Kashmir Economic Review, Volume 32, Issue 1, June 2023

Kashmir Economic Review
ISSN(P): 1011-081X, ISSN(E): 2706-9516
http://www.ker.org.pk

Assessing the Technical Efficiency of Small Farmers Cultivating Wheat in Punjab, Pakistan: A Stochastic Frontier Analysis (SFA)

ABSTRACT

Agriculture is essential in developing countries since it employs most people and contributes significantly to GDP. Wheat is an important crop for both money and food. Land utilization, productivity, and efficiency increase agricultural output. This study aims to asses the technical efficiency of small farmers cultivating wheat in Punjab, Pakistan.The dataset used in this study encompasses 419 small-scale wheat farmers from 2018-19. It offers a comprehensive information regarding production costs and input utilization for the wheat crop. The Stochastic Frontier Analysis yields an average technical efficiency estimate of 84%. The findings suggest that technical efficiency increases by 16 percent without altering the level of inputs utilized.

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Keywords
Technical efficiency, Stochastic Frontier Analysis, PERI

JEL Classification
Q12, O13, Q17

Please cite this article as:
Amin, B., Tahir, M.A., Amin, S., & Hussain, S. (2023). Assessing the technical efficiency of small farmers cultivating wheat in Punjab, Pakistan: A Stochastic Frontier Analysis (SFA). *Kashmir Economic Review*, 32(1), 80-89.

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Author's contribution in the article: 1- Conceived and designed the analysis, 2- Reviewed and compiled the literature, 3- Collected the data, 4- Contributed data or analysis tools, 5- Performed the analysis, 6- Wrote the paper, 7- Financial support for the conduct of the study, 8-Other

1. INTRODUCTION

Agriculture is essential in developing countries since it employs most people and contributes significantly to GDP. Wheat is considered a vital cash crop contributing to food security. Land utilization, productivity, and efficiency all play a role in increasing agricultural output. Productivity can be improved by developing technology or increasing the performance of the resources available. Improving the quality of the tools at the farmer's disposal is a significant concern. The analysis of technical efficiency (T.E. hereafter) is critical. Because through T.E. production of wheat can be improved. In this paper, we calculate the T.E. of small wheat farmers. The small farmer is more concerned about food security rather than profitability. Most of the world's rural population relies on smallholder farming for food production and income, particularly in developing nations. There may be 500 million smallholdings worldwide and 2.1–2.5 billion individuals engaged in small-scale farming (FAO). Efficiency growth and the utilization of extra production variables are two significant elements that could increase agricultural production Ahmad & Bravo-Ureta, (1995). Moreover, Salam and Hameed (2022) , Diaz Balteriro et .al (2006) analyzed the technical efficiency of producing major food grains in Punjab. Results of the study show a large variation in the farmers' technical efficiency at the farm level. Most of the wheat farmers are working under increasing return to scale. Results of the study also show that if the inputs decrease from 10 percent to 29 percent without reducing the outputs.

Prices of inputs also matter in agriculture because high input prices increase the cost of production. For example, prices of diesel, fertilizers, and pesticides increase the cost of production, and the efficiency of the farmers will be affected (Chandio et al.,(2017), Bachewe et al., (2019) . According to Good et al. (1993), productivity is made up of two components: technological change and T.E. According to Kalirajan (1997), research and development are the primary drivers of technological advancement, while education, experience, and a more extensive infrastructure are crucial for boosting the effectiveness of the system. Wheat yields may also vary on farms with similar topographic features and availability of varied input resources. The "technical efficiency gap" is primarily caused by the variations in management strategies used at these farms, which in turn cause yield variation. Citing several research, including those by Fresco et al. (2021), Wadud and White (2000), Pingali (2002), Ahmad et al. (2002), Heisey (2001), Kalirajan et al. (1997), Thirtle et al. (1995), and Lin (1992). Moreover, credit is essential for the improvement of the technical efficiency of the farmers. Masuku et al. (2015) , Ahmed et al. (2014), analyzed how credit affects technical efficiency. Results of the study showed that credit positively influences the efficiency of the farmers.

