Measuring the efficiency of Pakistani rice production via stochastic frontier and data envelopment analyses.

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Abstract

Improving technical efficiency enables farmers to realize maximum production with a given amount of input. This study aims to apply stochastic frontier analysis (SFA) and data envelopment analysis (DEA) to compare estimates of production efficiency. Technical efficiency was estimated using farm level primary data of 350 rice farmers, 175 from Kambar Shahdadkot and 175 from Badin. The results indicate that the mean technical efficiency of rice production derived from SFA and DEA in Kambar Shadadkot (0.988 and 0.965, respectively) was greater than the mean technical efficiency obtained by SFA and DEA in Badin (0.960 and 0.958, respectively). The farmers in Kambar Shahdadkot have high technical efficiency because they use more technology, and, machinery than the rice farmers in Badin.

Keywords: Badin. Data envelopment analysis. Kambar Shahdadkot. Stochastic frontier analysis. Technical efficiency.

1. Introduction

Typically, efficiency is calculated using a parametric approach, such as stochastic frontier analysis (SFA), or a nonparametric approach, such as data envelopment analysis (DEA). Both approaches have different strengths and weaknesses. The DEA approach only requires information about the amount of input and output, and it assumes that the data is free of error or noise. Parametric methods, such as SFA consider noise and error in the data.

However, the main weakness of SFA is that it makes an obvious distributional assumption for inefficiency and it explicitly imposes a specific parametric functional form representing basic technology (Hossain *et al.* 2012; Timothy *et al.* 2005; Kim and Donghwan 2015; Richard. and Shively, 2010). Both competing methods are used to determine if the results obtained from one approach can be confirmed by the other approach. Agricultural development is a base of economic development and main factor of poverty reduction and food security in the world (Wagan *et al.* 2018). Agricultural sector has sustainably growing to ensure food security and alleviate poverty in Pakistan (Ullah. A, Khan. D, Zheng. S. 2017).

The increasing prices of agricultural inputs and decreasing agricultural productivity leads the decline in economic growth and creates problem of poverty and food security, thus subsidy on inputs and the significant application of inputs agricultural, increases the agricultural productivity (Iqbal *et al.* 2018; Memon *et al.* 2017; Li. X, Zhang. Y, Liang. L, 2017). While agricultural production has an impact on economic growth, changes in agricultural productivity and its determinants are not always well-measured or well-understood (Hossain *et al.* 2012; Villano. R, and Euan. F. 2010). Rice is an important food and cash crop in Pakistan; it contributes more than two million tons of the food demand in Pakistan (GOP, 2016; Watto. M. A. and Amin. W. M. 2014).

In Pakistan, rice is an important source of rural income and employment; it accounts for 3.1% of the value added in agriculture and 0.6% of the gross domestic product (GDP) (GOP, 2016). It is the second most important staple food crop, after wheat; and is the leading export crop after cotton (Arshad *et al.* 2016; Nawaz *et al.* 2017; Memon *et al.* 2015). After meeting its national requirement, Pakistan is the third largest exporter of rice in the world (Irfan. M, Muhammad. I, Muhammad. T. 2013). In Pakistan during the 2014 growing season, the rice crop was expanded, but a remarkable production of rice was not achieved due to various uncertainties (Rehman *et al.* 2017; Khan 2014).

2. Literature Review

Wadud. A, and White. B. (2000) compared the technical efficiency of rice production in Bangladesh using SFA and DEA. Wadud. A, White. B. (2000) used farm level survey data to analyze the technical efficiency of rice production. They found that technical efficiency is impacted by socioeconomic factors, environmental factors, and irrigation infrastructure factors. Their results showed that environmental degradation and irrigation systems are the main factors that affect rice production efficiency.

Gendara *et al.* (2012) examined the factors that affect the technical efficiency of rice farmers in village reservoir irrigation systems in Sri Lanka. That study used primary data obtained from 460 questionnaires to examine the stochastic translog production frontier for rice production. The average technical efficiency of rice grown using irrigation systems was found to be 0.72; however, for 63% of the farmers, that average was higher. One study found that membership in a farmer's organization was the main factor impacting technical efficiency. Buriro. A, Khooharo. A. A, Ghulam. T. (2015) analyzed the technical efficiency of rice production in different agro-ecological zones in Sindh, Pakistan.

A primary data collection method was used, and Cobb Douglas frontier production was applied to analyze the technical efficiency of rice production. That study's results indicate that about 10% of the rice farmers in Larkana had technical efficiency; in contrast, the technical efficiency of the rice farmers in Badin was only 6%. That study concluded that knowledge of and awareness about advanced technology can increase the production of rice in Pakistan. Liu *et al.* (2016) analyzed productivity and efficiency changes in Chinese rice production during the new farm subsidy years. Panel data from 23 Chinese provinces over 11 years were used to analyze the efficiency and productivity changes in rice production.

That study reported that the major rice producing regions in China are relatively efficient. Increasing investment in agricultural research and development, increasing the literacy rate of rural inhabitants, and providing improved technology and government agricultural subsidies are helpful for efficient rice production in China. Chandio *et al.* (2017) noted the relationship between agricultural credit, farm size, and technical efficiency of rice farmers in Sindh, Pakistan using SFA. Their results showed that agricultural credit, farm size, fertilizer, and labor had a significant impact on rice production in Sindh.

