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How Efficient Are Egyptian Maize Producers? A Study of Maize Production in Egypt Using Stochastic Frontier Analysis Approach

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Abstract: This study aims to examine the technical efficiency (TE) and factors affecting maize (Zea mays) production. Scores of TE were obtained utilizing two stages Stochastic Frontier Analysis (SFA). TE scores were obtained at the first stage. Then, TE scores were used by applying regression technique against factors that may affect these scores to understand variation in TE scores. Data span range from 1961 to 2019 and were mainly obtained from FAOSTAT. During the study period, imports showed superiority over local production creating a gap between increased demand and local supply. This widening gap may create concerns related to food security suggesting a problem of inefficiency in maize production. Results showed that the average TE is 92% with 54% as a minimum and 98% as a maximum. This means that using the current level of technology, the output can be increased by 8% using the same level of inputs. Factors that affect TE scores the most were the women workforce in agriculture, political stability, competitive agricultural commodities, credit devoted to agricultural activities, and rural areas percentage with electricity access.

Keywords: Egypt, maize, stochastic frontier analysis, technical efficiency.

Introduction

Maize is considered one of the important field crops in Egypt. It came third in occupying the Egyptian arable land. Maize is also considered as a complementary good when mixing with wheat in bread preparation. It is also used to feed animals as an important component in their daily diet.

Egypt is not producing enough maize to meet the local demand. Based on the FAO stat, Egypt imported about 161,075,021 tons between 1961 and 2019 even though the local demand in the same period reached 276,751,814 tons. Based on simple calculations, the demand per year, on average, is 7548738.534 tons. Imports occupy about 38% of the yearly needs of the Egyptian population. Relying highly on international imports, failing to obey the local demand, shortage of maize production have led stakeholders to find a way in improving local maize production to make the country more food secured and help rural communities being more developed. This is particularly true in Egypt, where growing demand overweight maize supply. By examining production habits and applicable policies, improvements are possible in Egypt.

Materials and methods

- **Literature Review**

To understand differences in inefficiency at the microeconomic level, two approaches need to be followed. The first one is nonparametric, in which a distance of economic production function is measured relative to efficient frontier than can be described as hypothetical. The second one is the parametric optimization approach. This approach estimates parameters in trying to explain technical efficiency variation by utilizing production and sociodemographic factors. Starting from the seminal work by Farrell (1957) in which he provided a context for measuring economic efficiency. Farrell's approach is conceptual but it characterized the parametric and non-parametric approaches when investigating the source of inefficiency. After Farrell's approach, Aigner et al. (1977), Schmidt (1976), Duggar (1974), Timmer (1971), Aigner and Chu (1968), and Aigner et al. (1976) developed what is now called Stochastic Frontier Analysis or (SFA). In their work, they argued that individual firms may deviate from an efficient frontier due to optimization error and random shocks. After these revolutionary approaches in developing the SFA approach, Battese and Coelli (1992, 1995) developed an approach by coming up with a technique that include firm specific characteristics in addition to production factors. Battese and Coelli (1995), estimated (TE) scores that are non-negative using two stages of econometric estimation. In the first stage (TE) scores are estimated. These non-negative scores are regressed against sociodemographic variables to shed light on each possible inefficiency source. This approach is the crux of the estimation method followed in this paper.

This piece is utilizing some meta-analysis literature. Coelli (1995), Bravo-Ureta and Pinheiro (1993), Bravo-Ureta et al. (2001) reviewed both Data Enveloped Analysis (DEA) and Stochastic Frontier Analysis (SFA). This is done to understand which one can explain differences in efficiency. One of the strengths of SFA is that it is utilizing econometric approach by incorporating stochastic noise. Also, this approach is allowing decomposition of error term into optimization errors as well as the effect of exogenous shocks. However, one drawback of SFA is specifying production function and distribution for error term that is related to inefficiency. Based on that and since this piece is dealing with agriculture activity and all the risk that may entail, SFA is the approach that will be followed.

Literature that estimated technical efficiency in Egypt enriched this piece with the methodology used and the choice of variables. More specifically, a significant relationship between different sorts of capital (financial, human, land) and productive efficiency. The next part showed previous literature in efficiency of Maize production that is relevant.

Previous studies that tackle agricultural productivity in Egypt are relevant. Examples are SALEH 2016), Altaie (2019), Ahmed et al. (2020), Omar (2020), shawky El-khalifa and Zahran (2020), Abdelradi (2020), and Elasraag et al. (2020). This literature assessed technical efficiency in Egypt but they did not use Stochastic Frontier Analysis, and the efficiency of productive of Maize is not studied.

