Determination of technical efficiency in cotton production by using data envelopment and stochastic frontier analysis methods: a case study of Hatay Province in Turkey

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Abstract

The main aim of this study is to determine the technical efficiency of cotton production in the province of Hatay, which is one of the major cotton production areas of Turkey. The data of the study were gathered from 136 cotton enterprises by the face-to-face survey method, and the Random Stratified Sampling method was used in determining the sample size. In the data analysis; the Data Envelopment Analysis (DEA), (Variable Return to Scale - Output Oriented), and Stochastic Frontier Analysis (SFA) methods, which are commonly being used in technical efficiency measurements of agricultural enterprises, were used. The determinants of technical efficiency were calculated by the Tobit Regression Analysis (for DEA) and TE Effects Model (for SFA). In the analysis, cotton yield per decare was considered as output; and seed usage (kg da^{-1}), pure nitrate usage (kg da^{-1}), pure phosphorus usage (kg da^{-1}), labor force (h da^{-1}), machinery power (h da^{-1}), pesticide cost (USD da^{-1}) and the number of irrigation were considered as inputs. According to the analysis results, the technical efficiency score average of cotton enterprises was found as 0,82 with the DEA-VRS method and was found as 0,86 with the SFA method. Besides, it was found that the enterprises which produce cotton at the minimum efficiency level, could increase the cotton production amount by 78% according to the DEA-VRS, and by 0,72% according to the SFA method. The scale efficiency average was calculated as 0,97. It was concluded that the main reason for high scale efficiency was derived from a false input combination; nonetheless, it was determined that there were enterprises which weren't utilising scale efficiency. In the study, it was observed that some inputs were overused, such as the number of irrigation (36,79%), fertiliser-N (17,88%), and pesticide cost (8,22%). Hence, cotton yield could be increased with proper input combinations. Also, producer training activities about input usage levels and methods could be useful in order to increase awareness about the issue.

Keywords: Cotton. Data Envelopment Analysis. Stochastic Frontier Analysis.

1. Introduction

The agricultural sector provides raw materials to many other production sectors. Cotton is one of the strategic products that is being used widely as a raw material in textile, vegetable oil, forage, and paper industries. Due to wide usage areas, cotton has an economic importance which creates added value and employment. Due to specific climate requirements, cotton is produced in specific countries in the world. Seven countries including Turkey provide 80% of the total global cotton production (Anonymous, 2019).

Cotton production takes an important place in Turkey's economy. According to data of 2018, Turkey has 1,6% of the global cotton production area, and around 3,6% of global cotton production is provided by Turkey. In addition, a 263 million USD export value was gained only from cotton products such as lint, linter, waste, combed, and seed (FAO, 2020). According to the data of 2019, around 12% of Turkey's cotton production was produced in the Hatay province (TurkStat, 2020).

Today, it's important to determine the efficiency level of resources that are used in agricultural production, and it's possible to analyse resource usage efficiency by data that are collected from field researches. Afterward, those results would be important in determining the factors that cause inefficiency, and in making policies to increase efficiency (Parlakay, 2011).

In order to increase countries' agricultural production potential; it is necessary to improve the level of technological usage, prevent loss of production due to inefficiency, and to perform micro and macro measurments for making policies about production increase (Günden and Miran, 2001).

There are various studies about efficiency measurement for many agricultural products. Most of the studies in the literature carried out 'the Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA)' methods to measure efficiency for different agricultural products such as; goat breading, grape, peanut, dairy breeding, wheat, cotton, etc. Some recent examples were as follows: Aydemir et al., (2020); (Örük, 2020); Wei et al., (2020); Kumar, et al., (2019); Zulfiqar et al., (2017); Parlakay, et al., (2016); Gül et al. (2016); Theriault and Serra, (2014); Solakoglu et al. (2013); Azdawla et al., (2013); Parlakay and

Alemdar (2011); Günden et al. (2001); Dagistan et al. (2009); Gul et al. (2009); Alemdar and Oren (2006); and Binici et al., (2006).

The main purpose of this study was to measure the technical efficiency scores of cotton production in the Hatay province, which is one of the major cotton production areas of Turkey. Also, it aimed to determine the factors which caused inefficiency in light of efficiency scores of the cotton enterprises.

2. Literature Review

Cotton production is a subject in many studies due to its importance. Some of the studies that are specific to the efficiency score measurment of cotton production are listed below.

Binici, et.al. (2006), found that cotton production efficiency in the Harran Plain of Turkey was high. However, 72% of the cotton enterprises' input usage efficiency was found inefficient especially in chemical pesticides, urea, and machinery and labor inputs. The study suggested educational seminars for producers to raise awareness about input usage.