Therefore, determining the main factors limiting wheat yield and the poor levels of technological diffusion are the main areas of concern. It will be easier to prioritize technical interventions, recognize the need for agroecology-specific enhanced varieties, and plan future policies with the support of documentation of restrictions. The main objective of this study has designed to evaluate Punjab's wheat farms' productivity and compile the factors affecting it. The survey's top priorities included analyzing the efficiency levels of wheat farmers in various production systems, the factors that affect efficiency levels, and then ranking the technological interventions and best agricultural practices required to close yield gaps in multiple zones in order of importance.

2. SPECIFICATION OF THE EMPIRICAL MODEL

The idea of efficiency illustrates how a production process' inputs and outputs are connected (Diaz et al., 2004). Several efficiency metrics can be utilized to assess the capabilities of farmers, including T.E., allocation efficiency, and economic efficiency. The research uses metrics, Farrell (1957) first suggested to evaluate T.E. (1957). T.E. is the capacity of a piece of land to yield as much as possible with a given level of input or to do so while using the fewest number of information possible. These two ideas are input-oriented $(I - O)$ and output-oriented $(O - O)$. T.E. has been analyzed by numerous scholars, including

Coelli et al. (2002), Dhungana et al. (2004), Rodríguez Díaz (2005), We use $(I - O)$ TE in this paper to increase production by using various inputs more effectively. Technical effectiveness can be further broken down into scale effectiveness (SE) and pure technical effectiveness (TE), as suggested by Rodriguez Diaz et al. (2005).

3. DEA AS A MEASURE OF EFFICIENCY

Parametric and nonparametric approaches to measuring performance through stochastic frontier production function method and the DEA methodology. The DEA methodology offers several distinct advantages compared to the econometric approach for evaluating productivity. It is a nonparametric technique that does not require assumptions about the distribution of inefficiency terms. Additionally, DEA allows for comparing performance indexes between different production methods. This enables the calculation of the "efficiency gap" that isolates each farmer's behaviour from the best production practices, which can be evaluated based on observed inputs and outputs of efficient firms. (Haji, 2006; Malano et al., 2004; Wadud & White, 2000). Several other researchers have made substantial contributions in measuring technical efficiency like Aparicio et al. (2020), Ebrahimi et al. (2021).

Moreover, by applying data envelopment analysis, a small sample size cannot significantly affect the measure of efficiency (Chambers, 1998; Toma, 2017) and the selection of data envelopment analysis because of its flexibility and ability to calculate sub-vector efficiencies. The research model presented in this study incorporates information on K inputs and M outputs collected from n individual farms. The input and output data for the i^{th} farm are represented by column vectors x_i and y_i, respectively. The $K \times N$ input matrix X, and $M \times N$ output matrix Y, represent data for all small wheat farms in the sample. Equation 1 is used in the DEA methodology to calculate T.E.

$$\boldsymbol{Min}_{\ \theta\lambda}\theta \tag{1}$$

Subject to

$$-y_i + Y\lambda \geq 0 \tag{2}$$

$$\theta x_i - X\lambda \geq 0 \tag{3}$$

$$N_1\lambda = 1 \tag{4}$$

$$\lambda \geq 0 \tag{5}$$

By resolving equation 1, where is a scalar, N_1 is a $N \times 1$ vector of ones and is a $N \times 1$ vector of constants, one can determine the T.E. score for the i^{th} farm. Each farm goes through this process once, and the final value—which ranges from 0 to 1—represents the T.E. score. The farm is effective and located on the frontier, according to a score of one. It is worth noting that the variable returns to scale (VRS) specification of Equation 1 includes a convexity constraint $N_1 = 1$. This constraint is implemented to ensure that the farms are not operating above their ideal scale. Equation 1 would adopt a CRS without this limitation if the farms operated optimally (Fraser & Cordina, 1999).

In agriculture, increasing the number of inputs does not necessarily result in a proportional output increase. For example, increasing the amount of water supplied to crops may not result in a linearly proportional increase in crop volume. This highlights the need for a variable return-to-scale option, which may be more appropriate for addressing the productivity assessment problem in agriculture Rodríguez -Deaz et al., 2005). Furthermore, comparing both scores holds great significance, providing valuable insights regarding scale efficiency (S.E.). Coelli et al. (2002) showed that the relationship is as follows:

$$SE = TE_{crs}/TE_{vrs} \tag{6}$$

If scale efficiency (S.E.=1), it shows CRS and efficiency if the value of the scale efficiency is less than one, it shows that scale inefficiency exists.

