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ANALYSIS OF THE EFFICIENCY IN PRODUCTION OF TOMATOES AMONG AGRICULTURAL ESTABLISHMENTS: DATA ENVELOPMENT ANALYSIS AND STOCHASTIC FRONTIER ANALYSIS

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Abstract

Technical efficiency of tomato producers in Ankara was evaluated using Data Envelopment Analysis and Stochastic Production Frontier methods. Using Stratified Random Sampling method 77 tomato producers were selected and structured questionnaire was used to collect data from the selected farmers. The main tomato production problems faced by tomato producers are diseases representing 22.4%, low labour force 20.0%, cost of inputs 17.7% and access to irrigation water 1.9%. The main marketing problems faced by farmers are transportation cost of tomatoes to sales point %39.9 and low selling of tomatoes 38.6%. Technical efficiency was found to be 55.55% under stochastic production frontier while under Data Envelopment Analysis was found to be 86.43%. Stochastic Frontier Analysis separates causes of changes in output into managerial and chance hence lower efficiency score compared to data envelopment analysis approach which does not. The results of Stochastic Production Frontier indicate that all factors of production that include labour, land, seedling, animal manure, chemical fertilizer, pesticides, irrigation and tractor expenditure where all found to be statistically significant in influencing production on the other hand formal education of the farmer, use of agricultural credit and membership to agricultural organisation were found to be statistically significant in influencing technical efficiency scores.

Key words: *efficiency, stochastic frontier analysis, data envelopment analysis, tomatoes production*

INTRODUCTION

Tomato (*Lycopersicon esculentum*) is one of the most important vegetables in the world. It contributes to a healthy and balanced diet. Tomatoes are rich in minerals, vitamins, important amino acids, sugars and dietary fiber. Tomatoes contain a lot of vitamins B and C, iron and phosphorus (Shankara et al. 2005) [9]. The vitamin A content in yellow tomatoes is higher than in red tomatoes, but red tomatoes contain lycopene, an antioxidant that can contribute to protection against carcinogens. Tomatoes are consumed in fresh (table) and processed (paste) forms. Tomato is one of the processed products, tomato juice, ketchup, tomato paste, peeled, tomato puree. Tomato demand and trade in the world is constantly growing. In 2017, it was estimated that world tomato production was 241 million tons, export and import trade was 81 million tons and 5 million tons, respectively (FAOSTAT 2017) [5]. This figure represents 36% of tomatoes traded in the international market, while the remaining 64% represents consumer consumption and domestic trade. In addition, this figure shows the economic importance of tomatoes in a country's foreign currency earnings and income earnings of tomato producers. The main activities involving tomato production are listed as soil preparation, seedling planting, fertilization, irrigation, pesticide, weed and disease control and harvesting operations (Shankara et al. 2005) [9]. Tomato (*Lycopersicon esculentum*) is one of the vegetables grown worldwide (Shankara et al. 2005) [9]. According to continents, tomato production is estimated to be 111 million in Asia, 23 million in Europe, 20 million in Africa, 13 million in North America, 6 million in South America and 500 thousand in Australia (FAOSTAT 2018) [6]. The countries where tomatoes are produced the most in the world are China 12 million tons, India 1 million 900 thousand tons, USA 1 million 300 thousand tons, Turkey 1 million

200 thousand tons, Egypt 662 thousand tons, Iran 665 thousand tons and other countries 6 million tons (FAOSTAT 2018) [6]. Turkey's highest tomato producing provinces Antalya 2 million 500 thousand tons, Mersin 1 million 300 thousand tons, Muğla 700 thousand tons, Bursa 340 thousand tons, Çanakkale 309 thousand tons, Hatay 62 thousand tons, Tokat 353 thousand and other provinces 3 million 400 thousand tons (Turkstat 2019) [10].

In this study, a research has been carried out for the problems related to tomato production activities in Ankara Province. The study focuses on tomato diseases, production cost, profit, yield and marketing. According to the reviewed literature, none of the previous studies focused on the analysis of the cost, income and profit efficiency of tomato growing agricultural enterprises. Therefore, this study focuses on the evaluation of technical efficiency, which is a component of the cost effectiveness of tomato growers in Ankara, and the problems experienced in tomato production and marketing using Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) methods.