Rizwan *et al.* (2017) applied DEA to analyze the impact of technical, allocative, and economic efficiencies on an input-oriented basis using data from 400 rice farmers in Punjab, Pakistan in order to determine the differences in efficiencies between two groups of farmers: off-farm work rice farmers and without off-farm work rice farmers. Their results shows the mean technical efficiency of off-farm working rice farmers was 0.90 and 0.82 was explored by without off-farm work rice farmers. The allocative efficiency of off-farm rice famer group was 0.88 and 0.76 from without off-farm work farmers, similarly economic efficiency were found higher in off-farm work famers as 0.83 then without off-farm work farmers as 0.74. Study suggested the training by extension workers to farmers for best input management practices may can helpful for efficient rice production.

The literature has shown that rice production efficiency is influenced by environmental degradation and the quality of irrigation systems, but few studies discussed farmers' organization as a key factor in such efficiency. Some studies probed into the knowledge and awareness of improved technology, investment in agricultural research and development, the increased literacy rate of rural residents, and agricultural subsidies as important production efficiency-related determinants, while others explored agricultural credit, farm size, agricultural labor, and agricultural education and extension services for the appropriate application of inputs for production.

Nevertheless the insights derived from the above-mentioned studies, none of them compared changes in production efficiency and the production input combinations used by rice farmers. To fill this gap, the current research examined and compared the production efficiency of two major rice-producing regions of Pakistan and the input combinations employed in these areas. For these purposes, data envelopment analysis (DEA) and stochastic frontier analysis (SFA) were conducted to determine the technical, pure, and scale efficiency of rice growing in the case regions. DEA and SFA models were then used to estimate changes in the efficiency with which Pakistanis produce rice. It is hoped that the results of the study will help farmers and agricultural policymakers understand the best input combinations for agricultural production and the effects of technology on rice production efficiency.

The rest of the paper is organized as follows: The Methodology section describes the study areas, the data collection process, and the empirical econometric models proposed in this work. The Results and discussion section discusses the findings of the analyses, and the final section presents the main conclusions drawn from the results.

3. Methodology

3.1. Study area

This study was carried out in Pakistan, where rice production is undertaken primarily by the provinces of Punjab and Sindh, whose agricultural outputs account for about 88% of the country's rice production. Sindh province, which was the main study site selected for this research, is divided into three agro-ecological zones: the upper, middle, and lower Sindh. The upper Sindh is home to the rice-growing districts of Larkana, Kambar Shahdadkot, Jacobabad, Shikarpur, and Sukkur; the middle Sindh encompasses the rice-growing district of Dadu; and the lower Sindh is where the rice-growing districts of Badin, Sijawal, and Thatta are found (Kouser. S, Khalid. M, 2007; Buriro. A, Khooharo. A. A, Ghulam, T. 2015; Wagan *et al.* 2016). Out of these localities, the major rice-producing districts Kambar Shahdadkot and Badin were chosen as the areas for investigation (Figure 1).

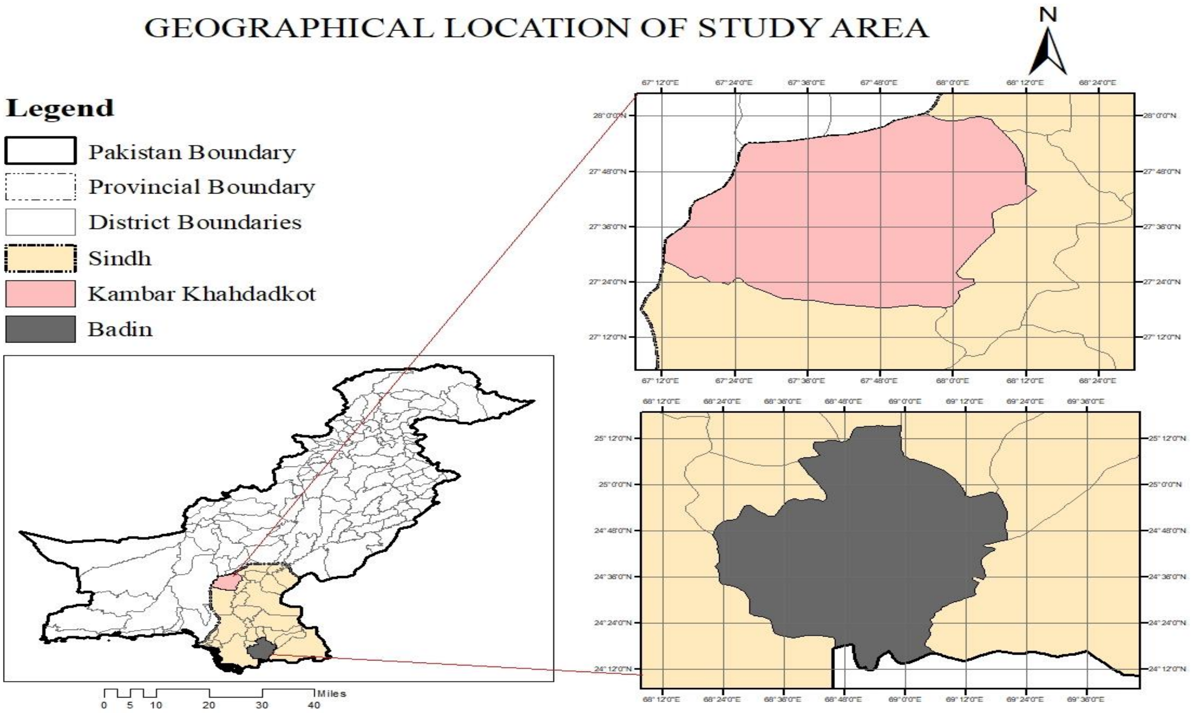

Figure 1: Geographical location of the rice-producing study area in Pakistan.
Authors own work

These districts are popular rice-production regions and have a long history of rice cultivation.