To sum up, previously mentioned literature guided the empirical approach followed in this piece. This literature also emphasized the significant and factors related to sociodemographic nature that may effect Maize production in Egypt. A gap of knowledge exists in utilizing efficiency tools in Egypt specifically. To the authors' best knowledge, this piece will be the first in employing SFA on Egypt and determining factors that may affect (TE) scores of Maize. Also, this piece approved its uniqueness in the way of gathering inputs used in maize production and variables related to the socioeconomic nature. These socioeconomic variables are believed to be the factors affecting (TE).

In the coming sections, the framework of concepts of SFA is presented.

- **Conceptual Framework of Stochastic Frontier Analysis (SFA)**

In this part, a general framework of (SFA) is described. This description is going to tell how this approach has been developed over time until it reaches the form followed in this study.

Let's suppose we have an i-th decision-making unit or DMU. The production function of these DMUs can be represented as:

Equation 1. Hypothetical production function

$$y_i = f(x_i; \beta) \quad (1)$$

Where y_i represents the dependent variable which is in this case the output (i.e. maize). This output produces a non-stochastic inputs vector x_i produced by the ith firm. Parameters that are unknowns are represented by β. Those parameters are showing the relationship between output and inputs.

The physical relationship described in equation 1 has a deterministic feature. This will result in the regularity condition violation of the maximum likelihood estimation (MLE). When this condition is violated, we will get misspecified model and inefficient estimators.

To solve this violation problem, Schmidt (1976) added error that is one-sided to equation 1. This would result in the following equation:

$$y_i = f(x_i; \beta) + \varepsilon_i \quad (2)$$

Where y_i is the output, x_i is the input, and ε_i is the error term for the decision-making unit (i.e. the ith unit).

Specification of Schmidt has its drawback. In Equation 2, even though the estimates will be efficient, the source of error is not specified. So, the violation of the regularity condition of MLE will still be obtained.

After Schmidt and in 1977, Aigner et al. (1977) tried to explain the violation problem of regularity condition. In the technique, they present a more complex characterization of the error term in their model. More specifically, they decomposed the error term into two components; half normal random that is non-negative variable and the stochastic error term. Their final characterization is:

$$y_i = f(x_i; \beta) + \varepsilon_i \text{ where } \varepsilon_i = v_i + u_i \quad (3)$$

In equation 3, v_i is a random variable representing a stochastic error term. This error term is independently and identically distributed with $N(0, \sigma_V^2)$. On other hand, u_i represents a random variable that is non-negative representing technical inefficiency score. This random variable is distributed as a truncated distribution of $N(\mu_i, \sigma_U^2)$. Source on inefficiency believed to be originated from misallocation of inputs by decision-makers.

To elaborate more on u_i, it is believed that this inefficiency is due to optimization error by decision-makers, while v_i, is obtained due to exogenous factors.

Based on the previous characterization, technical efficiency are obtained by equation 4:

(4)

$$TE_i = \exp(-u_i)$$

Each TE score is firm-specific. This means that each firm or ith DMU has its technical efficiency score.

To understand how different factors may explain variation in TE scores, Battese and Coelli (1995) employed factors with sociodemographic nature. They believed that these factors may affect efficiency in addition to the standard inputs. Their specification is such as:

$$TE_i = f(z_i; \beta) + W_i \quad (5)$$

Where z_i are DMU-specific characteristics. W_i is a variable that is random of normal distribution that is truncated. This distribution has mean equals zero and variance σ^2. The last equation specified earlier can be described as the second stage of efficiency analysis. In this stage, both effects of production and sociodemographic variables are explained.

To estimate the hypothetical efficiency frontier for 58 years, equation 3 is going to be employed. However, equation 4 is going to be used to calculate technical efficiency scores for each year. Traditional factors of production and sociodemographic variables are believed to affect technical efficiency scores. This is going to be investigated by equation 5.

- **Data**

The aim of using the SFA approach is to understand the effect of different types of variables on the efficiency of production of maize in Egypt. To do that, a conceptual framework represented by equations (1-5) has been utilized by the SFA approach. A data description is important and will follow this section. This is done to represent the relationship between variables conceptually.

In this study, data were obtained from The World Bank database (World Bank, 2019). More specifically, the Egyptian time series consists of 58 years were examined from 1961 to 2019. Egypt is a large producer of maize at the MENA level, and the increment in maize prices can contribute positively to the local food supply chain, in addition to the income that farmers can obtain from all Egyptian farmers.

