in India compared to the world average and the reasons quoted for it are non-adoption of available hybrid/HYV seeds and pest, disease and nutrient management technologies. Though sufficient information on the status of the allocative and technical efficiencies is available for agriculture sector in India and other countries, very little attention was paid to the estimation of the technical efficiency in horticultural crops in India.

For the estimation of technical efficiency, several methods like ordinary least squares (OLS) regression, stochastic frontier analysis (SFA) and total factor productivity (TFP) indices using price-based index numbers (PIN), are used. The OLS methods are well known and easy to implement, however, it has been documented that it requires the specification of a functional form for the production technology and provides information about the average performance rather than frontier performance. SFA is an econometric

* Author for correspondence,
Email: srinivas@iihr.ernet.in
The comments of the referee are gratefully acknowledged.

technique that addresses the latter problem, by specifying a composed error-term, with one part capturing data noise and the other, inefficiency. However, SFA methods still require a functional form to be specified, plus distribution forms for its composed error structure (Coelli and Battese 1996). PIN methods, such as the popular Tornqvist TFP index, suffer from the problem that it requires access to the reliable price information (which is often difficult to obtain) and it does not explicitly accommodate scale effects. Of late, the popular method of estimating the maximum possible output has been the "*data envelopment analysis*" (DEA), advocated by Charnes *et al.* (1978), which overcomes most of these limitations. The present paper has used this method to estimate the technical efficiency in one of the horticultural crops, viz. tomato in India. Further, the existing pattern of input use and constraints of production have also been examined in tomato as it may help the policymakers and others to take appropriate decisions for enhancing production to meet the growing demand related to nutrition and export requirements. Correction measures based on the determinants of inefficiency will help improve operational efficiency and profits of farmers. Thus, the present paper has addressed the issues such as the existing pattern of input use and profitability, technical efficiency and factors associated with the following specific objectives:

- To examine the economics of production and input-use pattern in tomato across different category of farmers,
- To analyze technical efficiency and scale efficiency in tomato using DEA, and
- To identify the productivity, human and institutional factors which determine the technical efficiency of tomato production.

Methodology

Tomato *(Lycopersicon esculentum* L*)*, which is identified for the present study, is one of the major vegetables grown all over the world with the production of 124.75 million tonnes. In India, it is the third largest vegetable next to only potato and brijnal with the production of about 7.60 million tonnes (FAO, 2007), accounting nearly for about 7.5 per cent of total vegetable area and 9.0 per cent of the vegetable production (NHB, 2008). Over the past 25 years, the production has grown at a compound growth rate of 7.23 per cent. However, examination of the source of growth has indicated that it is more due to increase in area (4.62 %) than increase in the yield (2.55 %).

Study Regions and Data

The state of Karnataka was purposively selected, as it is one of the important states in India with a contribution of 12.38 per cent to the total production (NHB, 2008). Kolar and Bangalore rural districts were selected as they ranked the highest in production in Karnataka. Three talukas in the Kolar district, viz. Kolar, Bangarapet and Mulbagil and one in Bangalore rural district, viz. Doddaballapur were selected based on their contribution to the total production. Six-farmers in each of the districts were selected randomly and data of 30 farmers in each of these three categories, viz. small, medium and large farm(er)s were collected during 2003-04. Thus, a total sample of 90 farmers was used for the analysis.

Analytical Framework

Technical efficiency refers to the firm's ability to produce the maximum possible output from a given combination of inputs and technology. *Data envelopment analysis* (DEA) advocated by Charnes *et al.* (1978) was used in the present study to examine the technical efficiency because of the advantages mentioned earlier.

Data Envelopment Analysis: The DEA method is a frontier method that does not require specification of a functional or distributional form, and can accommodate scale issues. This approach was first used by Farrell (1957) as a piecewise linear convex hull approach to frontier estimation and later by Boles (1966) and Afriat (1972). This approach did not receive wide attention till the publication of the paper by Charnes *et al.* (1978), which coined the term *data envelope analysis.* A large number of papers have extended and applied the DEA technology in the western world. Very few studies have used this approach in India, especially in agriculture or horticulture for measuring efficiency. DEA method has the disadvantage that it does not explicitly accommodate the effects of data noise. In the present case, the DEA method was preferred because data noise was less of an issue as most of the variables in tomato production were included and because of its ability to readily produce rich information on technical efficiency, scale efficiency and peers.