Applying the concept of sub-vector efficiency introduced by Farrell et al. (1957), the technical sub-vector efficiency for the variable input k is computed for each farm i by solving the following programming problem, as proposed in this study.

$$\boldsymbol{Min}\ _{\theta\lambda}\theta^{\boldsymbol{k}} \quad (7)$$

Subject to:

$$-y_i + Y\lambda \geq 0 \quad (8)$$

$$\theta^k \mathrm{x}_i^k - X^k\lambda \geq 0 \quad (9)$$

$$\mathrm{x}_i^{n-k} - X^{n-k}\lambda \geq 0 \quad (10)$$

$$N_1\lambda = 1 \quad (11)$$

$$\lambda \geq 0 \quad (12)$$

Within this equation, the variable θ^k signifies the T.E. score assigned to the sub-vector of input k for the i^{th} farm. The third constraint in the given equation takes into account the presence of xi and X, where the k^{th} input (column) is omitted and represented as x_i^{n-k} and X^{n-k}, respectively. Conversely, the second constraint only considers the k^{th} input and is represented by x_i^k and X^k. All other variables are defined similarly as in Equation 1.

4. DATA

The (PERI) provided the data for this study, which divided the Punjab province into three zones based on the irrigation sources. The zones are barrani (rain-fed), partially barren, and irrigated. To ensure representation of all farm types. Ecological zones were used to partition the irrigated area into Cotton-Wheat, Rice-Wheat, and Mixed-Wheat Zones. Respondents were chosen based on the size of their farms in the particular village that was included in the sample.

The selection criteria ensured that the study concentrated on a diverse range of farm sizes to capture an in-depth portrait of the village's agricultural landscape because the sample village was chosen to represent the larger farming community population. The study included small-sized farmers from Rawalpindi, Chakwal, Bhakkar, Sheikhupura, Gujranwala, Hafizabad, Narowal, Nankana, Faisalabad, Okara, Sargodha, Bahawalnagar, Rahim Yar Khan, Khanewal, Dera Ghazi Khan, Vehari, and Muzaffargarh. The study included 419 wheat growers, and the data collected included the cost of production and inputs used in wheat production, with wheat yield per acre serving as the dependent variable. Table 1 displays the range of values for the input variables that were employed in the study.

These variables include the total area of land allocated for wheat cultivation, the amount of farmyard manure applied per acre, the seed rate per acre, the number of pesticides and weedicides used per acre, the number of irrigations per acre, the number of labour utilized for wheat production per acre, the cost of land preparation per acre, and the number of fertilizer bags applied per acre. The minimum and maximum values of these variables are presented in Table 1 to provide a comprehensive overview of the input variables used in the study.

The study employed input variables measured per-acre basis, except for the area sown for wheat, which was used to assess the returns to scale of farming. Additionally, the study included efficiency variables such as the farmers' age and education, wheat cultivation area, credit access, awareness of the agriculture department, and traditional knowledge, with their respective minimum and maximum values also presented in Table 1.

Table 1: Summary of Statistics of Variables

Variable	Unit	Obs.	Mean	Std.Dev.	Min	Max
Land Rent	Rs	419	13691.050	6669.973	2000	32500
Seed quantity	Kgs	419	40.532	2.686	35	47.000
Irrigation Number	Number of irrigation water	419	3.937	1.819	0.000	8.000
Total fertilizer Bag	Number of Bags	419	2.744	.968	0.000	6.500
Fyam Yard manure	Number of cartloads	419	2.194	1.300	0.000	6.000
Weedicide Numbers	Number of sprays	419	.994	.289	0.000	2.000
Yield	40 kg	419	34.624	8.606	6.000	63.000
Man days	Man Days	419	9.072	27.584	.219	154.750

