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Original scientific paper

EFFICIENCY OF MAIZE PRODUCTION IN THE NILE BASIN COUNTRIES: A PARAMETRIC APPROACH FOR EFFICIENCY MEASUREMENT

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ABSTRACT

In this study we employ the stochastic frontier approach to estimates the evolution of technical efficiency for maize production in the Nile basin countries. The study is based on a panel data at the countries level and it represents the time period 1993-2016. The results indicate improving in the levels of technical efficiency for maize production in the Nile basin countries during the time period 1993-2016. The annual levels of technical efficiency for the studied period vary from a minimum level of 0.5310 to a maximum level of 0.9601. The Nile basin countries that are less efficient in maize production should make some adjustments to their agricultural policies to improve the capacity of farmers to efficiently use the existing resources to increase maize production.

Key words: Cobb-Douglas, maize production, Nile basin countries, stochastic frontier, technical efficiency, Translog.

INTRODUCTION

Maize is the most important cereal crop in the world after wheat and rice. It is grown in more diverse regions than any other crop; vast genetic differences occur among the kinds of maize grown in these disparate areas. It is cultivated from northern Europe and Russia to South Africa, eastward through Asia, the Himalayas, China, Southeast Asia and the Pacific Islands, westward from Puerto Montt in Chile to New Brunswick in Canada. Because of its wide climatic adaptability maize cultivation expanded rapidly and the grain became soon a part of the local diet as a diversification of traditional root crops (cassava, yams, sweet potatoes) and various small grains. Maize is now cultivated in more than hundred countries (Verheye, 2010). Maize production systems depend on multiple ecosystem services. Among these, there are supporting services, such as those underlying the structure and fertility of the soil and the nutrient cycles; regulation services, such as pest and disease control, crop pollination, water purification and weather regulation; and provisioning services, such as water supply (Zhang et al., 2007; Power, 2010). Without these services, maize production systems simply could not exist. At the same time, agricultural practices (e.g., soil management, input usage, irrigation and crop or livestock diversity) can either favor or downgrade these same services, creating new production conditions in subsequent agricultural cycles (CONABIO, 2017). Soil fertility and structure, as well as nutrient cycling, are closely linked services and determine, to a great extent, the availability of nutrients and moisture for crops, thus affecting their quantity and quality (Zhang et al., 2007). Maize is an important staple food in developing countries, in particular in Latin America and Africa, and a basic ingredient for local drinks and food products. It is also an outstanding feed for livestock, high in energy, low in fiber and easily digestible. As a source of starch, it is a major ingredient in industrialized food products (Verheye, 2010).

Although maize had multiple uses historically, some of them closely linked to the cultural development of both producers and consumers of this cereal, for thousands of years and up to the beginning of the 20th century it was mainly used for food. However, this changed in the 1940s when the so-called Green Revolution began. Since then, most of the maize grain worldwide is used by new mass production industries and international commerce in processed products, both edible and non-edible. Thus, as well as being directly consumed as food, maize is now used at large-scale mainly in the production of feed, but also in that of fructose, glucose, flour and oils. These first-stage industrial products are used in secondary products that are found in markets worldwide, as well as feed mainly for cattle and poultry, in order to produce meat, eggs and dairy products. Maize has also become one of the main sources for edible oil production, with constant growth recorded over recent decades. Its grain germ, which contains around 80% of the grain's fat, is mainly used to produce cooking oil, but is also used in other industrial products such as soaps, ointments, and nitroglycerine. In spite of the different socio-economic and political landscapes of the maize producing countries, some of their agricultural policies share common objectives, they aim to increase maize yields and productivity, protect smaller farmers, ensure food security, improve the economic conditions of rural and urban populations, allow countries to compete in international agricultural markets and, most recently, transfer to sustainable agricultural practices (CONABIO, 2017). Technical efficiency is a particularly useful and neutral concept for assessing the performance, because it focuses solely on the maximum attainable output level for a given set of inputs. As Brada et al. (1997) argues technical efficiency is a necessary, though not in itself sufficient, condition for profit maximization; it is also a precondition for fulfilling output plans. A stochastic frontier approach is used in this study, it allows to assume a stochastic relationship between the inputs used and the output produced. Specifically, it allows to assume that deviations from the frontier may reflect not only inefficiencies but also noise in the data (Bogetoft and Otto, 2011). The main objective of this study is to estimates the evolution of technical efficiency for maize production in the Nile basin countries during the time period 1993-2016. The paper is structured as follows. Section 2 presents the literature review. Section 3 contains the methodology. Section 4 describes the data. Section 5 provides the results. Finally, section 6 conclusions.