MATERIALS AND METHODS

Material

Data were obtained from enterprises producing tomato in Ankara province through a questionnaire. The questionnaire forms were filled in by going to sample tomato producers and interviewing them face to face. In addition to the primary data obtained, the findings of previous studies on the subject, published and the records of different organizations, and second data were used.

Data Analysis

SPSS, DEAP and R package programs were used in data analysis.

Methods

Sampling

Within the scope of the study, there are 394 tomato enterprises in Ankara Province Ayaş district. Tomato growers of 5 villages included in the study were selected because they produce intensive tomatoes. The total tomato cultivated area of these villages is 2,713.44 decares, and the average land is 9,120 decares. While the first layer allocated to the production of tomatoes was 0.15-9.15 decares, the second layer was allocated 10.15-50.15 decares for the production of tomatoes. Neyman method was used to determine the total sample volume (n). Using this method, the total sample volume was determined to be n = 77.

Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA)

Technical efficiency is the ability of a firm to avoid waste by using as few inputs as required by its technology and production (Coelli et al. 2005) [2]. Allocation activity is the firm's ability to combine inputs and/or outputs in optimal proportions in light of prevailing prices. There are two approaches to estimating technical effectiveness; Parametric and nonparametric approaches (Fare et al. 1985) [7]. Parametric approaches such as stochastic boundaries are to predict production functions using econometric techniques. Nonparametric approaches such as Data Envelopment Analysis are used in linear programming techniques for estimation of effectiveness (Cooper et al. 2007) [4]. In this study, Data Envelopment Analysis and Stochastic Frontier Analysis technique were used to predict the efficiency in tomato production. Output directional data envelopment and stochastic production limit are used to analyze the optimum amount of output that can be achieved with the current input level and technology. Output oriented data envelopment and stochastic production limit were used to analyze the scale of the business.

Data Envelopment Analysis (DEA) (maximization LP problem)

The Banker-Chaenes-Cooper (BCC) data envelopment model considers underproduction and the size of the scale process as sources of inefficiency. This is called the output-direction BCC data envelopment model and is expressed as follows:

$$\mathrm{Max}\ \theta + \varepsilon\left(\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+\right)$$

S.t.

$$\theta y_0 - Y_i\lambda + S_r^+ = 0$$

$$X_i\lambda + S_i^- = x_0$$

$$\sum_{i=1}^{n} \lambda_i = 1$$

Maximum output achievable with current technology level = θ * vector of output quantities (Yi)

$$\lambda.\theta.S_r^{+}.S_i^{-} \geq 0$$

θ = Effectiveness points ranging from 0 to 1
S_r^{+}= output scarcity (loose) due to output mix
S_i^{-}= over input (loose)
λ= Lamda
X_i= Vector of input quantities
Y_i = Vector of output quantities (Cooper et al. 2007) [4].

Stochastic frontier analysis (maximization problem)

The data envelopment analysis technique provides the analysis of the use of resources, the maximum amount of output that can be achieved with current input and technology levels. However, it does not show the factors that contribute to the source of changes in efficiency between businesses. On the other hand, stochastic production frontier technique provides analysis of the sources of efficiency changes (Fare et al. 1985) [7]. For this reason, stochastic probability frontier technique was also used to analyze the sources of variation in possible activities among tomato farmers in Ayaş district.

Selection of tomato production function

Estimation of the stochastic production limit requires the definition and selection of the appropriate production function. Common production function models Linear, Cobb-Douglas, Quadratic, Normalized quadratic, Translog, Generalized Leontief, Elasticity of Substitution Constant etc. (Battese and Coelli 2005) [1]. But commonly used are Cobb-Douglas and Translog. In this study, Cobb-Douglas and Translog production function was evaluated using log odds ratio test. For Cobb-Douglas, LR = 2 (least square - Cobb-Douglas stochastic frontier analysis). For Translog, LR = 2 (least square - Translog stochastic frontier analysis). The function of Cobb-Douglas was determined to be suitable for the production of tomatoes in Ayaş district. For this reason, the Cobb-Douglas function was used to analyze the technical efficiency of tomato producers in Ayaş district.

The model is specified as follows:

$$lny_i = lnf(x_i;\beta) + (v_i - u_i)$$

b= vector of technological parameters
ln = natural logarithm
v_i= white noise error term (iid~N(0. σ^2)
u_i= The term ineffectiveness (semi-normal, gamma, exponential or truncated normal distributed) is chosen as the semi-normal distribution ineffectiveness.
x_i= Vector of input quantities
y_i = Vector of output quantities (Coelli et al. 2005) [2].

