Measurement of technical efficiency in cotton production in Batman Province, Turkey: a comparison of DEA and SFA

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Abstract

This paper uses data envelopment analysis and stochastic frontier analysis to estimate technical efficiency of cotton production in Batman, Turkey. Full counting method was used for sampling. Data were collected on a sample of 64 cotton farmers in the production period of 2019/2020. Data on inputs such as land (ha), seeds (kg), N-P fertilizer (kg), machine and human labour (h), pesticides (litres), fuel (litres) and output such as yield (kg) were collected. According to the DEA results, the overall technical, pure technical, and scale efficiency were calculated as 0.90,0.98, and 0.91, respectively. The mean technical efficiency score obtained from SFA was calculated as 0.843. The mean technical efficiency obtained from the DEA was better than the result obtained from SFA. The empirical results indicated that technically inefficient farms had higher usage of land and P fertilizers. Therefore, cotton productivity can be increased with the proper use of inputs.

Keywords: Cotton. Technical efficiency. Data envelopment analysis. Stochastic frontier analysis.

1. Introduction

In addition to its high value to agricultural production, cotton agriculture is a source of income for a wide segment of people, with its seed, fertilizer, medicine, machinery industry, trade and logistics due to intensive use of inputs (Anonymous, 2020).

Current world production of cotton is 82.59 million tons and China is the largest producer of cotton. Turkey's share in world production of cotton is 2.66% (FAO, 2019).

Recently, it is becoming more important to determine and compare the performance of farms.

The most suitable method for this comparison is to determine the technical efficiency score (Dalgic et al., 2018). Technical efficiency can be estimated using a non-parametric, mathematical programming framework with Data Envelopment Analysis (DEA), or a parametric statistical framework with Stochastic Frontier Analysis (SFA). Both methods require construction of a production frontier which is used to evaluate individual production (Lovell, 1993). Both methods have different advantages and disadvantages. It is an important benefit of DEA that there is no limitation on the functional form of the production relationship between inputs and outputs. Also, DEA can accommodate multiple inputs and multiple outputs simultaneously. Otherwise, the main disadvantage of DEA is that it can be overly sensitive to variable selection and data errors (Seiford, 1996; Onder et al. 2003).

SFA consider noise and error in the data. The main disadvantages of SFA is that it makes an obvious distributional assumption for inefficiency and it explicitly imposes a specific parametric functional form representing basic technology (Timothy et al. 2005; Wagan et al. 2019).

In this study, the purpose is to determine the technical efficiency of cotton farms in Batman province in Turkey by using DEA and SFA.

2. Literature Review

Several researches have been conducted on determining technical efficiency of agricultural products using parametric and non-parametric approaches (Hediari et al., 2011; Koyubende and Ozden, 2011; Gunduz et al. 2011; Engindeniz and Ozturk 2013; Cukur et al., 2013; Haryanto et al., 2015; Parlakay et al., 2015; Gunduz et al., 2016; Gul et al., 2016; Kea et al., 2016; Ozden and Oncu, 2016; Ozturk and Engindeniz 2018; Ormeci Kart et al., 2018; Oguz et al., 2019; Oruk, 2020).

Koyubende and Ozden (2011) aimed to measure the performance of dairy farms in Izmır, Turkey with SFA. The average technical efficiency was calculated as 0.864. As a result of the study, it was stated that all of the firms have got much more efficiency than 59%. They noted that technical efficiency increased when the firms developed.

Engindeniz and Ozturk (2013) did the technical efficiency and economic analysis of tomato production in Izmir, Turkey. In the study, input use efficiency in the production of tomatoes was measured by DEA. That study's results indicate that average technical efficiency (CRS) determined as 0.787 and 0.753 for table and processing tomato farms, respectively.

Haryanto et al. (2015) estimated technical efficiency of rice production in Indonesia using apply two-stage DEA. The average technical efficiency that was found as 0.77. In that study, it was suggested that policy to increase the technical efficiency of rice production in Indonesian should be prioritized on the use of certified seeds, control of pests and diseases, government assistance, education and irrigation.

Ozden and Oncu (2016) determined the scores of technical efficiency and the factors affecting these scores in cherry production in Lapseki, Turkey. The technical efficiency scores were calculated as 0.83 with CRS and 0.85 with VRS.