Literature Review

The measurement of efficiency is based on the idea of comparing the real performance of an economic unit with respect to its optimal one. That is to say, it is compare what really the economic unit doing with what it should have done to maximize the benefit. At the empirical level this is possible if we define some forms of the frontier function that serves as a reference to compare if the economic units are efficient or not. In the last decades, frontiers have been estimated using many different methods. The two principal methods are (Coelli, 1996): Data Envelopment Analysis (DEA), which involve mathematical programming and Stochastic Frontiers Analysis (SFA), which involve econometric methods. Habitually, the two alternative approaches have different strengths and weaknesses (Hossain et al., 2012). The main advantages of DEA are its computational simplicity and DEA-based estimate not require any information more than output and input quantities. However, DEA is sensitive to measurement errors or other noise in the data because DEA is deterministic and attributes all deviations from the frontier to inefficiencies. The main advantages of SFA are that it considers stochastic noise in data and also allows for the statistical testing of hypothesis concerning production structure and degree of inefficiency. The main weaknesses are that it requires an explicit imposition of a particular parametric functional form representing the underlying technology and also an explicit distributional assumption for the inefficiency terms. However, from the most recent works in the agricultural field we can observe an increasing in the use of SFA approach. The reason of the increasing use of SFA is that most of the initial disadvantages of SFA have been overcome (Headey et al., 2010). One potential stumbling block of SFA is that it requires prior specification of the functional form for the production function. However, this is no longer a major issue as a number of flexible forms, such as the translog, have been found to provide suitable second-order approximations. Another potentially restrictive feature is that SFA can only handle single-output and multiple-input production processes, but this is no longer a critical constraint because of techniques that designed to directly estimate the input and output distance functions. These distance functions by definition are very general and provide a stochastic alternative to their computation using DEA (Coelli and Perelman, 2000; and O'Donnell and Coelli, 2005). Moreover, these distance functions can be estimated using standard software like Frontier program (Coelli et al., 2005), so computational complexity is no longer an issue. In addition, that SFA approach has overcome some of the initial disadvantage, from the empirical point of view it is highlighted that the most important potential advantage of SFA is that it can separate noise in the data from genuine variations in efficiency, whereas DEA attributes all measurement errors or omitted variable effects to inefficiency. This can lead to DEA results are difficult to interpret. Furthermore, with SFA the variability in production data is captured in standard errors around the estimated efficiency scores, allowing saying something about confidence intervals (Headey et al., 2010). The following are examples for empirical works in the field of agricultural production which focus on estimating technical efficiency using the stochastic production frontier. Abdallah and Abdul-Rahman (2017) examined the technical efficiency of Ghanaian maize farmers from the parametric perspective. The study used the stochastic frontier approach and the Cobb-Douglas functional form to estimate the technical efficiency of Ghanaian maize farmers. The study used data from the database of sub-Saharan Africa's intensification of food crops agriculture. The study found that farmers are producing below the frontier with average technical efficiency of 53%. Factors such as farm size, labor and access to agro-chemicals are the significant determinant of maize output. Significant factors that contribute to technical efficiency include household characteristics (sex and credit access), human capital (education and extension), farmer's resource situation (farm size) and years of experience (age of the farm manager). Bajracharya and Sapkota (2017) assessed the level of technical efficiency for the certified maize seed production. The total of 164 certified seed producer were interviewed in June, 2016 using simple random sampling technique in Palpa district of Nepal. The explanatory variables (inputs) used were seed, labor and tillage were statistically significant. The technical efficiency was estimated using stochastic production frontier model. The average technical efficiency was found 70% which revealed the scope of increasing technical efficiency by 30% using the existing available resources. Bati et al. (2017) analyzed the efficiency in maize production in Ilu Ababor zone of Oromo Regional State, Ethiopia using cross sectional data collected from randomly selected 240 sample households during 2014/2015 production season. The Cobb-Douglas production function was fitted using the stochastic production frontier approach to estimate the efficiencies levels. The inputs were used (seed, land, labor, fertilizer and oxen) had positive and significant effect on the level of output. The estimated results showed that the mean technical, allocative and economic efficiencies were 81.78%, 37.45% and 30.62% respectively. Miho (2017) compared the production efficiency of maize crops among small holder farmers in Tabora and Ruvuma regions, Tanzania. The study applied the stochastic frontier. The inputs used were land, capital, labor, fertilizer and seed; while the output was the maize production. Finding indicated that, Tabora small holder farmers were more technically efficient with mean technical efficiency of 61% compared to 53% of Ruvuma farmers. In both regions the results of technical efficiency indicated the room to increase output using resources available. Siziba et al. (2017) used the stochastic frontier production approach to estimate technical efficiency and its determinants in maize production based on data from 300 small holder farmers in Mazowe district, Zimbabwe. Inputs used were labor, land, seed and fertilizer.