The DEA was applied by using both classic models CRS (constant returns to scale) and VRS (variable returns to scale) with input orientation, in which one seeks input minimization to obtain a particular product level. Under the assumption of constant returns to scale, the linear programming model for measuring the efficiency of tomato farms are (Coelli *et al.,* 1998):

$$\begin{aligned} &\text{Min}_{\theta,\lambda}\,\theta \\ &\text{Subject to} \quad -y_i + Y\lambda \geq 0 \\ &\qquad \theta x_i - X\lambda \geq 0 \\ &\qquad \lambda \geq 0 \end{aligned} \qquad \ldots(1)$$

where,

y_i is a vector ($m \times 1$) of tomato output of the i^{th} Tomato Producing Farms (TPF),

x_i is a vector ($k \times 1$) of inputs of the i^{th} TPF,

Y is a tomato output matrix ($n \times m$) for n TPFs,

X is the tomato input matrix ($n \times k$) for n TPFs,

θ is the efficiency score, a scalar whose value will be the efficiency measure for the i^{th} TPF. If θ =1, TPF will be efficient; otherwise, it will be inefficient, and

λ is a vector ($n \times 1$) whose values are calculated to obtain the optimum solution. For an inefficient TPF, the λ values will be the weights used in the linear combination of other, efficient, TPFs, which influence the projection of the inefficient TPF on the calculated frontier.

The specification of constant returns is only suitable when the firms work at the optimum scale. Otherwise, the measures of technical efficiency can be mistaken for scale efficiency, which considers all the types of returns to production, i.e., increasing, constant and decreasing. Therefore, the CRS model was reformulated by imposing a convexity constraint. The measure of technical efficiency obtained in the model with variable returns is also named as 'pure technical efficiency', as it is free of scale effects. The following linear programming model estimated it:

$$\begin{aligned} &\text{Min}_{\theta,\lambda}\,\theta \\ &\text{Subject to} \quad -y_i + Y\lambda \geq 0 \\ &\qquad \theta x_i - X\lambda \geq 0 \\ &\qquad N_1\lambda = 1 \\ &\qquad \lambda \geq 0 \end{aligned} \qquad \ldots(2)$$

where, N_1 is a vector ($n \times 1$) of ones.

When there are differences between the values of efficiency scores in the models CRS and VRS, scale inefficiency is confirmed, indicating that the return to scale is variable, i.e. it can be increasing or decreasing (Färe and Grosskopf, 1994). The scale efficiency values for each analyzed unit can be obtained by the ratio between the scores for technical efficiency with constant and variable returns as follows:

$$\theta_s = \theta_{CRS}(X_K, Y_K)/\theta_{VRS}(X_K, Y_K) \qquad \ldots(3)$$

where,

$\theta_{CRS}(X_K, Y_K)$ = Technical efficiency for the model with constant returns,

$\theta_{VRS}(X_K, Y_K)$ = Technical efficiency for the model with variable returns, and

θ_s = Scale efficiency.

It was pointed out that model (2) makes no distinction as to whether TPF is operating in the range of increasing or decreasing returns (Coelli *et al.*, 1998). The only information one has is that if the value obtained by calculating the scale efficiency in Equation (3) is equal to one, the TPF will be operating with constant returns to scale. However, when θ_s is smaller than one, increasing or decreasing returns can occur. Therefore, to understand the nature of scale inefficiency, it is necessary to consider another problem of linear programming, i.e. the convexity constraint of model (2), $N_1\lambda = 1$, is replaced by $N_1\lambda \leq 1$ for the case of non-increasing returns, or by $N_1\lambda \geq 1$, for the model with non-decreasing returns. Therefore, in this work, the following models were also used for measuring the nature of efficiency.