Gül, et.al. (2009) researched the technical efficiency of cotton production in the Çukurova region of Turkey. The research results suggested that producers could achieve the same amount of cotton with 20% less input usage. Also, farmers' age, education level, and land size were found as factors which have an impact on technical efficiency.

Solakoglu, et.al. (2013) carried out a study about premium payments and efficiency in cotton production by the use of the Stochastic Frontier Analysis Model. The study indicated that the premium payment was found as the most important determinant on regional inefficiency.

Azdawla, et.al. (2013) found the technical efficiency scores of cotton production in Ghana to be between 0,70 and 0,99 (average: 0,88). In the research, making land reform policies to expand cotton production areas, and providing inputs and subsidy payments on time to the producers, were suggested.

Theriault and Serra (2014) examined the institutional environment and technical efficiency of cotton production in West Africa by using the Stochastic Frontier Analysis Method. According to the research results, cotton production in Burkina Faso and Benin were found more efficient than in Mali. In the study, new policies that focus on financial support for producers were suggested in order to decrease producers' financial stress, and to increase technical efficiency.

Zulfiqar, et.al. (2017) carried out a study in Pakistan about efficiency in cotton. Within the study, the technical efficency score was found as 55,2% with the DEA-CRS, 79% with DEA-VRS, and the technical economic efficiency average was calculated as 56%. Also, while there was a positive relationship between efficiency and producers' education level, experience level, and drainage; there was a negative relationship with household size and land size.

Kumar, et.al. (2019), examined efficiency scores of cotton production in India by the use of the Data Envelopment Analysis method. According to the research results, the efficiency score averages for technical, scale, allocative, and cost were respectively as follows; 97,3, 93,7, 87,6 and 85,2. Also, it was concluded that production costs could decrease 20% by proper input usage without any change in yield. In addition, it was suggested that premium payments help to increase efficiency.

Wei et al. (2020) carried out a study titled "Estimating the Economic and Production Efficiency of Cotton Growers in Southern Punjab, Pakistan''. The technical, allocative, and cost-efficiency of the cotton farmers were examined by means of the Data Envelopment Analysis. According to the study results, the technical efficiency score average was 0,90, allocative efficiency was 0,59, and the economic efficiency score was found as 0,53. In conclusion, carrying out training activities for farmers was suggested.

Örük (2020), found the technical efficiency average of cotton production in the Diyarbakır province of Turkey as 0,97. The research results pointed out that the technical efficiency level of cotton production would increase by raising the awareness of cotton producers about input usage and modern agricultural production practices.

3. Materials and Methods

The main material of the study consists of primary data gathered from cotton producers in the Hatay province by the face-to-face interview method in the season of 2016/17. Also within the study are secondary data from reports of several organisations such as; the Republic of Turkey Ministry of Agriculture and Forestry (MAF), the Turkish Statistical Institute (TSI), the Republic of Turkey Ministry of Development, and the Republic of Turkey Ministry of Trade.

In order to determine sample size, the Neyman Method, which is one of the Stratified Sampling methods, was used (Yamane, 2010). Accordingly, 136 cotton enterprises were determined as the sample size with a 5% margin of error, and at a 95% confidence interval.

An enterprise's capability of gaining maximum output with its own input combination is defined as technical efficiency, and the capability of producing at the optimum scale is defined as scale efficiency (Coelli et al., 2003).

Efficiency measurement is conducted as input oriented (IO) and output oriented (OO). In analysis towards input, the main focus is to determine the minimum input amount while the output amount is assumed stable. In analysis towards output, the main focus is to determine the maximum output amount while the input amount is assumed stable. Input and output efficiency analysis are carried out under the assumptions of the Constant Return to Scale (CRS) and the Variable Return to Scale (VRS).

The starting point of efficiency measurement methods is determining an efficient production limit as a reference. The common methods that are used in efficiency analysis are; the Data Envelopment Analysis (DEA) which is nonparametric, and the Stochastic Frontier Analysis (SFA) which is a parametric method.

Nonparametric methods have some advantages such as; not needing assumptions about production method, being able to work on more than one input and output, and being sensitive to errors due to not having random error terms. On the other hand, a disregarding factor of chance, and not being able to determine the confidence degree of findings are the biggest disadvantages of nonparametric methods. In the SFA method; the affects of random factors that are out of the enterprise's control are measured by adding two error terms to the model, and the SFA parameters are able to be calculated by the Maximum Likelihood method (Parlakay and Alemdar, 2011).

