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NONPARAMETRIC MODEL FOR MEASURING IMPACT OF INPUTS DENSITY ON EGYPTIAN TOMATO PRODUCTION EFFICIENCY

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Abstract

The present study was conducted to measure the production efficiency of tomatoes in Ismailia, Egypt, adopting Data Envelopment analysis (DEA) procedures. Fifty eight of tomato farms had been surveyed in Ismailia governorate for the season July to October 2013. DEA was adopted to estimate technical, allocative, cost, and scale efficiency scores for the surveyed farms. A two limited Tobit regression analysis was used to estimate the impact of inputs overuse on efficiency measures. The analysis revealed that the estimated mean of the technical efficiency was 91 percent indicating that the total output can be further increased with efficient use of resources and technology. The results of allocative, cost, and scale efficiency measures showed substantial degree of inefficiency. The inefficiency can be attributed to overuse of land, seedlings, manure nitrogen fertilizers, potassium fertilizers, and labor. Most of scale inefficiency (about 76%) arisen from farms revealing increased returns to scale implying that most of the farms operate at sub-optimal level. Therefore, recommendations issued by agricultural extension agency in Egypt need to be revised in the light of efficiency measures rather Than production maximization.

Keywords : *Allocative efficiency, cost efficiency, data envelopment analysis, inputs overuse, technical efficiency*

1. Introduction

There are many factors that make tomato the main vegetable crop in Egypt. Firstly, Changing Egyptian consumer attitudes have increased the interest in nutrition and health, which in turn has increased the demand for vegetables of high nutritional value like tomato. Secondly, the fact that tomato in Egypt can be grown in any type of soil, from pure sand to heavy clay. Thirdly, tomato can be grown all year round allowing three harvest season. The largest acreage is carried out between July and October, followed by a season (November-February). The smallest acreage is of the season from March to June. Consequently, tomatoes enjoy the highest cropping intensity ratio in land use among all vegetable crops in Egypt.

Ismailia is one of the leading tomato production governorates in Egypt, accounting for nearly 9% of total Egypt tomatoes production. According to (Economic Affairs Sector), Ismailia occupies the fourth rank in in tomato production after Sharkia, Noubaria, and Qena. On the other hand, Ismailia ranked second after Suhag in terms of productivity by 26.7[*] ton per acre in year 2012.

[*] The yield per acre was calculated as an aggregate average of all the cultivation systems (open field cultivation, greenhouses, and plastic tunnels)

Nevertheless, there is a significant shortage in researches concerned with either the economics of tomatoes production in Egypt in general or production efficiency measures in particular. Moreover, previous studies like El-Banna (1995) and Osman and Mahmoud (2006) based upon the estimation of profitability indicators, production function, and cost function rather than introducing reliable measures of efficiency.

Whereas, Sengupta (1995) and Cooper et al. (2007) define both productivity and efficiency as the ratio between output and input, Daraio and Simar (2007) described the efficiency as the quantity of input and output that defines the best possible frontier for a firm in its cluster.

The efficiency of a firm consists of two components: the first component is technical efficiency, which reflects the ability of a firm to obtain maximal output from a given set of inputs, which usually termed as output-oriented measure. Technical efficiency also refers to the ability of a firm to obtain a given output from a minimal set of inputs which is termed input-oriented measure. The second component is allocative efficiency, which refers the ability of a firm to use the inputs in optimal proportions, given their respective prices.