Non-increasing returns:

$$\begin{aligned} &\text{Min}_{\theta,\lambda}\,\theta \\ &\text{Subject to} \quad -y_i + Y\lambda \geq 0 \\ &\qquad \theta x_i - X\lambda \geq 0 \\ &\qquad N_1\lambda \leq 1 \\ &\qquad \lambda \geq 0 \end{aligned} \qquad \ldots(4)$$

Non-decreasing returns:

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

$$\text{Subject to} \quad -y_i + Y\lambda \geq 0$$

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

$$N_1\lambda \geq 1$$

$$\lambda \geq 0 \qquad \ldots(5)$$

It is to be stated here that all the above models should be solved *n* times, i.e. the model is solved for each TPF in the sample.

Tomato production (t/ha) was used as an output (Y) in the present case and total male labour (man days), total female labour (women days), seeds/plant population (No.), farm yard manure (t), plant nutrients N (kg), P (kg), K (kg) separately, capital inputs (Rs) on plant protection, other input costs and fixed input costs as inputs (X). The models were solved using the DEAP version 2.1 taking an input orientation to obtain the efficiency levels.

Determinants of Technical Efficiency

Ray (1991) and Worthington and Dollery (1999), used traditional DEA in the first stage to estimate the technical efficiency and in the second stage estimated the determinants of technical efficiency from the factors contributing to this technical efficiency by using econometric procedure.

In the present study, the technical efficiency values obtained from the DEA model considering the CRS input-oriented model were used for examining the relationship between the technical efficiency and factors influencing it. The technical efficiency score from CRS model was chosen as the dependent variable for its high accuracy in discriminating efficiency as compared to variable returns to scale (Gonclaves *et al*., 2008). The explanatory variables included were of three different types, viz. productivity (land, labour and capital), respondent farmers (age and education), and institutional-intervention factors (organizational participation, institutional credit use and technical input). The traditional method of regression was used for this purpose and ordinary least square analysis was carried out to estimate the regression equation. The regression model specified for the present study is given in Equation (6):

$$Y = a\, x_1^{\,b1}\, x_2^{\,b2}\, x_3^{\,b3} x_4^{\,b4}\, x_5^{\,b5}\, x_6^{\,b6}\, x_7^{\,b7}\, x_8^{\,b8}\, U \quad \ldots(6)$$

where,

Y = Technical efficiency scores,

x_1 = Land productivity measured in kg of tomato produced in one hectare,

x_2 = Labour efficiency measured in terms of total revenue from the tomato divided by the total labour costs,

x_3 = Capital-use efficiency estimated by dividing total yield with operating expenses,

x_4 = Age of the farmers in years,

x_5 = Years of education,

x_6 = Dummy variable to define whether farmers participated in any input and output marketing organizations (1) or not (0) over the years,

x_7 = Dummy to define whether the farmers used institutional credit (1) or not (0), and

x_8 = Dummy to define frequency of technical visits (1) or not (0).

'a' and 'b_i' are the constant and the co-efficients respectively, which were estimated through the ordinary least square analysis after appropriate log conversion.

Results and Discussion

Size of Farmholding, Input-use Pattern, Yield and Returns

The patterns of input use and yield in tomato among different categories of farmers, viz. small, medium and large in Karnataka have been given in Table 1. The average number of seedlings planted per hectare in Karnataka was around 17,833 and the difference in the number of seedlings used by different categories of farmers were found statistically at par, indicating that the farmers irrespective of size of their holding used almost the same number of seedlings. However, all the farmers used less than the recommended number of seedlings, which is 20,000 seedlings for 100 cm × 50 cm spacing.

Similarly, the difference in use of other inputs like male labour (191 man days), female labour (247 women days), farm yard manure (18 t), potash (242 kg), plant protection inputs (Rs 7,414) and fixed costs like depreciation, rental value of land, interest on working capital, etc. among different categories of farmers were also found statistically at par.