The DEA method focused on efficiency maximisation in terms of output is defined below (K: inputs, M: outputs, N: enterprise):

$$Max_{\phi,\ \lambda} \qquad \phi$$

Subject to

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

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

$$N1'\lambda = 1$$

$$\lambda > 0 \qquad (1)$$

In the model that is given above, 'ϕ' is a value between 1 and eternity, 'Y' is (M x N) the output matrix, *'X'* is (K x N) the input matrix, 'y_i' is the output of *i-th* farm, *'N1'* is a vector of (N x 1) and a convexity restriction, and 'λ' is (N x 1) a vector of intensity variables. The ratio of 1/φ defines a technical efficiency score between zero and one (Coelli et al., 1998).

The model used in the Stochastic Frontier Analysis is given below (Aigner et al., 1977; Meeusen and Van den Broeck, 1977).

$$Y_i = \beta * X_i + V_i - U_i \qquad (2)$$

In the formula above, *Yi*: output of *i-th* decision unit; *β*: parameters of input vector that is assumed (Kx1) dimensional; *Xi*: input line vector of (K+1) dimensional. The algorithm of '*U*' is the technical efficiency of *i-th* decision unit. *K* is the number of input, *X* and *Y* values are inputs and outputs in logarithmic forms (Coelli, 1996a).

In the analysis, the DEAP (Version 2.1) software that was created by de Coelli (1996b) was used in the Data Envelopment Analysis (DEA). The Frontier (Version 4.1) software that was created by Coelli (1996a) was used in the Stochastic Frontier Analysis (SFA). Efficiency scores of DEA were calculated by the assumptions of the Constant Return to Scale (CRS) and the Variable Return to Scale (VRS).

In the analysis, cotton yield per decare is considered as the output. Seed (kg da^{-1}), pure nitrate (kg da^{-1}), pure phosphate (kg da^{-1}), labor force (h da^{-1}), machinery force (h da^{-1}), pestiside cost (USD da^{-1}), and the number of irrigation are considered as inputs. Pesticide inputs were taken into consideration as value instead of usage amount due to each pesticide having its own affective substance. The dollar exchange rate of the production period was taken as 1 USD = 3,52 TL from the records of Turkish Central Bank.

In terms of technical efficiencies; some varieties such as production area size, education level, irrigation and harvest methods, experience level, and farmer's age were investigated by the Tobit Regression Analysis for the DEA, and by the TE Effects Model for the SFA.

4. Results and Discussion

Within the study the inputs were; seed (kg da^{-1}), pure nitrate (kg da^{-1}), pure phosphate (kg da^{-1}), labor force (h da^{-1}), machinery force (h da^{-1}), pestisice cost (USD da^{-1}), and the number of irrigation; while cotton yield (kg da^{-1}) was taken into consideration as output. Some of the variables that were used in the efficiency analysis are summarised in Table 1.

Table 1: Summary of statistics for variables used in the efficiency analysis.

Variables	Minimum	Maximum	Mean	Std. Deviation
Output				
Cotton Yield (kg da^{-1})	100,00	850,00	536,19	99,90
Input				
Seed (kg da^{-1})	1,60	3,50	2,64	0,25
Fertiliser – N (kg da^{-1})	4,20	42,70	23,38	6,82
Fertiliser – P (kg da^{-1})	0,00	34,73	10,24	6,09
Labor (h da^{-1})	10,26	20,38	13,65	1,87
Machinery operation time (h da^{-1})	1,30	3,02	1,75	0,20
Pesticide cost (USD da^{-1})	4,40	12,66	8,27	1,59
Number of irrigation	0,00	11,00	4,24	3,01

According to the research results, cotton yield per decare was between 100,00 kg and 850,00 kg, and the average was 536,19 kg per decare. Input averages per decare used in cotton production were; 2,64 kg of seed, 23,38 kg of pure nitrate, 10,24 kg of pure phosphate, 13,65 hours of labor force, 1,75 hours of machinery force, 8,27 USD of pesticide cost, and the number of irrigation was found as 4,24 times (Table 1).

Due to the SFA being output oriented, the DEA and SFA analysis results were compared with the output oriented results. In terms of efficiency scores, VZA was calculated output oriented with the assumptions of the Constant Return to Scale (CRS) and the Variable Return to Scale (VRS), and the log probability test was chosen to be used among other SSA models (Gujarati, 1999; Parlakay and Alemdar, 2011).