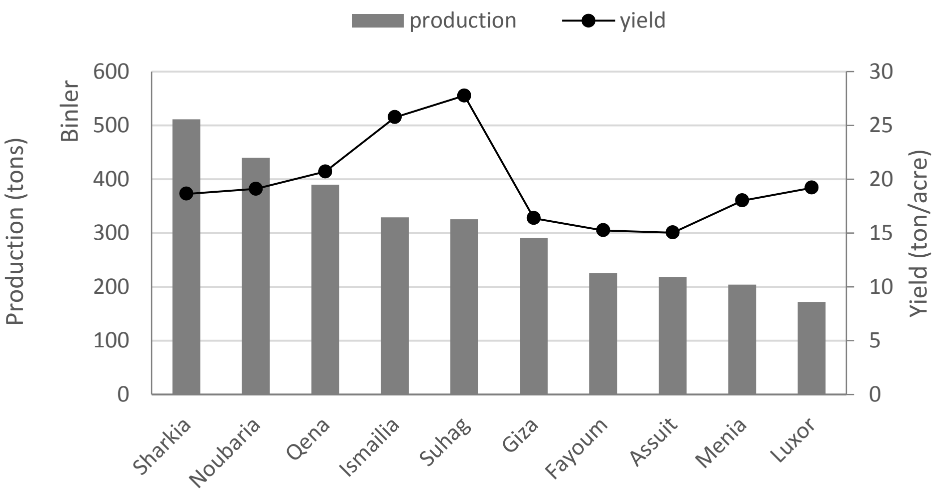

Figure 1. Top Ten Governorates of Tomato Production in Egypt in 2012

According to (Koopmans 1951) "a producer is technically efficient if an increase in an output requires a reduction in at least one other output or an increase in at least one input, or if a reduction in any input requires an increase in at least one other input or a reduction in at least one output". Differently, Debreu (1951) and Farrell (1957) defined the measure of technical efficiency known as the Debreu-Farrell measure: "one minus the maximum equiproportionate reduction in all inputs that still allows the production of given outputs, a value of one indicates technical efficiency and a score less than unity indicates the severity of technical inefficiency".

However, a rigorous analytical approach to the measurement of efficiency in production originated only with the work of Koopmans (1951) and Debreu (1951) empirically applied by Farrell (1957). There are two approaches to estimate technical efficiency, parametric and nonparametric. The stochastic production frontier (SPF) developed by Aigner et al. (1977) which is a parametric approach. Data envelopment analysis (DEA), developed by Charnes et al. (1978), is a non-parametric approach. The nonparametric data envelopment analysis (DEA) model has become increasingly popular in the analysis of productive efficiency.

The main objective of the current study is to measure the production efficiency of tomatoes in Ismailia, Egypt using DEA procedures. The efficiency measures included technical efficiency (TE), allocative efficiency (AE), cost efficiency (CE), and scale efficiency (SE). We also investigated the relationship between the excess input use and efficiency measures.

2. Data

The data used in the present study were from a sample survey of tomatoes producers in Ismailia governorate for the season July to October 2013. Fifty eight questionnaires had been administrated to tomatoes producers in three districts (Mrakaz in Arabic) which are Ismailia, Altal Alkabeer, and Alkassasien.

Summary statistics of output, inputs, and input prices are presented in Table 1. The output was measured in kilogram of harvested tomatoes. The inputs data included both quantities and corresponding prices. Harvested area of tomatoes, seedlings, farmyard manure, nitrogen fertilizers in kilograms of azote, phosphates and potassium fertilizers in kilograms of effective units, and labor either family and or hired.

3. Methodology

The efficiency measurement method adopted in this study was derived from those introduced in Wadud and White (2000), that based on the method developed by Charnes et al. (1978) which proposed an input-orientation and assumed constant return to scale (CRS). Later Banker et al. (1984) proposed a variable returns to scale (VRS) model.

Table 1. Output, Inputs, and Input Prices Summary Statistics Used in DEA Analysis

Variable	Unit	Mean	Standard deviation	Minimum	Maximum
Tomato output	Kg/acre	16006.9	3738.0	8400	24000
land	acre	1.7	1.2	0.5	5.0
Seedlings	Number/acre	5372.4	1331.2	2000	8000
Manure	M^3/acre	15.0	11.3	6	50
Nitrogen	Kg/acre	107.4	63.4	33	296
Potassium	Kg/acre	60.5	47.6	12	125
Phosphates	Kg/acre	31.2	18.7	8.0	77.5
Labor	Man-day/acre	77.9	29.8	42	145
Output price	L.E/Kg	1.78	0.33	1.51	2.01
land price	L.E/acre	3000.00	684	2000	4000
Seedlings price	L.E/seedling	0.300	0.17	0.10	0.70
Manure	L.E/M3	115.67	2.05	95.00	130
Nitrogen	L.E/Kg	5.75	0.53	5.00	6.25
Potassium	L.E/Kg	8.31	0.68	7.45	9.10
Phosphates	L.E/Kg	9.28	0.94	8.60	9.84
Labor	L.E/day	43.90	6.77	38.20	51.22

Source: Computed from Field Survey Data, 2013.
Note: All fertilizer quantities were calculated for the effective unit.