Table 1. Input-use pattern and yield in tomato under different sizes of holdings in Karnataka

Particulars	Farmers				Tests of significance
	Small	Medium	Large	All	
Plant population (No.)	17686	17802	18010	17833	Non-significant
Male labour (man days)	178.10	188.41	205.48	190.66	Non-significant
Female labour (woman days)	226.49	241.58	272.41	246.82	Non-significant
FYM (days)	18.01	21.08	15.04	18.04	Non-significant
N (days)	193.56	254.58	239.10	229.08	*
P (days)	213.04	303.81	257.70	258.18	*
K (days)	244.98	239.58	243.26	242.61	Non-significant
Capital inputs (Rs)	7530	11089	9948	9522	**
Fixed input costs (Rs)	16945	17500	17853	17433	Non-significant
Plant protection costs (Rs)	6899	8903	6439	7414	Non-significant

Notes: 1. ANOVA was conducted to test the significance for each of the input.
2. * and ** denote significance at 5 per cent and 1 per cent levels, respectively.

On the other hand, use of inputs like nitrogen (229 kg/ha) and potassium (258 kg/ha), and capital input (Rs 9,522/ha) such as tractor use, seed cost, etc. were found statistically different. The maximum quantities of nitrogen (254.5 kg/ha) and potassium (303.8 kg/ha) were used by the medium category of farmers. The quantities of nitrogen used by large and small farmers were 239.1 kg and 193.5 kg, respectively. As regards potassium nutrient, large farmers used 257.7kg/ha, while small farmers used 213 kg/ha.

The recommended doses of fertilizers for tomato cultivation were: 250 kg of N, 475 kg of P_2O_5 and 475 kg K_2O. It is to be noted here that none of the farms groups applied the recommended doses of N, P, K, except for nitrogen by the medium farmers. In fact, P and K nutrients were applied almost in half of the recommended doses.

Thus, it was evident that the majority of inputs used by different groups of farmers were almost similar, except nitrogen, potassium and capital inputs, indicating the existence of scale neutrality in these inputs. However, it is to be noted here that the all the nutrients were used in less than the recommended doses.

The average yield realized by the sample farmers in tomato for hybrids was 55.19 t/ha in Karnataka (Table 2). The yield was significantly higher in the medium category of farmers (57.65 t/ha); it was higher by 5.5 per cent than small farmers and 8.21 per cent than large farmers. The higher yield was due to the fact that this category of farmers had used higher levels of inputs, especially plant nutrients like farmyard manure and chemical fertilizers. Further, the use of capital inputs like costs on seeds and plant protection chemicals was also higher. As regards price realization, it was the small farmers who realized higher price than other categories

Table 2. Physical and economic indicators of tomato production in Karnataka

Category	Farmers			
	Small	Medium	Large	All
Yield (kg/ha)	54646	57651	53276	55191
Price realization (Rs/kg)	3.75	3.57	3.50	3.61
Gross return (Rs/ha)	204923	205814	186466	199068
Cost of production (Rs/kg)	1.72	2.00	1.85	1.86
Net returns (Rs/ha)	110671	90567	88108	96449
Profit (Rs/kg)	2.03	1.57	1.65	1.75
B:C ratio	2.17	1.79	1.90	1.95

of farmers, which indirectly suggested that the quality of production of tomato was relatively better. Due to the higher use of inputs, medium farmers incurred higher cost on cultivation per hectare on tomato production (22 % higher over small farmers and 18 % higher over large farmers).

As the results from above discussion did not throw light conclusively, the observed input-use efficiency parameters were combined with the measures like net return, profit per unit of production and BC ratio to decide the economically most efficient farms in production of tomato without going into the functional analysis. Small farmers emerged as the economically efficient farmers in production of tomato in Karnataka as suggested by the higher profit for every kg of production (Rs 2.30 compared to Rs 1.57 for medium farmers and Rs 1.65 for large farmers), higher net return (Rs 1,10,671/ha compared to Rs 90,567/ha for medium farmers and Rs 88,108/ha for large farmers) and higher BCR (2.17 compared to 1.79 in medium and 1.90 in large farms). Though medium farmers had realized higher yield, it was the small farmers who emerged as efficient producers due to their lower costs on production (Rs 1.72/kg compared to Rs 2.01/kg in medium and Rs 1.85/kg in large farms) and higher price realization.