Variable selection for tomato production function

Production is the process of combining and coordinating inputs (production resources or production factors) in the creation of a good or service (Colman and Young 1989) [3].

The production process of tomatoes requires the following inputs (Shankara et al. 2005) [9]. Workforce (working days), land (decare), seedling amount (piece), chemical fertilizer (kg), animal fertilizer (ton), pesticide (lt), Tractor (expenses) and irrigation (total irrigation times throughout the season), these inputs have been the selection criteria for the variables used in the analysis of production efficiency in both SFA and DEA methods.

RESULTS AND DISCUSSIONS

In this section, efficiency results of Stochastic Frontier Analysis and Data Envelopment Analysis are discussed.

Variables used in Stochastic Frontier Analysis and Data Envelopment Analysis

The statistical values of the variables used in the Stochastic Frontier and Data Envelopment technical efficiency analysis are presented in Table 1.

Table 1. Variables used in Cobb-Douglas model and Data Envelopment Analysis

Variables	Mean	Minimum	Maximum
Total tomato production quantity (kg)	59,487.01	1,000	300,000
Preparation of land throughout the season using a tractor (how many times)	2.81	2	5
Irrigation throughout the season (how many times)	21.58	10	40
Number of days family workforce and foreign workforce worked in tomato production	66.16	45	96
Land allocated for tomato production (decare)	15.49	1	60
The amount of seedlings used (number)	13,272.07	450	50,000
Chemical fertilizers used (kg)	883.84	0	10,000
Animal fertilizer used (ton)	36.55	0	400
Pesticide used (liter)	9.86	1	25

Source: Authors' calculation.

Continuous variables used in the analysis of variability affecting the technical efficiency level among farmers are given in Table 2.

Table 2. Variables used in the inneficiency model

Variables	Mean	Minimum	Maximum
Age of the business owner	54.79	34	72
Number of people in the family	3.06	2	6
The total number of years the farmer has grown tomatoes	25.58	6	45

Source: Author's calculations.

Analysis of technical efficiency with the stochastic frontier analysis

It includes the selection of the appropriate production function, the estimation of the selected production function, and the analysis of the factors affecting changes in the efficiency level of tomato farmers.

Selection of production functional form; odds ratio test

Commonly used types of production functions are translog and Cobb-Douglas production function, so both are considered here. Translog and Cobb-Douglas production is compared to stochastic frontier function versus non-stochastic frontier functions. First, the double error translog generation is compared with the single error translog generation using the stochastic margin, probability ratio test. This was done to test the significance of the variance of the ineffectiveness error term. Test results show that the variance of a component of ineffectiveness is not significant at an error rate of 5% (Table 3).

Table 3. Comparison of the double error translog stochastic generation function with the single error translog generation function using the probability ratio test

Model	#df	Log likelihood value	#df	Ki-square value	Pr > ki-square
First model	46	-28,051			
Second model	47	-28,051	1	0	1
Significance values: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

Source: Authors' calculation.

This demonstrated that the translog production function was not a suitable functional form. The signs of some coefficients of the translog production stochastic frontier function are reversed, which is another indication that the translog stochastic frontier function is not a suitable model. Log likelihood test and hypothesis are stated as follows.

LR = 2 (model 1 - model 2).

H_o: Model 1: Single error translog generation stochastic limit (No inefficiency)

H_1: Model 2: Double error component translog generation stochastic limit (inefficiency present)

Second, the double error components are compared with the single error Cobb-Douglas production function using the Cobb-Douglas production stochastic boundary function log likelihood ratio test. Log likelihood test results showed that ineffectiveness error components were significant at 0.1% error rate (Table 4). This shows the existence of inefficiency among tomato producers in Ayaş district. Also, the signs of the coefficients of the Cobb-Douglas production stochastic boundary function appeared as expected, which is an additional indication of the good model fit for the data. The log likelihood ratio test and the hypothesis are stated as follows.

LR = 2 (model 1 - model 2).