3.1. Technical Efficiency

Following Coelli et al. (2002), assume that there are data on a single output (M=1, i.e. tomato) for each of N farms (N=1,2,…,58) and K inputs (K=1,2,…,7) representing land area, seedlings, manure, nitrogen fertilizers, potassium fertilizers, phosphates, and labors. For *i*th farm input and output data are represented by the column vectors $x_i$and y_i. The data for all N farms are represented by $K \times N$ input matrix, X and $M \times N$ output matrix, Y. The Constant Return to Scale (CRS) input oriented DEA model for the *i*th farm can be expressed as,

$$\begin{aligned} & Min_{\theta_i,\lambda_i}\theta_i, \\ & s.t. Y\lambda - y_i \geq 0, \\ & x_i\theta_i - X\lambda \geq 0, \\ & \lambda > 0, \end{aligned} \qquad (1)$$

Where θ is a scalar and λ is a $N \times 1$ vector of constant. The CRS linear programming problem can be easily modified to account for Variable Return to Scale (VRS) by adding the convexity constraint: $N1'\lambda = 1$ to provide:

$$\begin{aligned} & Min_{\theta_i,\lambda_i}\theta_i, \\ & s.t. Y\lambda - y_i \geq 0, \\ & x_i\theta_i - X\lambda \geq 0, \\ & N1'\lambda = 1 \\ & \lambda > 0, \end{aligned} \qquad (2)$$

Where $N1$ is an $N \times 1$ vectors of ones. According to Coelli et al. (2005), the input technical efficiency score θ gets a value $0 \leq \theta \leq 1$. If the θ is equal to one, the farm is on frontier and then technically efficient.

3.2. Scale Efficiency

Banker et al. (1984) suggested the use of variable return that decomposes overall technical efficiency into a product of two components. The first is technical efficiency under VRS or pure technical efficiency and relates to the ability of manager to utilize firm's given resources. The second is scale efficiency (SE) and refers to exploiting scale economies by operating at a point where the production frontier exhibits CRS. Therefore,

$$TE_{CRS} = TE_{VRS} \times SE \qquad (3)$$

$$SE = TE_{CRS}/TE_{VRS} \qquad (4)$$

If scale efficiency equals to one, it means the field is operating at an optimal scale. While SE<1, it means the field is scale inefficient with the level of scale inefficiency equal to 1-SE. Scale inefficiency arises as a result of the presence of either Increased or Decreased Returns to Scale (IRS or DRS respectively). This may be determined for each farm by replacing $N1'\lambda = 1$ in equation (2) with $N1'\lambda \leq 1$. The results is no increasing returns to scale (NIRS). Therefore, if NIRS, then TE score is equal to the VRS TE score, then decreasing returns to scale exist for that farm. Conversely, if they are not equal, then increasing returns to scale exist (Coelli 1996; Watkins et al. 2014).

3.3. Allocative Efficiency and Cost Efficiency

According to Coelli et al. (2002), The cost and allocative efficiencies are obtained by solving the following additional cost minimization DEA problem:

$$\begin{aligned} & Min_{\lambda,x_i^*} w_i' x_i^*, \\ & s.t. Y\lambda - y_i \geq 0, \end{aligned}$$

$$x_i^* - X\lambda \geq 0, \quad (5)$$
$$N1'\lambda = 1$$
$$\lambda > 0,$$

Where w_i is a vector of input prices for the ith farm and x_i^* is the cost-minimizing vector of input quantities for the i^{th} farm (which calculated by the model). The total cost efficiency (CE) as,

$$CE = w_i' x_i^* / w_i' x_i, \quad (6)$$

Thus, CE is the ratio of minimum cost to observed cost for the i^{th} farm. Allocative efficiency (AE) is calculated as :

$$AE = CE/TE \quad (7)$$

4.4. Tobit analysis

Regression analysis was conducted to determine impacts of inputs overuse on production efficiency scores. A two limits Tobit model was used in the present study (Maddala 1986) because efficiency scores are bounded between zero and one. The Tobit model is expressed as follows:

$$y_i^* = \beta_0 + \sum_{k=1}^{K} \beta_k x_{ik} + \varepsilon_i, \varepsilon_i \sim IN(0, \sigma^2) \quad (8)$$