Kea et al. (2016) investigated the technical efficiency and establish core factors affecting rice production in Cambodia. SFA was performed to measured the technical efficiency. Their results indicated that the level of output of Cambodian rice production varied according to the different level of capital investment in agricultural machineries, total rice actual harvested area, and technical fertilizer application within provinces.

There are also many studies on comparison of these methods (Wadud and White, 2000; Chakraborty et al., 2002; Alemdar and Oren, 2006; Odeck, 2007; Olgun et al., 2011; Parlakay and Alemdar, 2011; Cobanoglu, 2013; Zamanian et al.2013; Madau, 2015; Wagan et al. 2019).

Wadud and White (2000) compared technical efficiency for rice farmers in Bangladesh using stochastic frontier analysis (SFA) and DEA. That study revealed that efficiency was significantly influenced by the factors measuring environmental degradation and irrigation infrastructure.

Chakraborty et al., (2002) measured technical efficiency for cotton growers in west Texas using stochastic frontier analysis (SFA) and DEA. Their results showed that the irrigated farms could be reduce their expenditures on other inputs by 10%, and the non-irrigated farms could be reducing their expenditures on machinery and labour by 12% and 13%, respectively, while producing the same level of output.

Parlakay and Alemdar (2011) calculated technical and economic efficiencies for peanut farming in Turkey with DEA and SFA. Their results indicate that technical efficiencies vary between 0.80-0.86 and economic efficiency was about 0.60. They found that efficiencies are positively correlated with education, peanut planting area, and observance of proposed nitrogen doses, and negatively correlated with ratio of family labor, number of irrigations and plots.

Madau (2015) estimated technical and scale efficiency in the Italian citrus farming using both DEA and SFA. As a result of the study, scale efficiency score (0.818) according to the SFA model was found to be lower than that estimated from the DEA model (0.894).

3. Material and Method

This study was performed in Batman province, Turkey. The full counting method was used in this paper for data collection and data were collected by using a face-to-face questionnaire from 64 cotton farmers in the production period of 2019/2020. Data on inputs such as land (ha), seeds (kg), N-P fertilizer (kg), machine and human labour (h), pesticides (litres), fuel (litres) and output such as yield (kg) were collected.

Technical efficiency of cotton farms was determined with DEA and SFA. Descriptive statistics for variables used in technical efficiency analyses are shown in Table 1.

Table 1: Descriptive statistics for variables

Variables	Mean	Minimum	Maximum	Standard deviation	Measurement
Outputs					
Cotton Yield	51.65	36.00	65.00	7.41	Kg ha^{-1}
Inputs					
Land	10.02	2.20	22.00	5.35	Ha
Seed	0.26	0.16	0.30	0.03	Kg ha^{-1}
N fertilizers	2.31	1.20	4.25	0.62	Kg ha^{-1}
P fertilizers	0.97	0.00	2.09	0.49	Kg ha^{-1}
Machine	0.17	0.14	0.21	0.02	Hours ha^{-1}
Labour	1.33	1.08	1.86	0.12	Hours ha^{-1}
Pesticide	0.08	0.06	0.12	0.01	Litters ha^{-1}
Fuel	2.47	1.26	5.43	1.01	Litters ha^{-1}

Source: Own calculation

Farmers have more control over their inputs than their outputs. Therefore, the input-oriented DEA model performed in this paper (Tipi et al., 2009, Oruk and Engindeniz, 2018).

Constant return to scale (CRS) input-oriented model is stated as follows (Färe and Grosskopf, 1994; Coelli et al., 2006).

$\min_{\theta,\lambda} \theta,$

$s.t \; -y_i + Y\lambda \geq 0$

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

$\lambda \geq 0$

where θ is the efficiency score for the i-th decision-making unit (DMU) with $0 \leq \theta \leq 1$. According to the Farrell (1957) definition, it will satisfy $\theta \leq 1$, with a value of 1 indicating a point on the frontier and thus technically efficient DMU. Therefore, the linear programming problem needs to be resolved n times and θ value is provided for each DMU in the sample.

(Coelli et al., 2006). The earlier work of Charnes et al. (1978) has been extended by Banker et al. (1984) by providing variable returns to scale (VRS).