H_o: Model 1: Single error Cobb-Douglas production stochastic limit function (no inefficiency)
H_1: Model 2: Double error components Cobb-Douglas production stochastic boundary function (inefficiency exists)

Table 4. Comparison of double error Cobb-Douglas production stochastic limit and single error Cobb-Douglas production function using probability ratio test

Model	#df	Log likelihood ratio	#df	Ki-square value	Pr > ki-square
First model	10	-64.624			
Second model	11	-55.815	1	17.618	0.000 ***
Significance values: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

Source: Authors' calculation.

The chi-square test was also performed for the inefficiency error term in the Cobb-Douglas production stochastic limit. According to the results, the variance of an ineffective error term constitutes 99% of the total variation and is statistically significant at an error rate of 0.1% (Table 4). This led to the rejection of the null hypothesis of no inefficiency in the data. Therefore, it has become appropriate to include explanatory variables for the inefficiency error term in the model.
As a reminder, the hypothesis for the Cobb-Douglas production stochastic limit function and the inefficiency error term is expressed as follows.
Cobb-Douglas production stochastic limit function:
$lny_i = lnf(x_i;\beta) + (v_i - u_i)$
v_i= white noise error term (iid~N(0, σ_{vi}^2)
u_i = inefficiency term is semi-normal (iid~N(0, σ_{ui}^2)
$\gamma = \frac{\sigma_{ui}}{\sigma_{vi}+\sigma_{ui}}$
Ho: $\gamma = 0$ there is no ineffectiveness
H1: $\gamma > 0$ there is ineffectiveness

This is a test of variance that monitors the chi-square distribution.

Table 5. Chi-square test of inefficiency variance components of Cobb-Douglas production stochastic boundary

Gamma	Estimated gamma value	Standard error	z-value	Pr(>|z|)
γ	0.999	0.00	18,221,462.85	0.000 ***
Significance values '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				

Source: Authors' calculation.

Estimation of the efficiency effect of the Cobb-Douglas production stochastic frontier analysis model

The combined results of the Cobb-Douglas production and inefficiency functions are shown in Table 6, respectively. The sum of all the coefficients of the Cobb-Douglas production stochastic boundary function is equal to 1.67. The fact that this total is more than one means that tomato production in Ayaş district provides increasing returns to scale. It means that farmers can increase their level of efficiency and production by increasing the size of their business. The coefficients of all Cobb-Douglas production stochastic boundary function were statistically significant and with expected signs (Table 6). The use of tractor expenditures as an input was considered as the appropriate variable, so a negative sign emerged. This indicates that a 1% increase in the use of inputs will result in a percent increase in tomato production up to the recommended or optimal ratio according to the magnitude of their coefficients. For example, a 1% increase in the use of family and foreign labor provides a 0.677% increase in tomato production, keeping all other inputs constant. On the other hand, a 1% increase in tractor expenditures will cause a 0.553% decrease in tomato production.

There are two basic approaches to estimating the inefficiency model; they are two-stage and one-stage. For the two-stage approach, technical efficiency scores are estimated in the first stage and limited dependent regressions such as the least square regression or the Tobit model are used to evaluate the variables that affect the changes in the efficiency scores in the second stage. For the one-step approach, the inefficiency model is substituted in the stochastic boundary function and estimated simultaneously (Kumbhakar and Lovell 2000) [8].

In this study, a one-step approach was used in the estimation of environment or situation variables affecting technical efficiency among tomato farmers in Ayaş district. The results of the inefficiency model are presented in Table 6 along with the results of the Cobb-Douglas production stochastic boundary function.

Table 6. Cobb-Douglas production efficiency effect stochastic frontier analysis model results