Technical Efficiency Using DEA

To obtain efficiency levels of each of the farms as decided by the physical inputs (quantities), DEA models, which are input-oriented, were used at different production scales under the assumption of constant returns to scale (CRS). After introducing convexity in the CRS model, the variable returns to scale (VRS) were estimated. By using the efficiency levels of these CRS and VRS models, the scale efficiency for each farm was obtained. The results on efficiency measures (with constant and variable returns) and the descriptive statistics for tomato producing farms in the state of Karnataka are given in Table 3. The criterion used by Ferreira (2005) was used in the present study to decide the cut-off score for efficient farms. Farms that operated at 0.90 or more score were considered as 'efficient farms'. The explanation for this flexibility, according to Ferreira (2005), is to avoid compromising the analysis through a farm that stands out as being an outlier rather than for its true relative efficiency. Data recording errors and external factors were attributed for this flexibility.

Table 3. Efficiency measures and descriptive statistics for tomato producing farms according to scale of operations in Karnataka

Scale of operations	Efficient farms ($\theta \geq 0.90$)		Efficiency measures			
	No.	%	Mean	Standard deviation	Maximum	Minimum
Small farms						
Technical efficiency (Constant returns)	06	20.0	0.7768	0.1400	1	0.538
Technical efficiency (Variable returns)	13	43.3	0.8686	0.1045	1	0.648
Scale efficiency	18	60.0	0.8922	0.0975	1	0.627
Medium farms						
Technical efficiency (Constant returns)	15	50.0	0.8187	0.1707	1	0.380
Technical efficiency (Variable returns)	20	66.7	0.8792	0.1442	1	0.478
Scale efficiency	19	63.3	0.9242	0.0756	1	0.733
Large farms						
Technical efficiency (Constant returns)	5	16.7	0.7287	0.1538	1	0.358
Technical efficiency (Variable returns)	13	43.3	0.8673	0.1168	1	0.648
Scale efficiency	17	56.7	0.8604	0.1521	1	0.426
All farms						
Technical efficiency (Constant returns)	26	28.9	0.7767	0.1586	1	0.358
Technical efficiency (Variable returns)	46	51.1	0.8673	0.1220	1	0.478
Scale efficiency	54	60.0	0.8931	0.1151	1	0.426

Small Farms: It was observed that only about 20 per cent of farms under assumption of constant returns to scale performed with efficiency level equal to 0.90 or greater, i.e. 6 of the total 30 farms. The average efficiency score was 0.7768. Based on this, it could be inferred that remaining 24 farmers, which did not operate at the maximum efficiency level, could reduce the input level by 22.32 per cent and maintain the same level of tomato production as achieved by 20 per cent of the farmers.

When the assumption of constant scale was relaxed and the model with variable returns to scale was calculated, the impact of production scale on technical efficiency level was visible. This relaxation was necessitated, as all the tomato-producing farms did not operate at the optimum scale due to imperfect competition, constraint in finance, etc. In small farms, the number of efficient farms increased more than double to 43.3 per cent and the average technical efficiency score increased to 0.8686. These better results from the model with variable returns were mainly due to the inclusion of scale efficiency, which the previous model did not take into consideration. Further, the lower value of standard deviation of mean in model with variable returns suggested concentration of farms in the higher efficiency levels.

As regards to the scale efficiency, 60 per cent of tomato farms (18 out of 30 farms) under small farm category either performed at the optimum scale or were close to the optimum scale (farms having scale efficiency values equal to or more than 0.90).

Medium Farms: Under the assumption of constant returns to scale, 50 per cent of the farmers in medium category were found efficient with values equal to or more than 0.90. The average technical efficiency score was higher in this category at 0.8187. In the case of variable returns, the average technical efficiency score was 0.8792 and nearly 66.7 per cent of the farms had the score equal to or more than 0.90. Thus, six percentage points from the 18 per cent ascribed to the technical inefficiency (constant returns) were caused by the scale inefficiency. The number of medium farms who performed at the optimum scale was marginally higher at 63.3 per cent than the small farms.

Large Farms: Only about 16.7 per cent of large farms were found efficient and the mean technical efficiency score for the entire group was 0.7287, which is the lowest when compared to other categories of farms. Nearly 14 per cent of the farms showed a greater measure of technical inefficiency, which indicated that they were not performing at the optimum scale.