Table 2: Distributions of technical efficiency scores obtained with DEA (Output Oriented)

Efficiency Scores	DEA			
	DEA-CRS	DEA-VRS	DEA-SE	SSA
1.00	18	33	67	-
0.91-0.99	15	16	58	53
0.81-0.90	39	30	6	55
0.71-0.80	29	27	4	22
0.61-0.70	21	20	1	4
0.51-0.60	10	7	0	1

0.41-0.50	3	2	0	0
<0.41	1	1	0	1
Minimum	0,22	0,22	0,68	0,27
Maximum	1,00	1,00	1,00	0,96
Mean	0,80	0,82	0,97	0,86
S.D.	0,15	0,06	0,05	0,09

The efficiency score average of the enterprises which were examined was found as 0,82 with the DEA-VRS method, and was found as 0,86 with the SFA method. Thus, without any change in input amounts, cotton yield could be increased by 18% (1-82/100) according to the DEA-VRS method, and it could be increased by 10% (1-86/96) according to the SFA method. Besides, enterprises which were working at the minimum efficiency level could increase cotton yield by 78% (1-22/100) according to the DEA-VRS method, and by 72% (1-27/96) according to the SFA method (Table 2).

Efficiency scores with the SFA method were calculated higher than expected. In general lower results could be expected with the VZA method, due to any deviation from production level being considered inefficiency (Coelli et al. 2003).

Efficiency scores of the research showed similarities to previous studies in Turkey. Efficiency scores of cotton production by the DEA method from some previous studies were as follows; Günden (1999) found it as 0,68 in the Menemen district of the İzmir province; Aktürk (2000) found it as 0,84 in the Söke district of the Aydın province; Binici et.al. (2006) found it as 0,79 in the Harran plain; and Gül et.al. (2009) found it as 0,89 in the Çukurova region.

In general, inefficiency is caused by either production at an improper scale, or wrong resource distribution. While improper scale indicates that scale economies are not being applied, wrong resource distribution indicates inefficient input combinations (Oren and Alemdar, 2006). Within the study, the scale efficiency average was found as 0,97 which means it is high. So, it could be said that inefficiency is mostly caused by wrong input combinations. However, there were also some enterprises determined which weren't utilising scale efficiency. Among the 136 enterprises; 56 of them showed increasing returns to scale, 49 of them showed constant returns to scale, and 31 of them showed decreasing returns to scale. Characteristics of farms according to returns to scale are given in Table 3. According to the analysis results, the optimal farm size was found as 108,41 da, and the optimal output average was found as 560,65 kg da^{-1}.

Table 3: Characteristics of farms with respect to returns to scale

Indicator	The Number of Farms	Mean Cotton Farm Size (da)	Mean Output (kg da^{-1})
Sub-optimal (irs)	56	122,38	511,13
Optimal (crs)	49	108,41	560,65
Super-optimal (drs)	31	80,94	542,81

Within the study, slack variables were examined. Slack variables state excessive usages in input. An agricultural enterprise can decrease input cost as much as the slack variable amount (Oren and Alemdar, 2006). The slack variables and input usage means, and the excessive input usage ratios are given in Table 4. According to the analysis results; the most excessive usage occured in irrigation, which was respectively followed by fertiliser-N, pesticide cost, and fertiliser-P. In other words, the same cotton yield could have been produced by using 36,79% less irrigation, 17,88% less fertiliser-N, 8,22% less pesticide cost, and 7,42% less fertliser-P. Similar results were gathered in some previous studies. Gül et.al. (2009) found an excessive usage of fertiliser-P, labor, seed, and the number irrigation. Günden and Miran (2001) found input losses in labor, machinery power, seed, and fertiliser-P.

Table 4: Slack Variables and Excessive Input Usage in Enterprises

Input	The Number of Enterprises	Slack Mean	Input usage Mean	Excessive input usage (%)
Fertiliser-N (kg da^{-1})	74	4,18	23,38	17,88
Fertiliser-P (kg da^{-1})	37	0,76	10,24	7,42
Seed (kg da^{-1})	41	0,07	2,64	2,65
Labor (h da^{-1})	63	0,78	13,65	5,71
Machinery operating time (h da^{-1})	71	0,10	1,75	5,71
Pesticide cost ($ da^{-1})	63	0,68	8,27	8,22
Number of irrigation	62	1,56	4,24	36,79

In general it is hard to offer policy solutions by only technical efficiency scores, also external factors that have affects on production should be taken into consideration (Parlakay, 2011). It is possible to determine relationships between efficiency scores and external factors that cause inefficiency in production by the use of the Tobit Regression Analysis and the TE Effect Model. The other variables that may have an affect on technical efficiency such as; land size, education level, harvest method, irrigation method, and farmer's age and experience level, were included in the model. The relationships between the DEA technical scores and external factors are given in Table 5. However, it wasn't commented on due to the results being statistically insignificant.