Table 2: Socioeconomic characteristics

Age	**Frequency**	**Percentage (%)**
>=30	68	16.23
31-40	85	20.29
41-50	97	23.15
51-60	89	21.24
>60	80	19.09
Household Size	**Frequency**	**Percentage (%)**
1-4	94	22.43
5-9	276	65.87
10-14	45	10.74
>14	4	0.95
Mean	6.38	
Education Level	**Frequency**	**Percentage (%)**
No Formal Education	118	28.16
Primary Education	67	15.99
Matriculation	183	43.68
Intermediate	31	7.4
Bachelours	20	4.77
Mean	6.23	
Farming Experience	**Frequency**	**Percentage (%)**
1-20	88	21
21-40	201	47.97
>40	130	31.03
Farm Size (Acres)	**Frequency**	**Percentage (%)**
0-1	18	4.3
1-2	95	22.67
2-3	125	29.83
3-4	90	21.48
4-5	81	19.33
5	10	2.39
Mean	2.54	
Zone	**Frequency**	**Percentage (%)**
Baraani	55	13.13
Partial Baraani	42	10.02
Irrigated Rice	94	22.43
Irrigated Mix	67	15.99
Irrigated Cotton	161	38.42

The socioeconomic characteristics of the farmers are presented in Table 1. The age distribution of the farmers shows more than 15 percent (16.23 %) of the farmers are not more than 30 years of age. Similarly, more than 20 percent (20.29 %) of farmers aged between 31 to 40 years and less than 25 percent (23.15) of farmers aged between 41 to 50 years. At the same time, less than 20 percent of the farmers were above 60. Their mean age was 46.38 years. The mean age of the respondents shows that most of the farmers are young and physically active. Most respondents (65.87 %) had household sizes of 5 to 9 people, and more than 10 percent (10.74) farmers had household sizes between 10 to 14 per person.

The respondents' educational attainment has been classified into five groups: no formal education, primary education, matriculation, intermediate education, and bachelor's education level. The results indicate that most respondents possess a matriculation education level (43.68%), whereas more than one-quarter of farmers (28.16%) have not received any formal education. Thus, the literacy level of the farmers is high in farmers. More than 50 % of the farmers had more than 50 years experienced. The distribution of the farm sizes respondents shows that most farmers cultivated up to 2 to 3 acres.

The mean farm size of the respondents is about 2.45 acres. The distribution of the zones is barani, partial barani, irrigated rice, irrigated mix, and irrigated cotton. More than 20 percent of the wheat grower in irrigated rice zones, and more than 10 percent (10.02) of farmers were in partial barani areas.

Table 3: Average Estimates of Technical Efficiency Estimates from DEA Models

Variable	Observation	Mean	Std.Dev.	Min	Max
CRS	419	.833	.155	.235	1
VRS	419	.987	.04	.75	1
SE	419	.844	.153	.235	1

Table 4: Technical Efficiency Estimates using DEA Models

	CRS		VRS		SE	
Technical Efficiency	Number of farmers	Percentage of farmers	Number of farmers	Percentage farmers	Number of farmers	Percentage farmers
0 -0.5	12	2.86	-	-	11	2.63
0.5-0.6	23	5.49	-	-	20	4.77
0.6- 0.7	45	10.74	-	-	42	10.02
0.7- 0.8	85	20.29	3	0.72	75	17.90
0.8- 0.9	89	21.24	24	5.73	91	21.72
0.9-1.00	165	39.38	392	93.56	180	42.96

Variable return to scale and constant return to scale input-oriented T.E. are calculated using data envelopment analysis DEA. The DEA model-derived T.E. estimates are displayed as average values. Compared to the other farms in the sample, these estimates show how effectively the sample farms convert their input resources into output. The average T.E. estimates provide a helpful summary of the sample farms' overall efficiency and can be used to pinpoint areas where productivity increases may be possible. According to Table 3, the mean T.E. scores for constant return to scale (CRS-DEA) and variable return to scale ($CRS - DEA$) are 0.833% and 0.987%, respectively. In addition, scale efficiency is calculated by using the relationship between CRS and variable return to scale. The average scale efficiency is .84 percent. Most farmers are technically efficient between 0 .9 -1 range (Table 5). Thirty-nine percent of farmers are technically efficient in CRS and 93.56 percent in VRS, which lies in this range. Moreover, agriculture department awareness and traditional awareness have positively and significantly affected the efficiency of the farmers when the farmers have more understanding about crop activity.