3.2. Survey design and data collection

The survey was used as the primary data collection instrument, and questionnaires were administered to residents of 28 villages in Kambar Shahdadkot and Badin (15 and 13 villages, respectively) in January and February 2017 with the help of the local governments of the investigated districts and the agricultural department of Pakistan (Table 1).

Table 1: Study sampling details

Sample Area	District	Selected Villages	Selected Households	Geographical Location
I	Kambar Shahdadkot	Village Ghatahar Wagan Village Yarodero Peer Jo Goth Village Ali Khabar Village Khairo Jatoi Village Khatan Khan Village Bandi Ali Village Thardi hasim Village Belhati Village Kambar Kot Village Bhola Kot Meehar Goth Village Sumanabad Village Jani jo Band	175	27° 32' - 27° 25' N 67° 58' - 67° 55' E
II	Badin	Village Haji Karam khan Village Chakhro Nohani Village Majeed Nohani Village Allah Dino Malah Village Allah Bachayo Junejo Village Ghulam Shah Nizamani Village Ismail Dal Village Mihro Kolhi Village Lal Bux Almani Village Amir Bux Jat Village Nim Ansari Village Sobho Kolhi Village Achar bheel	175	24° 38' - 24° 40' N 68° 30' - 68° 32' E

The selected villages located in Kambar Shahdadkot had 3868 rice growers from 1984 households, and those located in Badin had 3096 rice growers from 1898 households. A total of 350 rice farmers from Kambar Shahdadkot and 175 rice farmers from Badin were randomly selected for participation in the survey. After the survey was concluded, one family member involved in rice production was chosen from each household for interviews. The respondents voluntarily took part in the study and were very cooperative. As a result, we were able to conduct very informative interviews and obtained 350 fully completed questionnaires.

3.3. Proposed empirical models

Production efficiency is usually estimated using SFA and DEA, as stated by Coelli. T. J, Rao. D. S. P, Battese. G. E. (1998). Correspondingly, we used both analytical approaches in estimating rice production efficiency in the context of Pakistan.

3.3.1 Stochastic frontier analysis

Parametric SFA, which was introduced by (Aigner *et al.* 1977; Meeusen, W.; Julien, V. B. D. 1977) is a statistical technique for estimating parameters; most empirical studies on the development of the agricultural sector widely use the Cobb–Douglas form of SFA (Battese. G. E, Coelli. T. J, 1995). The current work employed an SFA model to calculate the technical efficiency of rice production in the different agro-ecological zones of Pakistan. The fundamental form of the SFA model can be defined as

$$Y_i = f(x_i;\, \beta)\, e^{(\xi_i - \zeta_i)} \qquad (1)$$

$u_i = \xi_i - \zeta_i$ and n=1, 2, 3, …, n

Where Yi is the output of the ith rice farm, xi denotes the input variables of the ith rice farm, β represent the estimated unknown parameters and ξ_i, the systematic random variable, takes explanation to measure error and ζ_i, the irregular nonnegative error factor measuring the technical inefficiency effects. The ξ_i's are supposed to be independent and identically distributed with the average 0 and variance σ_ξ^2, and the nonnegative variable ζ_i's are assumed to be independent and identically distributed truncations (at zero from below) of the N(µ, σ_ξ^2) distribution. Additionally and are estimated to be independent of input variables X and also independent to each other. The variance factors of the model are estimated as

$$\sigma_u^2 = \sigma_\xi^2 + \sigma_\zeta^2, \qquad \gamma = \sigma_\xi^2 / \sigma_\zeta^2 \text{ and } 0 \leq \gamma \leq 1 \qquad (2)$$

To estimate the technical efficiency of rice in Pakistan we used SFA model. The estimated technical efficiency of rice farm can be defined as

$$TE = \frac{Y_i}{\exp(X_i'\beta + v_i)} = \frac{\exp(X_i'\beta + v_{it} - u_i)}{\exp(X_i'\beta + v_i)} = \exp(-u_i) \qquad (3)$$

Where, Yi is the output of the ith rice farm, Xi denotes the input variables of the ith farm, and β0, βi, and βii represent the estimated unknown parameters. The expected identically distributed random error and technical inefficiency are represented by ui. The ratio of observed output to the corresponding stochastic frontier output is measured on the basis of ui, which takes a value between 0 and 1, and c represents the parameters to be estimated.

The empirical SFA model was used thus:

$$\text{Ln } Y_i = \beta_0 + \beta_1 \ln(\text{land}_i) + \beta_2 \ln(\text{Seed}_i) + \beta_3 \ln(\text{fertilizer}_i) + \beta_4 \ln(\text{pesticides}_i) + \beta_5 \ln(\text{micronutrients}_i) + \beta_6 \ln(\text{labor}_i) + \beta_7 \ln(\text{tractor}_i) + v_i - u_i$$

where I = 1, 2, 3, … , 10; Yi represents the ith rice farm production; Landi is the land area occupied for the ith rice farm production; Seedi denotes the quantity of seeds used for the ith rice farm production; Fertilizeri represents the amount of fertilizer used in the ith rice farm production; Pesticidesi pertains to the quantity of pesticides applied during the ith rice farm production; Labori stands for the number of workers for the ith rice farm production; and Tractori is the frequency at which a tractor is used for the ith rice farm production. In the equation above, i represents the number of rice farms, and ln is the natural logarithm.