Where y_i^* is a latent variable representing the efficiency score for the i^{th} farm; β_0 and β_k are unknown parameters to be estimated; x_{ik} express seven explanatory overuse inputs associated with the i^{th} farm; ε_i is an error term that is independently and normally distributed with zero mean and constant variance σ^2. The latent variable y_i^* is derived from the observed variable y_i using DEA analysis as follows:

$$y_i = \begin{cases} 1 & if\ y_i^* \geq 1 \\ y_i^* & if\ zero \leq y_i^* \leq 1 \\ zero & if\ y_i^* \leq 0 \end{cases} \quad (9)$$

5. Results and Discussions

A summary of the statistics for the Technical, Allocative, Cost, and scale efficiency scores are presented in Table *2*. Technical efficiency scores are presented under both VRS and CRS. The mean of the TE score under VRS is 0.91 and ranges from 0.60 to 1.00, while the mean of the TE score under CRS is 0.71 and ranges from 0.37 to 1.00. Twenty one farms are fully efficient under VRS, implies that 63.7% of farms have to decrease input quantities at given output level to approach efficient performance.

The mean allocative efficiency score is 0.75 with range of 0.44 – 1.00 implying that the surveyed tomatoes farms are not using inputs at minimum cost level which would reduce the average costs by approximately 25% to achieve the same output level. Such reduction can go up to a maximum of 56%. The DEA model determines minimum cost quantity of inputs for each farm. Therefore, one can specify which inputs are being over or under used by comparing cost efficient inputs with technically efficient input levels (Coelli et al. 2002).

The mean cost efficiency score across the sample is 0.69 and ranges from a minimum of 0.38 to a maximum of 1.00 with only one farm was 100% efficient. The frequency distribution presented in Table *2* shows that cost efficiencies of 43 farms, counting for about

74%, of all farms are less than 80%. These results indicate that tomato farms in Ismailia governorate are economically inefficient on average and that the total cost of tomato production for each farm could be reduced on average by approximately 31% to achieve the same level of output.

Table 2. Technical, Allocative, Cost and Scale Efficiency Estimates

	Technical efficiency (VRS)	Technical efficiency (CRS)	Allocative efficiency	Cost efficiency	Scale efficiency
Mean	0.91	0.71	0.75	0.69	0.77
Std.dev.	0.12	0.03	0.13	0.17	0.17
CV	13.19	4.22	17.33	24.64	22.37
Minimum	0.60	0.37	0.44	0.38	0.42
Maximum	1.00	1.00	1.00	1.00	1.00
<50%	-	9	4	10	2
50% - < 60	1	8	3	11	10
60% - < 70%	5	14	15	10	10
70% - < 80%	5	11	16	12	14
80% - < 90%	11	2	12	8	5
90% -100%	36	14	8	7	17

The mean score of scale efficiency is 0.77 ranged from 0.42 to 1.00 with 9 farms achieved the full scale efficiency. The classification of the scale of such efficiency is presented in *Table 3*. The results showed that about 19% of the sample farms are efficient while the rest 81% are not. Most of scale inefficiency (about 76%) arises from that most of the farms were revealing increased returns to scale implying that they were operated at sub-optimal level. Only about 5% of the sample farms showed decreased returns to scale, i.e., were operated at optimal level.

Table 3. Frequencies of Scale Efficiency Classification

Scale	Frequency	Percentage
Constant Returns to Scale (CRS)	11	18.97%
Increased Returns to Scale (IRS)	44	75.86%
Decreased Returns to Scale (DRS)	3	5.17%
Total	58	100%

Summary statistics of inputs overuse ratios are presented in *Table 4.* The input ratios are calculated by dividing the technically efficient input levels over the cost efficient levels for each of the seven inputs. One can see that all inputs except phosphate fertilizers were overused by the farms. Overuse of potassium and nitrogen fertilizers are notably significant (about 88% and 86% respectively). Labor, seedlings, land, and manure overuse are 45%, 43%, 36%, and 32% of tomatoes farms. Surprisingly, it is worth mentioning that most of the applied quantities of inputs like seedlings, manure, nitrogen and potassium were used in line with the recommendations of the agriculture extension agency in Ismailia governorate, which requires reviewing with regard to the economic principles.