Literature studying the economics of production in countries with the same characteristics as Egypt suggested different types of capital that may determine the level of productive efficiency.

Examples of these literatures are such as Ahmad et al. (2002), Hasan and Islam (2010), Tleubayev et al. (2017) , Tavva et al. (2017), Battese et al. (1993),Battese et al. (1996), and Battese and Broca (1997)

Previously mentioned literature are relying more on a survey as an attempt to characterize factors affecting technical efficiency. More specifically, variables used were targeting education level, human capital, way of irrigation, cultivated land, and energy source. The current study uses a similar estimation approach with cross-sectional data instead of a survey. Primary data were gathered from USDA, FAO, and the World Bank. Data can be provided on request from authors.

- Specification of the Model

Model of the production relationship is specified as:

$$y_t = f(schsf_t, scps_t, ahar_t, gni_t, rurp_t, impo_t, mech_t) \quad (6)$$

And the coming equation is the second stage analysis which was adopted by in both DEA and SFA.

$$te_t = f(acce_t, cred_t, empf_t, pols_t, ppie_t, impq_t, expm_t\ imps_t, tempc_t) \quad (7)$$

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Their variables are defined as:

Table 1. variables used in first and second stage of productive efficiency of maize production

Variable name	Definition	
analyzisng variables of the First stage		
y_{it}	the regressand. yield of maize per unit of land in time *t (hg/acre)*.	Dependent variable
$schsf_t$	school enrolment, secondary, female in time *t*.	Human capital variables
$scps_t$	school enrolment, primary, female in time *t*.	
$rurp_t$	rural population in time *t*.	
gni_t	gross national income in time *t* (USD).	Capital related to finance
$ahar_t$	area harvested of maize in time *t*.	Operational capital variables
$mech_t$	the tractors numbers in time *t*.	
$impo_t$,	quantity of maize imported in time *t* (tons).	Imports variable
analyzing variables in the Second stage		
te_{it}	regressand obtained by the analysis of first stage. It is the (TE) obtained from 1st stage.	Dependent variable
$acce_t$	is the rural areas percentage with electricity access to in time *t*.	Human capital variables
$empf_t$	is the percentage of women working in ag-related labor in time *t*.	
$cred_t$	credit paid to the farmers in time *t*.	Financial capital variable
$ppie_t$	the producer price index of producers (USD per ton) in time *t*.	
$expm_t$	export quantity of maize (ton)	Imports and exports variables
$imps_t$	import quantity of sheep (ton)	
$impq_{t,}$	import quantity of cattle (ton)	
$tempc_t$	Temperature change °C	Political effect variables and temperature variables
$pols_t$	political stability and absence of violence/ terrorism in time *t*.	

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Results and discussion

To estimate technical efficiency scores, two stages of estimation were performed using STATA (version 14). The first stage was performed to obtain technical efficiency scores. The second stage analysis was made to know if the technical efficiency variation is related to standard production factors. Stochastic Frontier Analysis (SFA) is used as an econometric tool in the previously mentioned stage.

Parameters in the first stage were obtained by using the logarithmic transformation of variables in equation 6. The distribution of error term is decomposed into stochastic error term and optimization error. In this stage, estimates were obtained utilizing Stata version 12 and the “frontier” command proposed by Kumbhakar and Lovell (2000).

In table 2, first stage results were reported. Individual estimated parameters and standard error for each variable are shown as well as statistics of equation overall.

Table 2. Parameter estimates for stage 1 using SFA of yield per acre on independent variables (n=59)

Type of Variables	Variable Name	1st stage output
school enrolment, secondary, female in time *t*.	$lnschsf_t$	-0.0602***
		(2.42e-07)
area harvested of maize in time *t*.	$lnahar_t$	-0.203***
		(5.00e-07)
rural population in time *t*.	$lnrurp_t$	1.942***
		(6.14e-07)
school enrolment, primary, female in time *t*.	$lnscps_t$	-0.135***
		(1.18e-07)
gross national income in time *t* (USD).	$lngni_t$	0.0109***
		(7.88e-08)
quantity of maize imported in time *t* (tons).	$lnimpo_t$,	-0.0224***
		(7.80e-08)
the number of tractors in time *t*.	$lnmech_t$	-0.189***
		(1.68e-07)
	Constant	-3.928***
		(9.13e-06)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

$$LR\ chi^2(12) = 1.43e+15, \text{Prob} > chi^2 = 0.001, \text{Log Likelihood} = 73.903$$

In the first stage of analyzing factors affecting maize yield, all variables were statistically significant at a 0.01 significance level. Variables that can affect maize yield positively are rural population and gross national income. However, variables that negatively affect maize yield per unit of land are school enrolment in secondary school education of females, school enrolment in primary education of females, area harvested of maize, the quantity of maize imported, and the number of tractors.