Simultaneously, to estimate the technical inefficiency of a household, the non-negative random variable u is indicated as follows:

$$|ui| = \delta 0 + \delta 1Z1 + \delta 2Z2 + \delta 3Z3 \qquad (4)$$

where

Z1 = Age of household head

Z2 = Educational level of household head

Z3 = Farming experience (years)

The SFA model estimates parameters and standard errors. All the parameters were estimated using the Frontier 4.1 program written by Coelli, T. J. Rao, D. S. P. Battese, G. E. (1998).

3.3.2 Data envelopment analysis

To estimate the technical and scale efficiency of rice production, we used an input-oriented measure because input- and output-oriented measures are equivalent scales of technical efficiency Coelli. T. J, Rao. D. S. P, Battese. G. E. (1998). In accordance with this principle, then, rice production was regarded as the output, and land area, seeds, fertilizers, labor, and tractors were considered inputs. Input orientation was employed to encompass the households that use a number of inputs (X_i) to produce rice outputs (Y_i) by assuming a constant return to scale (CRS). The isoquant unit of efficient households was assumed on the basis of an S curve that measures technical efficiency. If a household uses the amount of inputs denoted by P to produce a unit of output, the technical inefficiency of the household is represented by the distance of QP, which is the amount of inputs that is proportionally reduced without changing outputs (Figure 2).

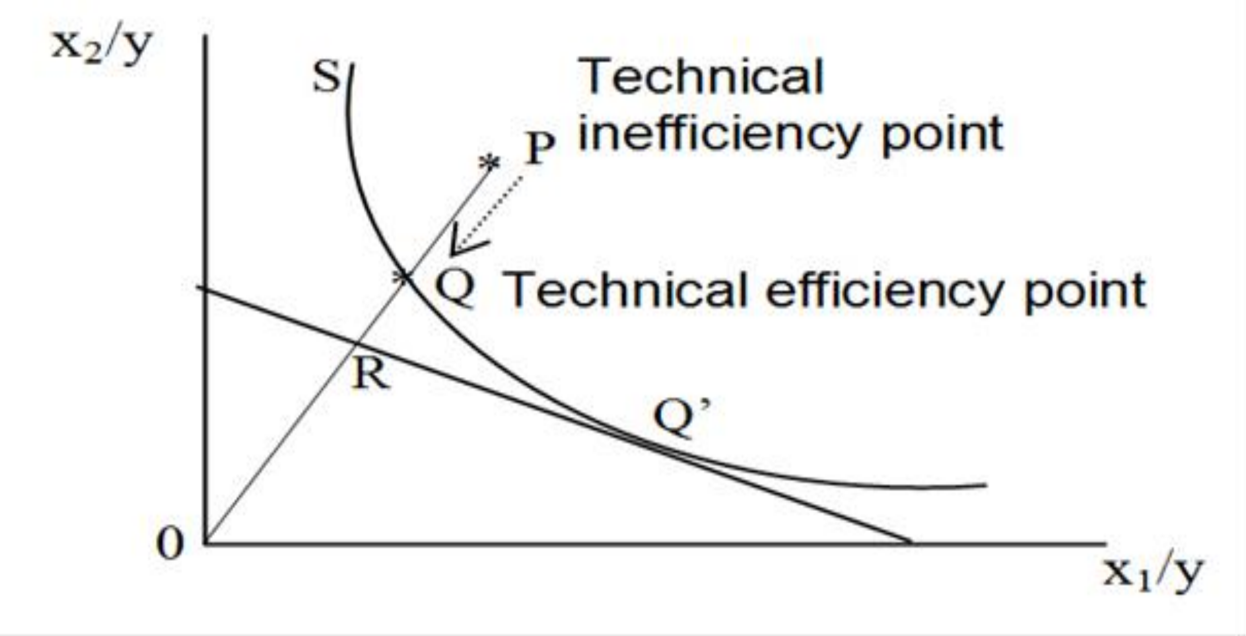

Figure 2: Measurement of Technical efficiency
Source: Coelli. T. J, Rao. D. S. P, Battese. G. E. (1998).

In estimating the technical efficiency of each household, the following ratio is used:

TE = OQ/OP

The resultant value of the technical efficiency (i.e., the degree of technical efficiency) of a household falls between 0 and 1. A value of 1 indicates that a household is technically efficient (point Q in Figure 2). For the calculation of technical efficiency, we assumed that a set of inputs K and output variable M for each household N must be defined as notations. The ith household is denoted by column vectors Xi and Yi, where K×N is the matrix of input (X) and M×N is the matrix of (Y). For the jth household out of N households, the input-oriented technical efficiency under a CRS is ascertained as follows:

$$\begin{aligned} &\mathrm{Min}\theta\ \lambda\ \theta \\ &\text{Subject to } -yi + Y\lambda \geq 0 \\ &\theta XI - X\lambda \geq 0 \\ &\lambda \geq 0 \qquad (5) \end{aligned}$$

Where, the ith household's technical efficiency score is obtained from a value of θ. If θ is equal to 1, then the household is regarded to have gained full technical efficiency.