Irrespective of groups (all tomato farms analyzed together), it was found that only about 29 per cent of tomato farms in the current production scenario were efficient. The mean average technical efficiency score was 0.7767, which indicates that tomato farms could reduce the use of inputs by up to 22 per cent of the present usage level and still will be able to reach the yield achieved by the efficient farms. Nearly 90 per cent of the farms were found operating near close to the optimum scale of efficiency.

Regions of Operations in the Production Frontier

In addition to knowing about the number of efficient farms, extent of inefficiency and optimum scale of operation, it is also important to understand the distribution of farms in the three regions of production frontier, i.e. how many farms are under increasing, decreasing or constant returns. These were estimated using the equations given under methodology and the results have been presented in Table 4.

Nearly 57 per cent of the farms in the small farm category were found operating in the region of increasing returns or the suboptimal region. The production scale of these farms could be increased by

Table 4. Distribution of tomato farms in Karnataka according to types of return among different scale of operations

Types of return		Small farms	Medium farms	Large farms	All farms
Increasing returns	No.	17	16	17	50
	%	56.67	53.33	56.67	55.56
Constant returns	No.	2	5	1	08
	%	6.67	16.67	3.33	8.89
Decreasing returns	No.	11	9	12	32
	%	36.67	30.00	40.00	35.55

decreasing the costs, since they were performing below the optimum production scale. Nearly 37 per cent of tomato farms in the small farms category who were found in the decreasing returns region, could increase their technical efficiency by reducing their production levels. This region is also called as supraoptimal, i.e. the farms were performing above the optimum scale of production. In the constant region of frontier, i.e. optimum scale of production, only seven per cent of the farms were found operating.

Determinants of Technical Efficiency of Tomato Production

The technical efficiency scores were compared with the input-use efficiency parameters and technical efficiency factors of the farm through observed values as well as functional analysis. The results have been given in Tables 5 and 6, respectively.

Among observed input productivity factors, land and labour productivity have been found higher in medium farmers, while the capital efficiency factor has been observed higher in small farmers (Table 5). This suggests that probably small farmers could efficiently manage their limited resources.

As regards factors influencing efficiency, land and labour productivity has been found to influence the technical efficiency significantly and positively in all the three categories of farms (Table 6). The influence of land (yield) on efficiency was higher in the medium farms and one per cent increase in their yield could influence the efficiency to the extent of 0.797 per cent compared to 0.587 per cent in small farms and 0.528 per cent in large farms. As regards labour efficiency, the influence was higher in small farms and nearly 0.376 per cent influence could be observed due to one per cent increase in labour efficiency. The capital efficiency factor was found statistically non-significant, suggesting that it had no influence on the technical efficiency of tomato production.

Regarding human influence on technical efficiency of tomato production, it was observed that medium and small farmers had longer education periods. It was further captured in the production functional analysis that educational level had significant and positive influence on the technical efficiency. It was more pronounced in the medium farmers, wherein with every one per cent increase in the education period, the technical efficiency was likely to increase by about 0.236 per cent. This impact was marginal in the case of small farmers, though it was found significant. On the other hand, with regards to the age of farmers, the observed values suggested that the farms managed by the relatively younger farmers were more efficient technically as observed in the medium farmers. But the age factor was found not sufficient enough to influence the technical efficiency. In the case of large farmers, none of the two human factors was found

Table 5. Relationship between technical efficiency and input-use efficiency in tomato production in Karnataka

Variables	Small farms	Medium farms	Large farms	All farms
Technical efficiency	0.7768	0.8247	0.7287	0.7767
	(18.0%)	(20.7%)	(21.1%)	(20.4%)
Land	53764	56400	52706	54290
	(17 %)	(12.3%)	(23%)	(17.8%)
Labour	11.57	12.05	10.04	11.22
	(18.4%)	(27.7%)	(28.1%)	(25.9%)
Capital	1.03	0.89	0.79	0.90
	(26.9%)	(32.7%)	(33%)	(32.2%)
Age	49.53	45.43	49.57	48.18
	(19.4 %)	(12.4%)	(18.6%)	(17.6%)
Education level	7.13	8.50	5.67	7.10
	(49%)	(38%)	(61%)	(50%)
Credit availed	22	14	19	55
Organisational participation at least once	29	29	29	87
Technical visit to farm at least once	23	13	20	56