Variables	**Variables in natural log form**	**Coefficients**	**Estimated coefficients**	**Z value**	**Pr(>|z|)**	**Significance value**
Production function	Intercept	b_0	6.387	9.985	0.000	***
Number of family and foreign labor days	lnx_1	b_1	0.677	3.810	0.000	***
Tomato planting land	lnx_2	b_2	0.573	16.618	0.000	***
Total amount of seedlings used (pieces)	lnx_3	b_3	0.239	33.919	0.000	***
Total chemical fertilizer used (kg)	lnx_4	b_4	0.102	6.018	0.000	***
Total used animal manure (tonnes)	lnx_5	b_5	0.111	4.126	0.000	***
Total pesticide used (lt)	lnx_6	b_6	0.145	16.981	0.000	***
Tractor cost (TL)	lnx_7	b_7	-0.553	-8.349	0.000	***
How many times irrigation is done (Number)	lnx_8	b_8	0.253	2.665	0.008	**
Inefficiency function	Z (intercept)	δ_0	-2.074	-1.997	0.046	*
Age of the owner of the business	Z1	δ_1	0.033	1.504	0.133	
Educational status of the owner of the business	Z2 secondary school	δ_2	1.271	2.779	0.005	**
Educational status of the owner of the business	Z2 high school	δ_3	-0.424	-0.976	0.329	
Educational status of the owner of the business	Z2 bachelor	δ_4	-1.039	-1.046	0.296	
Years the owner of the business spent in tomato production	Z3	δ_5	-0.032	-1.180	0.238	
Number of family members	Z4	δ_6	-0.008	-0.060	0.952	
Credit utilization status of the business owner	Z5 (no)	δ_7	0.612	1.725	0.085	,
Status of the owner of the business as a member of the cooperative	Z6 (no)	δ_8	1.133	3.080	0.002	**
Sigma square	sigmaSq	δ^2	0.846	12.268	0.000	***
Gamma	Gamma	γ	0.999	18,221,462.858	0.000	***
Log likelihood value: -45,16988						
Significant value: ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘,’ 0.1 ‘’1						

Source: Authors' calculation.

Testing the significance of all the coefficients of the inefficiency model

The statistical significance of all coefficients in the inefficiency model was tested using the Log likelihood ratio test.

The test results showed that all coefficients were statistically significant in influencing the changes in activity level among tomato farmers (Table 7).
This led to the rejection of the null hypothesis. The log likelihood test is expressed as follows:
LR = 2 (model 1 - model 2).

Model 1: as all explanatory variables to Zi have the effect $lnf(x_i;\beta) + [(v_i - f(\gamma, z_i) + \epsilon_i]$

Model 2: as all explanatory variables to Zi have no effect $lnf(x_i;\beta) + [v_i - f(\gamma_0) + \epsilon_i]$

Ho: $\gamma_1 = \cdots = \gamma_6 = 0$
H1: $\gamma_1 \ldots \gamma_6$ does not equal at least zero

Table 7. Log odds ratio test for the effect of all inefficiency coefficients

Model	#df	Log ratio value	#df	ki-square value	Pr > ki-square
First model	20	-45.170			
Second model	12	-54.231	8	18.122	0.020 *

Source: Authors' calculation.

Evaluation of efficiency scores

Technical efficiency average of tomato producers in Ayaş district is 55.55% (Table 8). This is to keep all other factors affecting production such as diseases, input costs, profitability constant. It means that there is a possibility of increasing output by 44.45% by better use of existing inputs of tomato producers in Ayaş district.

Table 8. Summary statistics of efficiency points

Statistical parameters	Efficiency scores %
Mean	55.55
Median	54.00
Mod	100
Minimum	7.00
Maximum	100.00

Source: Authors' calculation

Considering that tomato producers are not fully efficient, the calculation of the actual amount of tomatoes they will produce if they use their inputs correctly is given below.
Calculation of technical efficiency score:

$$TE_i = \exp(-u_i) = \frac{y_i}{y_i^*} = \frac{y_i}{f(x_i;\beta) + (v_i - f(\gamma.z_i) + \epsilon_i)}$$

$TE_i =$ Technical efficiency
Exp= Exponential
$y_i =$ Actual output vector (amount of tomatoes) (Kg)
$y_i^* =$ Vector (amount of tomato) of maximum outputs achievable with current technology and input level (Kg).

Maximum achievable output average (kg):

$$average\ maximum\ output = \sum (y_i^*)/n = \sum \left(\frac{y_i}{TE_i}\right)/n$$

Average of poor output (kg):
$low\ output = \sum (y_i^* - y_i)/n$
$n =$ Total number of tomato producers (sample volume)
If tomato producers had used their inputs properly, they would have obtained an average of 95.235 kg of tomatoes compared to an average of 59.487 kg realized. It shows that the average amount of loss is 35.748 kg (Table 9).

Table 9. Realized and realizable production quantity distribution

Output	Mean (kg)	Median (kg)	Minimum(kg)	Maximum(kg)
y_i^*	95,235	61,268	71,136	468,235
y_i	59,487	30,000	1,000	300,000
$y_i^* - y_i$	35,748	24,308.36	13.14	268,234

Source: Authors' calculation.