The CRS model can be modified in case of situations characterized by a variable return to scale (VRS). This modification is implemented by adding the convexity constraint $N1`\lambda = 1$ to the CRS model:

$$\begin{aligned} &\mathrm{Min}_{\lambda\theta}\ \theta \\ &\text{Subject to } -y_i + Y\lambda \geq 0 \\ &\qquad \theta X_I - X\lambda \geq 0 \\ &\qquad N1`\lambda = 1 \\ &\qquad \lambda \geq 0 \end{aligned} \qquad (6)$$

In which N1 is an N×1 vector of ones. Therefore, the technical efficiency score under a VRS is usually equal to or greater than the technical efficiency score under a CRS.

3.3.3 Calculation of scale efficiency

Scale efficiency is estimated on the basis of the CRS-to-VRS ratio if a difference exists between the CRS and VRS scores of a particular household; this difference points to scale inefficiency Coelli. T. J, Rao. D. S. P, Battese. G. E. (1998). Scale efficiency can be measured in the following manner:

$$TE_{CRS} = AP_C/AP$$

$$TE_{VRS} = AP_v/AP$$

$$SE = AP_C/AP_v$$

All the measures of scale efficiency fall between 0 and 1. If a household is working at a point R, then this household influences a full optimal scale (Figure 3).

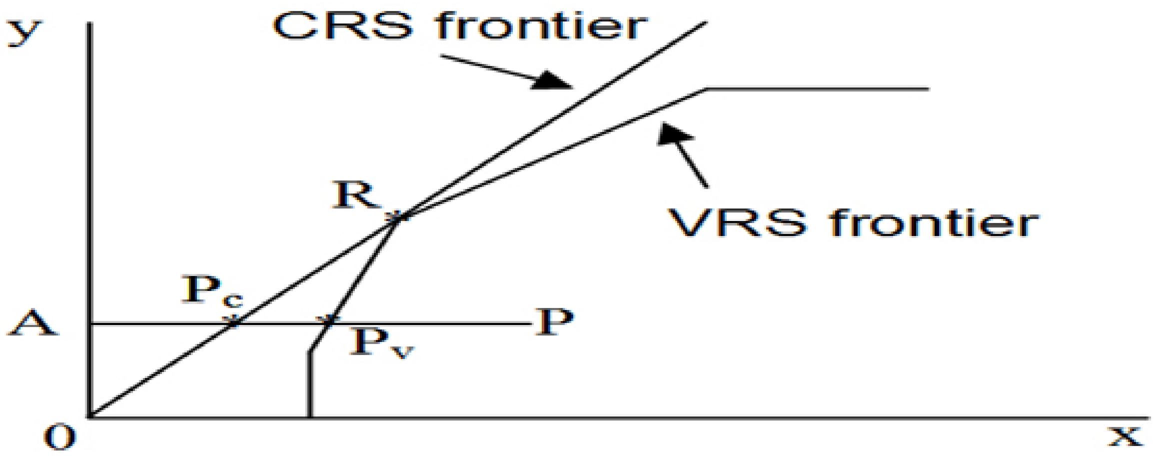

Figure 3: Production frontier curve
Source: Coelli. T. J, Rao. D. S. P, Battese. G. E. (1998).

The score of return to scale reflects the operating relationship between amounts of inputs and the output in certain households. Return to scale is expressed as a CRS, an increasing return to scale, or a decreasing return to scale, which determines the estimation of the elasticity of total production Ɛ, which is derived in the following manner:

$$\mathcal{E} = \sum_{i=1}^{n} E_i \tag{7}$$

where

$$E_i = (\partial y/\partial x_i)(x_i/y) \tag{8}$$

In Eq. (6), Ei indicates the partial elasticity of the production of each input, and the value of Ɛ is related to return to scale (Table 2).

Table 2: Elasticity of the production and Return to scale (RTS)

Return to scale	Production elasticity (E)
Constant return to scale	=1
Increasing return to Scale	>1
Decreasing return to scale	<1

Source: Coelli, T. J. Rao, D. S. P. Battese, G. E. (1998).

A CRS reflects that the output of production increases with the same proportional change in inputs and that an increasing return to scale means the quantity of the output increases to a level greater than the proportion of input augmentation; if the increasing proportion of output is less than the proportional change in inputs, this occurrence translates to a decreasing return to scale.

4. Results and discussion

4.1. Descriptive statistics

Table 3 lists the descriptive statistics of the variables used in this work. The first variable is production, which is defined as the total rice farm yield in kilograms; the descriptive unit of land is acre, and seeds, fertilizers, and micronutrients are expressed in kilograms used per rice farm; pesticides comprise the insecticides and fungicides used in a rice farm are expressed liters. Labor input variables denote the total number of persons working on a total number of days during rice production Dhungana. B. R, Nuthall. P. L, Nartea. G. V. (2004).

Table 3: Summary of descriptive statistics

Kambar Shahdadkot

Variables	Measurement	Minimum	Maximum	Mean	Std. Dev.
Production	Kgs	2960.000	38400.00	5359.090	7238.187
Land	Acres	1.000000	12.00000	4.842857	2.212723
Seed	Kgs	4.000000	55.00000	22.06857	11.25531
Fertilizers	Kgs	220.0000	3000.000	743.8286	437.2507
Pesticides	Litters	1.500000	10.00000	4.198571	1.993758
Micronutrients	Kgs	30.00000	360.0000	139.4857	63.65477
Labor	Persons	55.00000	363.0000	141.7314	60.15738
Machine	Hours	7.000000	69.00000	29.17714	12.30912
Age	Years	24.00000	59.00000	44.19429	9.025951
Education	Years	0.000000	14.00000	4.022857	3.652985
Farming Experience	Years	4.000000	30.00000	16.48000	5.343209