After implementing the first stage of analysis and getting regression residuals, technical efficiency scores are calculated using equation 6. Those technical efficiency scores are then compared across years.

Table 3. Summarizing technical efficiency scores for each ten years

	Mean	Median	CV	Minimum	Maximum
Technical Efficiency 1961-1970	0.941922	0.969886	6.009678	0.800676	0.988897
Technical Efficiency 1971-1980	0.947188	0.947479	3.570674	0.891157	0.993305
Technical Efficiency 1981-1990	0.954732	0.967454	3.369092	0.884295	0.979477
Technical Efficiency 1991-2000	0.95246	0.975415	5.015273	0.840597	0.993027
Technical Efficiency 2001-2010	0.93209	0.934179	4.803825	0.859922	0.986639
Technical Efficiency 2011-2019	0.788848	0.823983	13.30001	0.545661	0.893762

The whole data set was divided into 6 subsets to understand the trend in each subset. The period between 2011 and 2019 recorded the lowest while the period between 1991-2000 recorded the highest. What can be concluded from above is that when the mean is less than the median, there are a lot of poor TE years that lower the mean score of TE. However, if the median is lower than the mean, there are some years with relatively high TE scores.

The coefficient of variance (CV) is calculated by dividing standard deviation on mean. While it is not always true, periods with high median TE recorded low CV. The implication here is that years with low TE in producing maize also have the biggest dispersion in yield per acre. This would also mean that domestic production and income earned by farmers are also varied between years within the data set.

Figure 1 is showing the frequency of calculated TE scores across 68 years using the SFA approach. Variation in TE within each subset is apparent given the distance between the maximum and minimum of TE. Mean TE is depicted on the TE line. Of interest is the position of the mean on the TE line relative to the maximum and minimum TE. For some subsets, mean TE is very close to the maximum suggesting TE is relatively high.

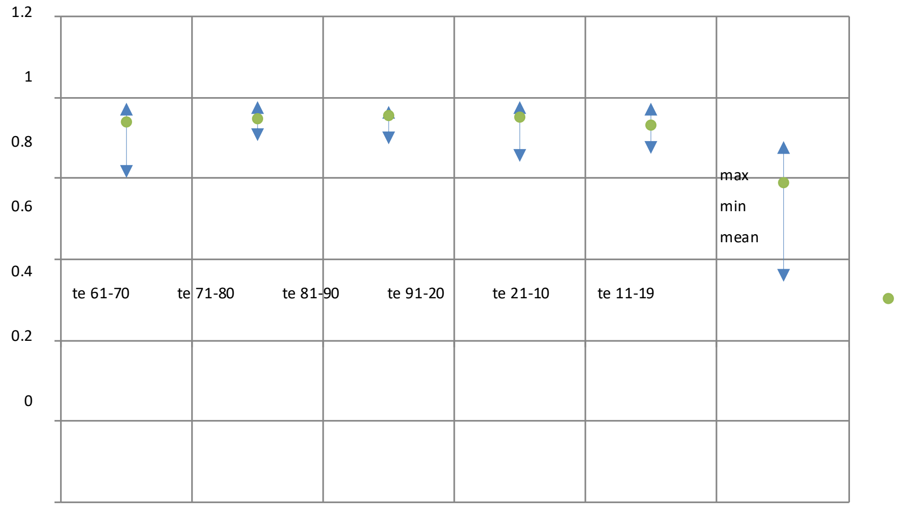

Figure 1. Distribution of TE scores in Egypt between six data subsets as estimated by SFA

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The second stage is trying to explain the difference in TE. In other words, the second stage is trying to explain if the variation in TE scores across the studied time series can be explained by the variation in some factors of production. These factors such as human capital variables, financial capital variables, import and export variables, and political effect and temperature change variables. Estimates of parameters are listed in table 4.