Factors affecting changes in efficiency scores

The majority of tomato producers in Ayas district, representing 18.18% of the total population, have a technical efficiency of 41-50%, the second majority representing 15.58%, technical efficiency is in the range of 91-100%, the rest is 18.18%. It is distributed above and below (Table 10 and figure 1). Given these changes in the level of technical efficiency among tomato producers, the variables that affect the environment in which tomato production takes place are; formal education, use of agricultural credits, membership in agricultural organizations, experience in tomato production and age of tomato producers were evaluated.

Formal education level, use of agricultural credit and membership in agricultural organization were statistically significant among all environmental variables used to explain changes in the level of technical efficiency among tomato producers, while the age of the farmer and experience in tomato production were statistically insignificant.

Table 10. Distribution of efficiency points

Efficiency groups (%)	Frequency (Number of establishments)	Frequency (Number of establishments) (%)
1-10	5	6.49
11-20	4	5.19
21-30	5	6.49
31-40	8	10.39
41-50	14	18.18
51-60	9	11.69
61-70	9	11.69
71-80	5	6.49
81-90	6	7.79
91-100	12	15.58
Total	77	100.00

Source: Authors' calculation.

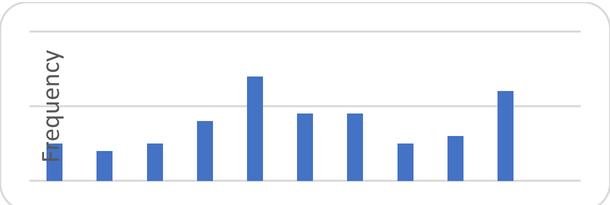

Fig. 1. Distribution of efficiency points (SFA)
Source: Own results.

Data envelopment approach output oriented (maximization LP problem)

In this section, the technical efficiency results of data envelopment are presented and compared with the results of stochastic frontier analysis. The results of the stochastic frontier analysis show that the production function of tomato producers in Ayaş district exhibits an increasing return to scale. Therefore, in the comparison of effectiveness scores, Data Envelopment analysis was used for the analysis of technical effectiveness according to the varying scale for the output.

Analysis of changes in efficiency scores

The average efficiency score of tomato producers was determined as 86.43%, indicating that producers are likely to increase their output by 13.57% without needing additional inputs while keeping all other factors affecting output (Table 11).

The majority of tomato producers have technical efficiency in the range of (91-100%) (Table 12 and Figure 2).

Table 11. Summary statistics of efficiency points

Statistical parameters	Efficiency points%
Mean	86.43
Median	100.00
Mod	100.00
Minimum	32.50
Maximum	100.00

Source: Authors' calculation.

Table 12. Distribution of efficiency points

Efficiency groups %	Number of establishments	Number of establishments (%)
31-40	4	5.19
41-50	2	2.60
51-60	4	5.19
61-70	7	9.09
71-80	5	6.49
81-90	7	9.09
91-100	48	62.34
Total	77	100.00

Source: Authors' calculation.

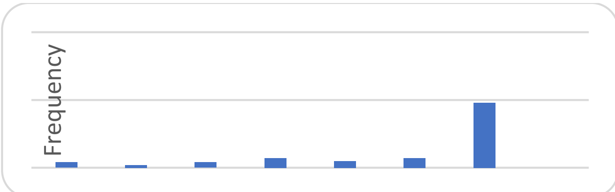

Fig. 2. Distribution of efficiency points (DEA)
Source: Own results.

Considering that tomato producers are not fully technically efficient, the actual average amount of output they can achieve if they use their inputs properly is calculated as follows.

Maximum output (kg) achievable with current technology level:

$$y_i^* = \left(\frac{y_i}{\theta} + S_r^+\right)$$

$y_i^* =$ Vector of achievable maximum outputs
$\theta = vector\ of\ efficiency\ scores\ as\ fractions$

y_i = vector of output quantities
S_r^+= output shortage due to output mix (loose)
Average maximum achievable output (kg)
$average\ maximum\ output = \sum(y_i^*)/n = \sum\left(\frac{y_i}{\theta} + S_r^+\right)/n$
Low output average (kg)
$Low\ output = \sum(y_i^* - y_i)/n$
n = Total number of tomato producers

If the producers had used their inputs appropriately, the average output of tomatoes would have reached 68,536.37 kg, which is 9,049.36 kg greater than the actual production (Table 13).