Badin

Variables	Measurement	Minimum	Maximum	Mean	Std. Dev.
Production	Kgs	4960.000	57000.00	15359.09	8771.581
Land	Acres	2.000000	19.00000	5.794286	2.768454
Seed	Kgs	4.000000	76.00000	23.62286	13.20704
Fertilizers	Kgs	200.0000	2850.000	856.9286	424.4452
Pesticides	Litters	1.000000	15.00000	5.234286	2.698866
Micronutrients	Kgs	50.00000	570.0000	171.5429	82.84917
Labor	Persons	70.00000	570.0000	195.1143	90.07839
Machine	Hours	11.00000	133.0000	38.20857	19.90937
Age	Years	22.00000	60.00000	42.90857	8.018132
Education	Years	0.000000	10.00000	2.920000	2.942827
Farming Experience	Years	4.000000	30.00000	16.48000	5.343209

Source: Authors calculations by using Eviews 8 version

As an input variable, a machine is regarded as the total number of hours during which a tractor, thresher, and other mechanical equipment are used in a rice farm. Input variables such as age, education, and farming experience are calculated in terms of number of years. The descriptive statistics for the variables used in the analyses of the 350 questionnaires showed high variations across the sample. Consequently, the standard deviations of the variables were higher than their mean values.

The mean values of production in Kambar Shahdadkot and Badin were 15359.09 and 17213.71 kg, respectively. The mean values of land in Kambar Shahdadkot and Badin were 4.842857 and 5.794286 acres, respectively. The mean values of seeds, fertilizers, and micronutrients were 22.06857, 743.8286, and 139.4857 in Kambar Shahdadkot, respectively, and 23.62286, 856.9286, and 171.5429 in Badin, respectively. The mean quantities of labor used for rice production in Kambar Shahdadkot and Badin were 141.7314 and 195.1143 workers, respectively. Machine use spanned 29.17714 hours on average in Kambar Shahdadkot and 38.20857 hours on average in Badin. The mean values of the rice farmers' ages, education, and farming experience in Kambar Shahdadkot were 44.19429, 4.022857, and 16.48000, respectively. The values for Badin were 42.90857, 2.920000, and 16.48000, respectively.

4.2. Results of stochastic frontier analysis

The results of the maximum likelihood estimation (MLE) obtained from the SFA are presented in Table 4.

Table 4: Maximum Likelihood Estimates (MLE) results of stochastic frontier analysis

Kambar Shahdadkot				**Badin**		
Variables	**Coefficient**	**Std-error**	**t-ratio**	**Coefficient**	**Std-error**	**t-ratio**
Intercept (β_0)	-0.444	0.860	-0.517	0.545	0.232	0.235
Land (β_1)	0.308***	0.379	0.814	0.285***	0.494	0.578
Seed (β_2)	0.210**	0.631	0.332	0.657**	0.880	0.746
Fertilizer (β_3)	-0.368	0.908	-0.405	0.913	0.790	0.116
Pesticides (β_4)	0.427**	0.196	0.218	0.352	0.414	0.849
Micronutrients (β_5)	0.221	0.797	0.278	-0.100**	0.511	-0.196
Labor (β_6)	-0.118*	0.794	-0.148	0.111***	0.258	0.431
Machine used hours (β_7)	0.134***	0.446	0.301	0.746***	0.129	0.578
Technical inefficiency						
Age of farmer (β_8)	0.589	0.252	0.234	-0.200*	0.717	-0.279

Education years (β_9)	0.979**	0.536	0.183		0.248*	0.202	0.122
Farming experience (β_{10})	*0.535**	0.485	0.110		-0.105	0.115	-0.916
sigma-squared (σ^2)	0.691***	0.124	0.555		0.716***	0.109	0.657
gamma (γ)	0.556***	0.981	0.566		0.861***	0.396	0.218
log likelihood function	-0.119			log likelihood function			-0.136
LR test of the one-sided error	0.147			LR test of the one-sided error			0.203

Note * P<0.1percent, **P<0.05 percent and ***P<0.01 percent significant level.
Source: Authors calculations by using Frontier 4.1 program

The parameters, land size, and machine use positively affected rice production in Kambar Shahdadkot at the1% significance level; land size, labor, and machine use exerted a positive effect on rice production in Badin at the 1% significance level. These results are consistent with the findings reported in Chandio *et al.* 2017; Vu. L. H, 2006; Wadud. A, White. B. (2000). The parameters, land size, and machine use were the most significant factors for high rice productivity.

Parameters such as seeds, pesticides, and education had a positive effect at the 5% significance level; farming experience exerted a positive effect at the 10% significance level; and labor had a negative effect at the 10% significance level. The coefficients of educational level and farming experience were positive and statistically significant, indicating that low education and minimal farming experience causes high technical inefficiency in Kambar Shahdadkot. In Badin, seed quantity positively affected rice production at the 5% significance level, and educational level positively influenced rice yield and productivity, at the 10% significance level. Micronutrients, such as zinc, and other growth regulators, negatively affected rice yield and productivity at the 5% significance level.

The coefficient of educational level was positive and statistically significant, indicating that low education among farmers increases technical inefficiency. These results demonstrated that in both the studies districts, the farmers’ educational level and farming experience favorably affected rice production and crop yield. Similar results were reported in (Ahmadu. J, Erhabor. P. O, 2012); Bäckman *et al.* 2014; Bakhsh *et al.* 2007; Shaheen. S, Fatima. S. H, Khan. M. A. 2017).