Table 5: Comparison of Factors Affecting Technical Efficiency

Variables	(1)	(2)	(3)
	CRS	VRS	SE
Age	0.154***	1.206***	0.160***
	(0.0112)	(0.0365)	(0.0111)
Household size	0.0560***	0.323***	0.0524***
	(0.0183)	(0.0595)	(0.0182)
Education	0.0129*	0.0545**	0.0139*
	(0.00747)	(0.0243)	(0.00743)
Area sown	0.0217	0.0161	0.0309**
	(0.0141)	(0.0460)	(0.0141)
Credit	0.0881***	0.109	0.0817**
	(0.0340)	(0.110)	(0.0338)
Agriculture department awareness	0.118***	0.721***	0.101***
	(0.0331)	(0.108)	(0.0329)
Traditional awareness	0.113***	0.704***	0.0990***
	(0.0292)	(0.0949)	(0.0290)
Observations	419	419	419
R-squared	0.964	0.992	0.965

S.R in parentheses; *** p<0.01, ** p<0.05, * p<0.1

The OLS regression results are presented in Table 5. Table 5 shows the determinants of the T.E. of small farmers. The dependent variable of the OLS regression model is the T.E. score of the wheat crop's small farmers for 2017-2018. The respondent's age in CRS and variable return to scale have a positive and significant impact on the efficiency of the farmers. It means older farmers have more efficient compared to young farmers. The reason is that farmers have become more skillful as they grow older due to cumulative farming experience. This result was consistent with the argument (Alemu, 2018; Liu et al., 2000). Farmers' ability to acquire and use knowledge of improved technologies is aided by education. In this study, education is measured in years of formal schooling. The sign of education is positive and significant. It means educated farmers are more efficient as compared to uneducated farmers. This may be because trained and educated farmers can better combine information from different sources and apply new knowledge and technology to their farms, resulting in higher wheat yields. More educated farmers use inputs in wheat growing better way.

Similarly, the coefficient of the estimated household size of the farmers and the education of the farmers positively and significantly affects the efficiency of the farmers in CRS and VRS. The wheat crop area is statistically significant and positively affects the efficiency of the farmers. The coefficient value of the area sown of wheat shows that the area of crop increases; farmers are more efficient.

Credit is a crucial component of agricultural production systems. It helps producers to fulfill their cash needs because of the output cycle. Since it temporarily fixes a liquidity/working capital shortage, the amount of Credit increases farmers' performance. In this analysis, the amount of Credit is hypothesized in such a way that farmers who received Credit from formal or informal sources during a given production season were expected to be more productive than those who received no credit. The empirical studies by Biam et al. (2016), Ali et al. (2014), found a positive and significant relationship between Credit and farmers' T.E., which was in line with this study. The study results indicate that Credit is an essential determinant of efficiency. The availability of Credit increases the efficiency level of the farmers. The estimated coefficient value of the Credit shows that efficiency and Credit positively correlate.

5. CONCLUSION AND POLICY IMPLICATIONS

The primary objective of this study was to apply SFA analysis methods to assess the T.E. of smallholder wheat farmers. The data utilized in this study was acquired from the Punjab Economic Research Institute (PERI) based in Lahore. This study analyzes a dataset of 419 small wheat farmers and includes information on production costs and input utilization for the crop. The SFA estimate for T.E. was 84 percent on average. The results of the SFA study indicate that T.E. can be enhanced by 16% without any alteration in the input levels. The analysis further suggests that factors such as education level, transportation costs, farm size, and geographical area positively impact T.E.

The study lends credence to the claim that Punjabi wheat farmers may be more technically effective, which would improve wheat production. We suggest the following policy alternatives to increase the productivity and effectiveness of small-scale wheat growers in Punjab based on the findings of this study. First, the SFA model's parameters demonstrate that labour, seed, and farmyard manure impact productivity. In light of these findings, policymakers should prioritize educating farmers on the appropriate and balanced use of inputs. Based on the second recommendation's analysis, irrigation water availability significantly impacts crop yield, emphasizing the need for accessible canal water at the appropriate time. Water shortages can be resolved by implementing plans to make rainwater collection more widely used and limiting water loss through canal or watercourse lining. Thirdly, it is recommended that the agricultural extension service plan be scheduled at the beginning of each year, with extension agents organizing training sessions to educate farmers on effective crop production methods. Moreover, there is a need to restructure the wheat extension efforts.

Acknowledgment
The authors express their gratitude for the valuable input provided by the reviewers and members of the editorial board during the review process of the previous version of this manuscript.

Funding Source:
The author(s) did not receive any dedicated funding for this research paper.

Conflict of Interests:
The authors have stated that they do not have any conflicts of interest to disclose.

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