Input-oriented DEA model based on the VRS is stated as follows: (Färe and Grosskopf, 1994; Coelli et al., 2006)

min θ,λ θ,

s. t –yi +Yλ≥ 0

θxi – Xλ≥ 0

N1'λ=1

λ≥ 0

where, N1 is an N ×1 vector of ones.

Total or overall technical efficiency score can be obtained with the CRS model, and pure technical efficiency score can be obtained with the VRS model. Scale efficiency measure can be calculated by dividing the total technical efficiency by pure technical efficiency:

Scale efficiency = Overall technical efficiency score / Pure technical efficiency score

If scale efficiency = 1, then a DMU is scale efficient and the DMU is operating under increasing returns to scale, if scale efficiency <1, then a DMU is not scale efficient and the DMU is operating under decreasing returns to scale (Aldeseit, 2013; Gunden et al., 2006).

The stochastic frontier production function model is expressed below (Battese and Coelli, 1995; Coelli et al. 1998):

$$(Y_i) = f(X_i;\beta)\exp(V_i - U_i)$$

where Y_i is the output value of the *i*th farm, β is a vector of parameters to be estimated, exp is the exponential function, V_i is the random error term assumed to be independently and identically distributed, U_i is the inefficiency term with half-normal distribution.

This study used a Cobb-Douglas functional form. Cobb-Douglas function form of the SFA model:

$$ln(Y_i) = lnf(X_i;\beta) + V_i - U_i$$

Technical efficiency was calculated using the following equation:

$$TE_i = \frac{Y_i}{\exp(X_i\beta)} = \frac{\exp(X_i\beta - U_i)}{\exp(X_i\beta)} = \exp(-U_i)$$

In the stochastic model given above, inefficiency effects or factors thought to cause inefficiency are not included.

4. Results and Discussion

Efficiency scores of cotton farms were given in Table 2. The mean values of overall technical, pure technical, and scale efficiency were 0.90,0.98, and 0.91, respectively. The results showed that cotton farmers within the studied area could reduce their inputs by 2% without reducing their cotton production. By eliminating scale inefficiency, the cotton farms can increase their average technical efficiency level from 90.4% to 98.8% (Table 2).

Table 2: The overall, pure and scale efficiencies

Efficiency measures	Mean	Std.deviation	Min	Max	Efficient farms (%)
Overall technical efficiency	0.904	0.118	0.620	1.000	46.88
Pure technical efficiency	0.988	0.023	0.914	1.000	70.31
Scale efficiency	0.914	0.108	0.637	1.000	46.88

Source: Own calculation

In the studies conducted to determine technical efficiency in cotton production, the scale efficiency value has been determined as; 0.677 (Gunden, 1999), 0.972 (Akturk and Kıral, 2002), 0.79 (Binici et al. 2006), 0.79 (Gul et al.2009), 0.33 (Cobanoglu, 2013) and 0.89 (Oruk, 2020).

Distribution of technical efficiency coefficients calculated for farms were given in Table 3. In this study, 30 farms under constant return to scale (CRS) and 45 farms under variable return to scale (VRS) were found to be fully efficient. 26.69% of the cotton farms had pure technical efficiency scores of %90 or higher and 70.31% of the cotton farms had pure technical efficiency scores of %100 (Table 3).

Table 3: Frequency distribution of technical efficiency scores

	CRS		VRS		SE	
Technical Efficiency Level	Cases	Percentage	Cases	Percentage	Cases	Percentage
0.100-0.200	0	-	0	-	0	-
0.201-0.300	0	-	0	-	0	-
0.301-0.400	0	-	0	-	0	-
0.401-0.500	0	-	0	-	0	-
0.501-0.600	0	-	0	-	0	-
0.601-0.700	5	7.81	0	-	3	4.69
0.701-0.800	9	14.06	0	-	9	14.06
0.801-0.900	13	20.31	0	-	14	21.87
0.901-0.999	7	10.94	19	29.69	8	12.50

1.000	30	46.88	45	70.31	30	46.88
Total	64	100.00	64	100.00	64	100.00

Source: Own calculation

Differences between efficient and inefficient tomato farms were investigated using some variables and results were given in Table 4. As can be seen in the table, technically inefficient farms had higher usage of land and P fertilizers compared to technically efficient farms.