4.3. Technical efficiency via stochastic frontier analysis

The estimated technical efficiency in Kambar Shahdadkot ranged from 0.95 to 0.99, denoting the considerable capability of the rice growers to improve rice production. The mean technical efficiency score was 0.98, which signifies that 98% of the rice farmers in Kambar Shahdadkot are technically efficient. The estimated technical efficiency in Badin ranged from 0.86 to 0.99, pointing to the potential of rice farmers to increase the per capita rice production in the district. The mean technical efficiency score in Badin was 0.96, which indicates that 96% of the rice farmers in the district have the technically efficiency necessary to increase rice production. Overall, the results revealed that the technical efficiency of the rice farmers in Kambar Shahdadkot was greater than that of the rice farmers in Badin (Table 5).

Table 5: The technical efficiency results by stochastic frontier analysis

Kambar Shahdadkot			**Badin**	
Technical Efficiency Level	**Cases**	**Percentage**	**Cases**	**Percentage**
0.80-0.82	0	0	0	0
0.83-0.85	0	0	0	0
0.86-0.88	0	0	3	1.714
0.89-0.91	0	0	6	3.428
0.92-0.94	0	0	45	25.714
0.95-0.97	25	14.286	51	29.143
0.98-0.99	150	85.714	70	40.000
Total	175	100.000	175	100.000
Mean	0.98		0.96	

Source: Authors calculations by using Frontier 4.1 program

These findings are in line with those in Chandio *et al.* (2017); Buriro, A. Khooharo, A. A. Ghulam, T. (2015); Shaheen, S. Fatima, S. H. Khan, M. A. (2017) which reported that rice farmers in Pakistan are technically efficient and that this attribute can be enhanced further with expanding farming experience and education.

4.4. Results of data envelopment analysis

Table 6 presents the technical and scale efficiency results for Pakistan's rice-producing areas. Overall, the average technical, pure, and scale efficiency levels in Kambar Shahdadkot district were 0.965, 0.978, and 0.987, respectively, whereas those in Badin were 0.958, 0.965, and 0.993, respectively. The technical efficiency of the rice farmers in Kambar Shahdadkot ranged from 0.89 to 1.00, whereas that of the rice growers in Badin ranged from 0.85 to 1.00.

Table 6: Technical efficiency and scale efficiency results by Data Envelopment Analysis

Kambar Shahdadkot						
Efficiency Level	**Technical Efficiency**		**Pure Efficiency**		**Scale Efficiency**	
	Cases	Percentage	Cases	Percentage	Cases	Percentage
0.85-0.86	0	0	0	0	0	0
0.87-0.88	0	0	0	0	0	0
0.89-0.90	2	1.143	0	0	1	0.571
0.91-0.92	15	8.571	2	1.143	2	1.143
0.93-0.94	27	15.428	12	6.857	5	2.857
0.95-0.96	51	29.143	44	25.143	10	5.714
0.97-0.98	53	30.286	67	38.286	52	29.714
0.99-1.00	27	15.428	50	28.571	105	60.000
Mean	0.965		0.978		0.987	
Badin						
Efficiency Level	**Technical Efficiency**		**Pure Efficiency**		**Scale Efficiency**	
	Cases	Percentage	Cases	Percentage	Cases	Percentage
0.85-0.86	3	1.714	1	0.571	0	0.000
0.87-0.88	3	1.714	4	2.286	0	0.000
0.89-0.90	14	8.000	9	5.143	1	0.571
0.91-0.92	23	13.143	16	9.143	1	0.571
0.93-0.94	38	21.714	36	20.571	1	0.571
0.95-0.96	22	12.571	28	16.000	9	5.143
0.97-0.98	33	18.857	30	17.143	28	16.000
0.99-1.00	45	25.714	56	32.000	135	77.143
Mean	0.958		0.965		0.993	

Source: Authors calculations by using DEAP 2.1

The mean values of technical and pure efficiency in Kambar Shahdadkot were higher than those in Badin district. The farmers in Kambar Shahdadkot were more efficient rice producers than were the farmers in Badin because of significant variations in the application of input resources, such as rice seeds, fertilizers, pesticides, labor, micronutrients, and machinery. These findings accord with those presented in Aigner *et al.* (1977); Buriro, A. Khooharo, A. A. Ghulam, T. (2015); Rizwan *et al.* (2017) wherein the technical efficiency of rice farms varied with the intensity of input resource use.

The summary of the return to scale results revealed that in Kambar Shahdadkot, 16.571% of the rice farms enjoyed CRSs, and 75.428% enjoyed increasing returns to scale. In Badin, 50.286% of the rice farms achieved CRSs, and 39.428% realized increasing returns to scale. The overall findings showed that Kambar Shahdadkot was more efficient than Badin (Table 7).

Table 7: The summary of return to scale (RTS)

Kambar Shahdadkot		
Return to scale	**Cases**	**Percentage**
Increasing return to Scale	132	75.428
Constant return to scale	29	16.571
Decreasing return to scale	14	8.000
Badin		
Return to scale	**Cases**	**Percentage**
Increasing return to Scale	69	39.428
Constant return to scale	88	50.286
Decreasing return to scale	18	10.286

Source: Authors calculations by using Frontier 4.1 program and DEAP 2.1

4.5. Comparative results of technical efficiency from both stochastic frontier analysis and data envelopment analysis

Table 8 presents the technical efficiency score, obtained from the SFA and input-oriented DEA. In Kambar Shahdadkot, the mean technical efficiency obtained from the SFA was better than the result obtained from DEA; similarly, in Badin, the technical efficiency score obtained from SFA was found to have greater variability than the score obtained from DEA. For Kambar Shahdadkot, the efficiency score ranged from 0.95 to 1.00 and 0.91 to 1.00 using the SFA and DEA approaches, respectively. Similarly, for Badin, the efficiency score derived from SFA and DEA ranged from 0.86 to 1.00 and 0.83 to 1.00, respectively.