Table 5: The Relationships Between External Factors and Technical Efficiency Scores – Tobit Regression Analysis Results (VZA-Output Oriented)

Variables	Coefficient	Std. Error	Z-score	Significance
C	0.9761***	0.0814	11.9862	0.0000
Field size of cotton production	0.0001	0.0003	0.1810	0.8564
Education level	0.0001	0.0032	0.0317	0.9747
Harvest method	-0.0530	0.0381	-1.3901	0.1645
Irrigation method	-0.0557	0.0434	-1.2850	0.1988
Experience level	-0.0039	0.0028	-1.3787	0.1680
Farmer's age	0.0714	0.0591	1.2092	0.2266
R-squared	0.0160			
Adjusted R-squared	-0.0378			

The Ordinary Least Squares and Maximum Likelihood methods were taken into consideration in order to examine the relationships between external factors and the SFA Technical Efficiency Scores. The Maximum Likelihood method was chosen because of having the highest Log Likelihood function value (42,94). The Maximum Likelihood Method results of the SFA are given in Table 6.

Table 6: The Highest Likelihood Predictions of the Coefficients in Inefficiency Model

Variables	Parameter	Coefficient	Std. Error	T-ratio
Stochastic Frontier Analysis				
Constant	β_0	6.3320	0.3739	16.9351***
Ln (Seed)	β_1	0.2037	0.1553	1.3121
Ln (Fertiliser-N)	β_2	0.0547	0.0510	1.0741
Ln (Fertiliser-P)	β_3	0.0314	0.0067	4.6271***
Ln (Labour)	β_4	-0.1077	0.1152	-0.9352
Ln (Machinery operating time)	β_5	0.1686	0.1222	1.3792
Ln (Pesticide cost)	β_6	-0.0733	0.0789	-0.9281
Ln (Number of irrigation)	β_7	-0.0042	0.0058	-0.7182
Technical Inefficiency Model				
Constant	δ_0	0.0001	0.9981	0.0001
Field size of cotton production	δ_1	0.0053	0.0093	0.5662
Education level	δ_2	-0.0442	0.0296	-1.4918
Harvest method	δ_3	-0.0170	0.0543	-0.0313
Irrigation method	δ_4	-0.0193	0.2708	-0.0711
Experience level	δ_5	0.0759	0.1718	0.4420
Farmer’s age	δ_6	-0.0014	0.0521	-0.0272
Variance Parameters				
Gamma	γ	0.8824	0.0580	15.2099***
Sigma squared	σ^2	0.1145	0.0311	3.6866***
Log likelihood function		42.9420		
LR test		28.4801		
Mean technical efficiency		0.86		
Minimum TE		0.27		
Maximum TE		0.96		

According to the analysis results, four of the inputs have positive signs, and three of them have negative signs. Among the inputs that have positive signs, only fertiliser-P was found statistically significant which means an increase in the fertiliser-P usage amount would increase the total output. The parameter of γ was found high and statsitically significant (0,88), and this value indicates that 88% of the variation in cotton yield is caused by technical inefficiency.

5. Conclusions and Recommendations

This study was carried out in the Hatay province which is one of the major cotton production areas in Turkey. In order to predict efficiency scores two of the common methods, the DEA and SFA, were used.

The research findings indicate that the cotton output amount could be increased without changing input amounts. According to the technical efficiency scores, cotton yield could be increased by 18% based on the DEA, and could be increased by 10% according to the SFA. In the SFA method only fertiliser-P was found statistically significant among the other variables, so an increase in the fertiliser-P amount would make an increase in the total product amount.

Inefficiency is usually caused by either improper distribution of inputs or by improper production scales. In this study, it could be said that enterprises were producing at proper scales in general, and analysis results support that finding (97%). Within the research, it was also found that the number of irrigation (36,79%), fertiliser-N (17,88%), and pesticide (8,22%) were being used excessively. Cotton yield could be increased with correct input combinations. In this context, providing training programs for farmers about input distribution could be useful in terms of increasing yield and preventing resource waste. Another input that was found being used excessively was irrigation. Hatay province has a hot climate which causes a high level of evaporation especially in summers. An efficient use of water resources would help to utilise the agricultural potential of the province more efficiently, and to prevent the waste of scarce resources.

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