The results indicate that the quantities of nitrogen and potassium are used in quantities close to the double quantities of those meet both technical and of the cost efficient level i.e. 1.93 and 1.91 respectively. As the standard deviation of tomato acreage per farm surpassed two thirds its sample mean, Land input showed a high variation. It ranged from a minimum of 0.50 acres to a maximum of 6 acres.

Table 4. Summary Statistics of Input Use Ratios

Inputs	Mean	Std. Dev	Minimum	Maximum	Over use farms (%)
Land	1.74	1.36	0.50	6.00	36 (62.07%)
Seedlings	1.30	0.44	0.54	2.40	43 (74.14%)
Manure	1.31	1.04	0.36	5.62	32 (55.17%)
Nitrogen	1.93	1.06	0.39	4.20	50 (86.20%)
Potassium	1.91	1.20	0.50	5.61	51 (87.91%)
Phosphates	0.94	0.61	0.24	3.44	14 (24.38%)
Labor	1.27	0.34	0.58	1.97	45 (77.59%)

The results of the "Tobit Regression analysis" showing the impact of inputs overuse on efficiency measures are presented in *Table 5*. Tobit regression model parameters were estimated according to (Stata Corporation 2009). The Ordinary least squares estimators for the relationship between the excess of inputs (the difference between the actual applied inputs and the cost efficient quantities of inputs) are downwardly biased. However application of the Tobit analysis implied a plethora of censoring problems has been examined. Since, the observation of a particular random variable in this analysis depends on whether it is above or below a fixed threshold or the value of another random variable, the appropriate approach to obtain estimates under these circumstances is to derive a likelihood function and use its maximizer (Amemiya, 1984).

Table 5. Tobit Regression between Excess Input Use and Efficiency Measures

	Technical Efficiency	Allocative Efficiency	Cost Efficiency
Land	-0.016** (-3.46)	-8.712E-2** (-14.07)	-9.689 E-2** (-19.26)
Seedlings	-0.282 E-4 (-0.72)	-0.205 E-4** (-3.88)	-0.197 E-4** (-4.47)
Manure	-1.877 E-3** (-3.80)	-6.055 E-3** (-8.95)	-6.894 E-3** (-12.87)
Nitrogen	-2.876 E-4* (-2.83)	-2.016 E-4 (-1.50)	-4.218 E-4** (-3.60)
Potassium	-8.020 E-4** (-6.09)	-3.613 E-4* (-2.04)	-3.912 E-4** (-2.71)
Phosphates	-1.017 E-3* (-2.95)	1.395 E-3** (3.03)	7.728 E-4 (1.98)
Labor	-2.499 E-3** (-10.33)	-1.523 E-3** (-4.71)	-3.346 E-3** (-12.04)
Intercept	1.034** (97.17)	0.912** (64.30)	0.936** (77.64)
Log likelihood	101.10	83.46	97.35

Note: Values in parentheses are t statistics .

The results show as expected, that excess use of all inputs have negative impact on technical efficiency. Furthermore, the estimated parameters of land, manure, potassium, and labor are significant at the level of 0.01, while nitrogen and phosphates fertilizers are significant at level of 0.05. Allocative efficiency also is negatively affected by the excess use of inputs. Estimated input parameters are significant at level 0.01, except potassium which is significant at 0.05. Similarly, Cost efficiency is negatively affected by the excess use of inputs except for phosphates. All estimated parameters are significant at 0.01, except phosphates which is insignificant .

6. Conclusion

This study uses Data Envelopment analysis to estimate technical, allocative, cost, and scale efficiency scores for 58 tomato farms spread over three districts, Ismailia, Altal Alkabeer, and Alkassasien in Ismailia governorate for the season July to October 2013. The results indicated a technical efficiency mean of about 91.0 percent, allocative efficiency mean of 75 percent, cost efficiency mean of 69 percent, and scale efficiency mean of 77 percent.

The results indicated sizable degree of inefficiency. The inefficiency can be attributed to overuse of land, seedlings, manure nitrogen fertilizers, potassium fertilizers, and labor. On contrast, more phosphate fertilizers usage enhanced allocative and cost efficiency. One can infer from overuse of nitrogen and potassium fertilizers that recommendations issued by agricultural extension agency in Egypt need to be revised in the light of efficiency measures rather than production maximization.

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