Table 8: The technical efficiency results from both stochastic frontier analysis and data envelopment analysis

Kambar Shahdadkot	**Stochastic Frontier Analysis**		**Data Envelopment Analysis**	
Technical efficiency	**Cases**	**Percentage**	**Cases**	**Percentage**
0.80-0.82	0	0	0	0
0.83-0.85	0	0	0	0
0.86-0.88	0	0	0	0
0.89-0.91	0	0	5	2.857
0.92-0.94	0	0	39	22.286
0.95-0.97	25	14.286	77	44.000
0.98-1.00	150	85.714	54	30.857
Total	175	100.000	175	100.000
Mean technical efficiency	0.988		0.965	

Badin	**Stochastic Frontier Analysis**		**Data Envelopment Analysis**	
Return to scale	**Cases**	**Percentage**	**Cases**	**Percentage**
0.80-0.82	0	0	0	0
0.83-0.85	0	0	1	0.751
0.86-0.88	3	1.714	5	2.857
0.89-0.91	6	3.428	16	9.143
0.92-0.94	45	25.714	53	30.286
0.95-0.97	51	29.143	42	24.000
0.98-1.00	70	40.000	58	33.143
Total	175	100.000	175	100.000
Mean Technical efficiency	0.960		0.958	

Source: Authors calculations by using DEAP 2.1

Overall, the results show that the mean technical efficiency of rice production derived from SFA and DEA (0.988 and 0.965, respectively) was greater for Kambar Shahdadkot than for Badin (0.960 and 0.958, respectively). A number of studies have compared the technical efficiency estimates obtained from an SFA and DEA model, and most reported mix results. Sharma. K. R, Leung. P, Zaleski. H. M. (1997) found that the mean technical efficiency (0.749) from SFA was greater than the mean technical efficiency from CRS DEA and VRS DEA (0.726 and 0.644, respectively); this finding is similar to our results. Hossain *et al.* (2012) reported greater technical efficiency derived from SFA than DEA for Bangladeshi rice. Wadud. A, White. B. (2000) reported that the technical efficiency derived from DEA was better than the technical efficiency from SFA.

5. Conclusion

The present study used SFA and DEA to estimate and compare the technical efficiency of Pakistani rice. The econometric specification derived through MLE shows that parameters, such as land size and machine use, have a positive impact on rice production efficiency in Kambar Shahdadkot; in Badin, land size, machine use, and labor had a positive impact on rice production. The inefficiency analysis results revealed that, in Kambar Shahdadkot, the farmers' years of education and the duration of their farming experience had a significant impact on rice production efficiency; however, in Badin, the rice farmers appear to be less experienced and to have a lower level of education, so the rice production in that district was found to be slightly lower than it is in Kambar Shahdadkot.

The SFA results for technical efficiency indicate that rice production is more efficient for farmers in Kambar Shahdadkot than it is for farmers in Badin. Significant use of input resources, such as land, quality seed, fertilizer and machines, are the main determinants of rice production efficiency. The results of the nonparametric DEA show that the mean technical efficiency and pure efficiency were higher in Kambar Shahdadkot than in Badin, while the mean value of the scale of efficiency was slightly lower in Kambar Shahdadkot in comparison to Badin. The summary of the return to scale indicates that approximately 75.428% of the rice farmers in Kambar Shahdadkot are categorized by an increase in return to scale, while the DEA results showed that only 39.428% of the farmers in that district were categorized by an increase in return to scale.

The comparative results of the parametric approach (SFA) and nonparametric approach (DEA) in Kambar Shahdadkot indicate that the mean technical efficiency measurement obtained using SFA is greater than the technical efficiency measurement obtained from using DEA. Similarly, in Badin, the estimated mean efficiency score derived from SFA is higher than that of DEA. Overall, mean technical efficiency for rice production in Kambar Shahdadkot was 0.988 for SFA and 0.965 for DEA; in Badin, the mean technical efficiency for rice production was 0.960 for SFA and 0.958 for DEA.

Farmers in Kambar Shahdadkot use high quality rice, a significant amount of fertilizer, irrigation systems, and pesticide and then machines to prepare the land for rice production; this reduces the effects of technical inefficiency on rice production. The results of both models also indicate that technical efficiency is positively influenced by proper application inputs; moreover, greater use of modern technology and mechanization in rice farming have a positive influence on rice production in Pakistan.

Therefore, the study concludes that, among the rice farmers in the sample, rice production efficiency increases through the significant use of inputs and improved technology, such as land size, seed technology, and sufficient use of fertilizers and irrigation and mechanization systems. The study’s findings shed light on how rice production efficiency impacts different rice producing regions in Pakistan. The finding may help agricultural policymakers, researchers, and rice farmers increase rice production efficiency in different rice producing regions in Pakistan. Furthermore, the study demonstrated that DEA and SFA are appropriate approaches for estimating the technical efficiency of rice production in Pakistan.

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