Table 4. Estimates of variables affecting technical efficiency of maize production in Egypt using SFA (n=59)

Variable Type	Variable Name	1st stage output
is the percentage of rural areas with access to electricity in time *t*.	$acce_t$	3.734***
		(96.51)
credit paid to the farmers a in time *t*.	$cred_t$	-1.574***
		(34.34)
is the women percentage working in agriculture in time *t*.	$empf_t$	3.131***
		(0.728)
political stability and absence of violence/ terrorism in time *t*.	$pols_t$	9.275***
		(2.534)
the producer price index of local maize (USD per ton) in time *t*.	$ppie_t$	-4.502***
		(12.84)
import quantity of cattle (ton)	$impq_{t,}$	-0.309**
		(0.142)
export quantity of maize (ton)	$expm_t$	-0.590***
		(0.195)
import quantity of sheep (ton)	$imps_t$	-0.420***
		(0.146)
Temperature change °C	$tempc_t$	2.108***
		(0.433)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In this stage, all variables were significant. Variables that contributed positively to TE are, the rural areas percentage with electricity access, the women percentage working in agriculture, political stability and absence of violence/ terrorism, and temperature change °C. Factors that contributed negatively are the amount paid to the farmers as a credit, producer price index of local maize (US$/ton), import quantity of cattle (ton), export quantity of maize (ton), and import quantity of sheep (ton).

Interpretation of parameter estimates is as follows:

Percentage of rural area with access to electricity in time t ($acce_t$) came positively affecting TE in Egypt. One reason is that farmers are using electricity more for agriculture-related activities such as irrigation. Statistically, increasing provision of electricity by 1% is associated with a 3.7% increase in TE ceteris paribus.

The amount that paid to the farmers as a credit in time t ($cred_t$) came surprisingly negatively affecting TE scores. Increasing credit by 1% is associated with a -1.5% decrease in TE ceteris paribus. This might be due to the high-interest rate imposed by banks. This would make it too risky to borrow money especially any agricultural activity is associated with risk and uncertainty.

Percentage of women work in agriculture-related labor in time t ($empf_t$) was positively affecting TE scores. This is strong evidence of the strong role of women in the production process of maize. More specifically, increasing the female workforce by 1% is associated with increasing TE of maize by 3.1% ceteris paribus.

Political stability and absence of violence/ terrorism in time t. ($pols_t$) came statistically significant positively. This is very clear that if a stable government with no terrorist activity is available, TE is likely to increase. This can motivate investment in agricultural-related activities.

The producer price index of local maize (US$/ton) in time t. ($ppie_t$) came statistically significant affecting TE negatively. This may be due to that the price had been set by the government and the farmers has no port to market their maize except to the government. This will lead to $ppie_t$ to be described as a non-meaningful measure of profits.

Import quantity of cattle (ton) in time t ($impq_{t,}$) and import quantity of sheep (ton) ($imps_t$), as expected, can lower TE score in Egypt. This might be because that the more livestock is imported, the more maize is required to feed them. The other factor is that it may be that it is more profitable to sell cattle than produce maize.

Export quantity of maize (ton) in time t ($expm_t$) came affecting TE negatively. In other words, increasing exports by 1% is associated with %5 decreasing in TE ceteris paribus. Surprisingly, this might hurt efficiency. As everybody knows, increasing exports will increase national income but this case deserves more investigation.

Temperature change °C ($tempc_t$) came affecting TE positively. This is a more technical variable since maize planting took place when the temperature increase. So this came as expected.

Conclusion

This paper was trying to understand maize productive efficiency. This was done by comparing maize output in Egypt between 1961 and 2019. To do that, a conceptual framework of Stochastic Frontier Analysis was utilized and time-series data of maize were used. Data set were gathered from FAO and World Bank. After constructing the time series data, SFA was applied. SFA procedure entails two stages; the first one was about obtaining TE scores, and in the second stage, TE is regressed on variables that may show differences in mean TE in Egypt. SFA approach that is used here is a approach that can be described as a parametric that contains both error in optimization and stochastic error terms. Results of SFA are interpreted to understand the variation in TE across Egypt.

Electricity is very important affecting TE positively. This is because it is one of the means used to irrigate maize lands.

The high-interest rate imposed on farmers leads to credit being negatively affecting the TE score of maize production.

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Women workforce has a significant effect in raising TE scores of maize production since it is the dominant workforce in the field.
Political stability has a big significant marginal effect on maize technical efficiency. If this factor is unstable, this will put a big burden on food security.
Government is the only source of absorbing the output of maize. Due to that, the producer price index came negatively affecting TE scores.
More profitable agricultural activities lowered the TE of maize. This is because these competitive agricultural activities such as raising cattle or sheep are more profitable compared to maize production. Also, driving maize toward feeding cattle can lower the share of maize devoted to human consumption.

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