Note: Figures within the parentheses indicate the variabilities, i.e. coefficient of variation values

Table 6. Factors associated with technical efficiency of tomato-producing farms in Karnataka

Variables	Small farms		Medium farms		Large farms		All farms	
	Coefficient	t-value	Coefficient	t-value	Coefficient	t-value	Coefficient	t-value
Intercept	-7.820	-5.334	-9.906	-4.330	-5.995	-4.011	-7.408	-7.321
Land productivity	0.587	5.066	0.797	4.309	0.528	4.045	0.608	7.570
Labour productivity	0.376	3.457	0.239	2.457	0.208	2.434	0.308	5.121
Capital productivity	-0.015	-0.177	0.003	0.030	0.051	0.540	0.050	0.946
Farmers' age	0.008	0.086	-0.044	-0.237	-0.129	-1.014	-0.079	-1.022
Education	0.025	3.066	0.262	4.696	0.011	1.500	0.013	2.321
Organizational participation (D)	0.159	1.756	0.001	0.005	-0.024	-0.208	0.073	1.015
Credit availed (D)	-0.097	-2.210	0.047	0.958	0.062	0.888	-0.017	-0.540
Technical support (D)	0.134	2.970	-0.007	-0.161	-0.060	-0.851	0.035	1.085
F test	13.43	-	21.88	-	17.09	-	33.00	-
Adjusted R^2	0.78	-	0.850	-	0.820	-	0.740	-

D = Dummy variable

influencing the technical efficiency of tomato production.

Further, it was clear that a majority of farmers were involved in the organizational activities in the form of its member, director, etc. in input or output marketing agencies such as the primary agricultural co-operative societies, regulated markets, HOPCOMS, etc. As regards credit facilities, nearly 38 per cent of farmers used the institutional credit for tomato production. These figures were substantially higher in medium farmers at nearly 54 per cent and lower at about 27 per cent for small farmers. Similar observations were made regarding the technical support farmers got from the developmental, input suppliers, and research organizations for production of tomato.

But none of these institutional factors was found affecting the technical efficiency of medium and larger farmers. In the case of small farmers, a technical visit was directly related to the increase in efficiency, though marginally. In small farmers, credit was found to be negatively influencing the technical efficiency bringing forth the question whether small farmers were appropriately using the external borrowing for the purpose it was drawn. This needs to be confirmed by the studies on other crops in this category of farmers.

Conclusions

Technical and scale efficiencies have been estimated for one of the important vegetables, viz. tomato in India using data envelopment analysis (DEA). The factors, which influence the technical efficiency of tomato production, have also determined using regression equation.

The pattern of input use in tomato production among different categories of farmers has suggested scale neutrality among small, medium and large farmers, but most of the applied inputs have been found to be in lower than the recommended doses. This suggests that there is potential to increase the output, production and efficiency through the application of more inputs. It has been found evident from the fact that the medium farmers could realize higher productivity largely due to use of higher level of inputs.

Two production-related factors, viz. land and labour have turned out to be most critical in impacting the technical efficiencies in all the farms, thus increasing labour and land efficiencies would provide the higher production yields. In addition to these two variables, education and the technical support in small farms have to found to have significant impacts on the technical efficiency levels. Thus, these two inputs in small farms could potentially increase the productivity of tomato. The credit has been found to negatively affect the technical efficiency level of small farmers, which needs a detailed analysis on the utilization of external barrowings in tomato production as well as other crops. The medium category of farmers are significantly influenced by the education parameter.

Although medium farmers have been found to have higher productivity and higher technical efficiency related to physical optimum, it is the small farmers who have achieved the economic efficiency in terms of higher profit per unit of production. Because of their intensive cultivation of smaller area, the quality of tomatoes turned out to be better resulting in higher price realization. Thus, small farmers may be encouraged to use more inputs, particularly FYM and chemical fertilizers, which may shift them to higher level of efficiency of production as presently these farms are operating at low-input situations.

References

Afriat, S.N. (1972) Efficient estimation of production functions, *International Economic Review*, **13**: 568-598.