Table 4: The differences between technically efficient and inefficient cotton farms under constant return to scale

Variables	Efficient farms	Inefficient farms
Number of farms	30	34
Cotton Yield***	56.64	47.25
Land**	8.57	11.29
Seed	0.26	0.26
N fertilizers	2.26	2.37
P fertilizers**	0.81	1.11
Machine	0.18	0.17
Labour	1.34	1.31
Pesticide	0.08	0.08
Fuel	2.27	2.65

Source: Own calculation
*, ** and *** represents 10%, 5% and 1% levels of significance

It has been found that 14 of the 64 cotton farms use 32.93% surplus land and 26 of the apricot farms use 43.30% surplus P fertilizers (Table 5).

Table 5: Input slacks and excessive usage

Inputs	Number of farms	Mean slack (1)	Mean input use (2)	Excessive usage (%) (1/2)
Land	14	3.30	10.02	32.93
Seed	18	0.03	0.26	11.54
N fertilizers	23	0.63	2.31	27.27
P fertilizers	26	0.42	0.97	43.30
Machine	20	0.01	0.17	5.88
Labour	18	0.12	1.33	9.02
Pesticide	12	0.01	0.08	12.50
Fuel	19	1.03	2.47	41.70

Source: Own calculation

The results of the SFA estimates are shown in Table 6. The constant term is positive and significant. Machine use positively affected cotton production at the %10 significance level. When machine use was increased by 100%, holding all other inputs constant, output would also increase by about 35.4%. The estimates sigma squared was 0.052 and significant at 1%. The gamma value of the model was 0.953. This means that 95.3% of the total variation in output was as a result of factors within the control of the cotton farmers.

Table 6: Maximum likelihood estimates of the stochastic frontier model

Variables	Coefficient	Std.error	t-ratio
Constant	4.938***	0.401	12.309
Land	5.680	5.079	1.118
Seed	0.144	0.176	0.817
N	-0.063	0.068	-0.926
P	0.002	0.034	0.060
Machine	0.354*	0.192	1.846
Labour	0.254	0.222	1.149
Pesticide	0.048	0.101	0.480
Fuel	-0.037	0.052	-0.706
Sigma-squared	0.052***	0.018	2.992
Gamma	0.953***	0.087	10.953
Log-likehood function	37.891		
LR test	3.886		

*, ** and *** represents 10%, 5% and 1% levels of significance

The technical efficiency scores obtained from SFA ranges from 0.976 to 0.554 with a mean efficiency of 0.843. Among the farmers, 37.50 percent are producing at 90.1%-99.9% percent efficiency level. The mean technical efficiency score was 0.8430, which signifies that 84.30% of the cotton farmers in Batman are technically efficient. The analysis reveals that, on average, cotton farmers would be able to increase output by about 15.70% using their disposable resources more rationally. The mean technical efficiency obtained from the DEA was better than the result obtained from SFA. DEA efficiency scores have greater variability than the stochastic frontier efficiency measures (Table 7). Similarly, in previous researches related to cotton production, Solakoglu et al (2013) calculated technical efficiency as 0.65 when 2001-2008 period; Cobanoglu (2013) calculated that as 0.91.

Table 7: The technical efficiency results from both stochastic frontier analysis and data envelopment analysis

Technical Efficiency	DEA		SFA	
Level	Cases	Percentage	Cases	Percentage
0.100-0.200	-	-	-	-

0.201-0.300	-	-	-	-
0.301-0.400	-	-	-	-
0.401-0.500	-	-	-	-
0.501-0.600	-	-	1	1.56
0.601-0.700	-	-	6	9.38
0.701-0.800	-	-	14	21.88
0.801-0.900	-	-	19	29.69
0.901-0.999	17	26.56	24	37.50
1.000	47	73.44	-	-
Total	64	100.00	64	100.00
Mean	0.9901		0.8430	

5. Conclusion

This study used both DEA and SFA approaches to calculate and compare the technical efficiency of cotton in Batman province in Turkey. The comparative results of DEA and SFA showed that mean technical efficiency score obtained from the DEA was higher than SFA result. Highest score obtained from DEA-VRS model with a score of 0.988, followed by DEA-CRS (0.904) and SFA (0.843). Results concluded that little technical inefficiency among the cotton farmers in Batman. But efficient farms achieved higher yields and technically inefficient farms had higher usage of land and P fertilizers. Therefore, cotton productivity can be increased with the proper use of inputs.

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