Table 13. Distribution of realized and realizable production amount

Output	Mean (kg)	Median (kg)	Minimum (kg)	Maximum(kg)
y_i^*	68,536.37	36,945.36	1,000	300,000
y_i	59,487	30,000	1,000	300,000
$y_i^* - y_i$	9,049.36	6,945.36	0	67,318.67

Source: Own results.

Scale effectiveness: Data Envelopment Analysis

If an enterprise is of optimal size, if the resource used in its production increases by one percent (1%), the production amount increases by one percent (1%), this means that the production resource and the production amount are one-to-one scale efficiency (Cooper et al. 2007) [7]. It is calculated according to the formula below.

$$\text{Scale effectiveness} = \frac{Fixed\ return\ technical\ efficiency\ score\ of\ each\ farmer}{Variable\ return\ technical\ efficiency\ score\ of\ each\ farmer} * 100$$

The majority of tomato producers operate under increasing returns to scale representing 59.94%, while the second majority operating under fixed returns to scale representing 29.87% and operating under decreasing returns to scale representing at least 10.39% showing enterprises (Table 14).

According to the results, 29.87% of the tomato producers are scale efficient, that is, they operate in the optimum size of the tomato plant, while 70.13% of the producers are scale ineffective (Table 14). 70.13% of producers state that they should not only increase their technical efficiency but also change their tomato plant size. 10.39% of those with scale ineffective work more than the optimum tomato business size, so they need to reduce the size of the tomato business to the optimum level to become scale efficient. Those working above optimal have 98% efficiency of scale, so they need to downsize their tomato business by 2% to become scale efficient. Of those with scale inefficiency, 59.94% work less than the optimum size of the tomato plant, so they need to increase the size of the tomato plant to its optimum level to become scale efficient. Sub-optimal employees have a 70% scale efficiency, so they need to expand their tomato business by 30% to become scale efficiency.

Table 14. Data Envelopment scale distribution

State of return to scale	% Average effectiveness score	Number of establishments	%
Fixed	100	23	29.87
Decreasing	98	8	10.39
Increasing	70	46	59.74
Total	86.43	77	100.00

Source: Own results.

Comparison of stochastic production and data envelopment analysis approaches

The average technical efficiency from the data envelopment analysis was 86.43%, while the average technical efficiency from the stochastic frontier analysis was 55.56%, which made a difference of 30.87% (Table 15). The average technical efficiency from data envelopment analysis is higher than that from stochastic frontier analysis. The sources of variation in tomato production are divided into two. First of all, the factors affecting the amount of production out of the control of the producers, for example, some of the producers did not have any diseases in their fields during the season as luck, but some of them unluckily had harmful diseases in their fields.

Secondly, the factors that affect the production amount that can be controlled by the producers. For example, some of them use production resources well, some do not use them well, and good users can obtain higher production amounts than those who do not use them well. Because the data envelopment approach does not separate the chance of changes in tomato production and the effect from the use of appropriate resources. Stochastic frontier analysis, on the other hand, distinguishes the effect from the chance of changes in tomato production and the appropriate use of inputs. Data envelopment analysis is given higher technical efficiency than stochastic boundary analysis, since the chances of changes in tomato production and the use of appropriate resources do not separate the coming effect.

Table 15. Comparison of technical efficiency score of stochastic production limit and data envelopment analysis

Statistical parameters	**Efficiency Score %**	
	Stochastic Production Limit	Data Envelopment Analysis
Mean	55.56	86.43
Median	54.00	100.00
Mod	100.00	100.00
Minimum	7.00	32.50
Maximum	100.00	100.00

Source: Own results.

CONCLUSIONS

The production function selection process was carried out using the log likelihood test. According to the results of the log likelihood test, it was concluded that the Cobb-Douglas production stochastic boundary function is an appropriate function of the production process of tomato producers in Ayaş district. The one-stage Cobb-Douglas production stochastic boundary function was used to estimate the environmental factors that affect changes in technical efficiency. It was concluded that all inputs used in tomato production in Ayaş district were statistically significant in affecting the changes in the production amount of tomatoes. These are labor (days of working in family and foreign tomato production during the season), the amount of land allocated for tomato cultivation (decare), the number of seedlings (pieces), chemical fertilizers (kg), animal fertilizers (tons), pesticides (lt), tractor expenses (TL) and irrigation (irrigated times during the season) were concluded.