Bhattacharyya, Anjana, Bhattacharyya, Arunava and Kumbhakar, Subal C. (1996) Government interventions, market imperfections, and technical inefficiency in a mixed economy: A case study of Indian agriculture, *Journal of Comparative Economics,* **22**(3): 219-241.

Bagi, F.S. (1982) Economic efficiency of sharecropping: Reply and some further results. *Malaysia Economic Review,* **27**: 86-95.

Battese, G. and Coelli, T. (1988) Prediction of firm-level technical efficiencies with a generalized frontier production function and panel data, *Journal of Econometrics,* **28**: 387-399.

Battese, G. (1992) Frontier production functions and technical efficiency: A survey of empirical applications in agricultural economics. *Agricultural Economics,* **7**: 185-208.

Battese, G. and Coelli, T. (1992) Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India, *Journal of Productivity Analysis,* **3**: 153-169.

Battese, G. and Broca, S. (1997) Functional forms of stochastic frontier production functions and models for technical inefficiency effects: A comparative study for wheat farmers in Pakistan, *Journal of Productivity Analysis*, **8**: 395-414.

Boles, J.N. (1966) Efficiency squared – Efficient computation of efficiency indexes, *Proceedings of the the 39th Annual Meeting of the Farm Economic Association*, pp. 137-142.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978) Measuring the efficiency of decision making units, *European Journal of Operations Research*, **2**: 429-444.

Coelli, T., Rao, D.S.P. and Battese, G. (1998) *An Introduction to Efficiency and Productivity Analysis*. Kluwer Academic Publishers, Boston.

Coelli, T.J. and Battese, G.E. (1996), Identification of factors which influence the technical inefficiency of Indian farmers, *Australian Journal of Agricultural Economics***,** **40**: 103-128.

FAO (2007) *Production Year Book*, Food and Agriculture Organization, Rome, Italy.

Färe, R. and Grosskopf, S. (1994) Estimation of returns to scale using data envelopment analysis: A comment, *European Journal of Operational Research*, **79**: 379-382.

Farrell, M.J. (1957) The measurement of productive efficiency, *Journal of Royal Statistical Society*, **120**(3): 253-290.

Ferreira, M. A. M. (2005) *Eficiência técnica e de escala de cooperativas e sociedades de capital na indústria de laticínios do Brasil*, Ph.D. Thesis (unplished), Federal University of Viçosa, Brazil.

Gonçalves, R. M. L., Wilson da Cruz Vieira, João Eustáquio de Lima and Sebastião Teixeira Gomes, (2008) Analysis of technical efficiency of milk-producing farms in Minas Gerais, *Economia Aplicada*, **12**(2): 321-335.

Kalirajan, K. (1981) An econometric analysis of yield variability in paddy production, *Canadian Journal of Agricultural Economics,* **29**: 283-294.

Kalirajan, K. (1982) On measuring yield potential of the high yielding varieties technology at farm level, *Journal of Agricultural Economics,* **33**: 227-236.

Mehmet, Bozoðlu and Ceyhan, Vedat, (2007) Measuring the technical efficiency and exploring the inefficiency determinants of vegetable farms in Samsun province, Turkey, *Agricultural Systems*, **94**(3): 649-656.

NHB, (2008) National Horticultural Board, (web site: www.nhb.gov.in)**,** New Delhi.

Ray, S. (1991) Resource use efficiency in public schools: A study of Connecticut data, *Management Science*, **37**: 1620-1628.

Sharif, N. R. and Dar, A.A. (1996) An empirical study of the patterns and sources of technical inefficiency in traditional and HYV rice cultivation in Bangladesh, *Journal of Development Studies,* **32**: 612-629.

Villano, Renato and Fleming, Euan (2006) Technical inefficiency and production risk in rice farming: Evidence from central Luzon Philippines, *Asian Economic Journal*, **20**(1): 29 -46.

Worthington, A. and Dollery, B. (1999) Allowing for nondiscretionary factors in data envelopment analysis: A comparative study of NSW local government. *Working Paper Series in Economics*, No.99-12, University of New England, Armidale NSW 2351 Australia.