It was concluded that the factors affecting the changes in the agricultural efficiency of tomato producers, these are formal education, membership in agricultural organizations and use of agricultural credits, are statistically significant in influencing the appropriate use of tomato inputs by tomato producers. Technical activities were found to be statistically significant in influencing the changes, as they provided formal education, tomato producers, tomato production technologies, the importance of developing technologies for agriculture and the correct use of technologies, etc. Therefore, in general, those with higher formal education levels have higher technical efficiency than those with formal education levels. Agricultural organizations, tomato growers, the resources used in tomato production or general agricultural production have been found to be statistically significant in influencing the changes in their technical efficiency, as they provide wholesale purchases, access to information of advanced agricultural production, use of common agricultural machinery, etc. Therefore, those who are members of agricultural organizations have higher technical efficiency than those who are not members of agricultural organizations. Agricultural credits were statistically significant in influencing changes in their technical efficiency as tomato producers did not purchase advanced agricultural equipment and advanced inputs etc. Therefore, those who use agricultural credits have higher technical efficiency than those who do not use technical activities.

The average technical efficiency of tomato producers in Ayaş district was found to be 55.56% using stochastic frontier analysis approach and 86.43% using data envelopment analysis approach. According to the Stochastic Frontier Analysis approach, if tomato producers had used their inputs properly, they would have produced an average of 95,235 kg of tomatoes compared to an average of 59,487 kg realized. The average amount of loss was found to be 35,748 kg. On the other hand, with the data weakening analysis, if the producers had used their inputs appropriately, the average output of tomatoes would have reached 68,536,37 kg, which was 9,049.36 kg greater than the actual production. According to the Stochastic Frontier Analysis approach, since the sum of the coefficients (elasticities) of the whole model of production is equal to 1.67, which is more than one, it is determined that there is an increasing return to scale. It is concluded that tomato producers work under the increasing return production function. On the other hand, when using the Data Envelopment Analysis method, 59.74% of tomato producers are under increasing returns to scale, while 40.26% are working under constant and decreasing returns to scale. Overall, it was concluded that the majority of tomato producers operate under increasing returns to scale. According to the two approaches, it has been determined that the tomato enterprises in Ayaş are operating under increasing returns. Therefore, since tomato producers cannot increase scale efficiency, their businesses need to grow. The main problems encountered in tomato production are tomato diseases 22.4%, insufficient labor force 20%, high input costs 17.2%, access to water 16.9%, ineffectiveness of pesticides 13.1%. It was concluded that there were problems. Among the problems encountered in tomato marketing, 61.4% high transportation and low tomato price 38.6% were concluded. Tomato producers in Ayaş district should use the appropriate (optimal) combination of inputs that they do not use in tomato production, since they cannot increase the amount of tomato production and do not have technical efficiency. Tomato producers in Ayaş district should enlarge their tomato businesses in order to increase scale efficiency. In order to increase technical efficiency, tomato producers in Ayaş district should be advised that they do not have formal education, do not belong to agricultural organizations and do not use agricultural credits. In order to reduce tomato diseases, tomato producers in Ayaş should consult with experts in tomato diseases, do good weed control, pay attention to irrigation and other management practices. In order for the pesticides to be effective, the tomato producers in Ayaş must follow the written instructions for each pesticide, use clean water, spray at the right time, use the right pesticide for the identified insects (insect), and use pesticides that have not expired. In order to solve the problem of insufficient workforce in the agricultural sector in Ayaş district, social (sports, etc.), economic (good salaries for agricultural workers, suitable and flexible agricultural loan programs, banking services, insurances, etc.), education and health sectors (accessible schools and hospitals). Demand for agricultural products should be created through rural development programs. If the demand for agricultural products (tomato production) increases, the workforce in the agricultural sector (tomato production) may increase because other people have started to produce agricultural products. In order to solve the problem of high input cost and difficulties in accessing water in Ayaş district, it should be recommended to purchase tomatoes in bulk through agricultural organizations (agricultural cooperatives). In order to solve the problem of high transportation and low price of tomatoes in Ayaş district, it is necessary to direct tomato producers to contract farming. Tomato producers should also establish agricultural products marketing organizations that can assist farmers in providing transportation and marketing information.

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