The observed mean technical efficiency level of 0.52 indicates that efficiency level can be increased by 0.48 to realize full potential of maize production. Therefore, the immediate solution to increase maize output in smallholder farmers is embedded in raising technical efficiency levels in smallholder farmers. The study showed that technical efficiency can be increased significantly as a result of more farm visits by extension officers, more participation in agricultural training, membership to a social group and increasing access to credit. Technical efficiency in the study area can be raised by conducting more agricultural training, improving social networks among farmers and improving farm size. Usman (2017) analyzed the technical efficiency of rain-fed maize cultivation in Adamawa state, Nigeria using the stochastic frontier production. The study was based on primary data collected from 140 respondents using simple random sampling for the period of 2014-2015. From randomly selected 140 respondents, primary data related to socio-economic parameters, inputs (quantity and price) used for rain-fed maize cultivation. The result revealed that the mean technical efficiency is 0.69, indicates that an average farmer in the study area have the scope for increasing technical efficiency by 31% in short-run under the existing technology. Adhikari et al. (2018) analyzed the technical efficiency and its determinants of hybrid maize production in eastern Nepal. Using a randomly selected data from 98 farmers in eastern Nepal. The study employed the stochastic frontier production model. The inputs were seed, fertilizer, labor, tillage, and Urea determinants. The study indicated that farmers are not technically efficient, with a mean technical efficiency 79%. Socioeconomic variable age had a negative and significant, while the household size had a positive and significant related to maize output. The younger farmers were observed more technically efficient than older farmers. The significant determinants of technical inefficiency variables include age, family size and total land holdings. Chijioke and Akaninyene (2018) used the stochastic production frontier model to determine the technical efficiency of small holder maize farmers in Abuja, Nigeria. Multi-stage random sampling technique was employed to select a target sample of 300 maize farmers for the study. Inputs were seed, land, labor, and fertilizer. The stochastic frontier model showed that the determinants of technical efficiency for adopters were age, educational status and farm income while the determinants of technical efficiency for non-adopters were educational status, farm income and capital input. The results showed that the mean technical efficiency was 0.56 and 0.49 for adopters and non-adopters, respectively. Felix et al. (2018) estimated the level of technical efficiency in maize production in North Western and Southern zone of Tamil Nadu, India using the stochastic frontier approach. The study used the primary cross-sectional data 2016-2017 for agricultural year. The results indicated that the mean technical efficiency of adopter category in less vulnerable (southern zone) had the highest value with 93.6% followed by adopter category in high vulnerable zone with 89.5% followed by non-adopter category in less vulnerable zone with 77.5% and finally non-adopter category in high vulnerable zone with 77.1%. Ogunwande and Ajila (2018) investigated the technical efficiency of maize for the small scale farmers under the growth enhancement scheme in Egbeda and Surulere local government areas of Oyo State, Nigeria. Multistage sampling technique was used in the random selection of 250 respondents using copies of structured questionnaire. Input variables were farm size, seed, fertilizer, herbicide and labor. The stochastic frontier production function used in this study. Efficiency of farmers was influenced by the significant input variables such as farm size, fertilizer and experience. The distribution of efficiency score showed that farms within the range of 0.81–0.90 were highest. Salat and Swallow (2018) assessed the technical efficiency of maize production among small holder farmers in Nyando, Kenya. The stochastic frontier analysis is used. Inputs were labor, land, seeds, and carbon. The study revealed that maize production in Nyando is associated with mean technical efficiency of 45% and soil conservation practices such as residue management, legume intercropping, and improved varieties significantly increase farmers' technical efficiency. There is a scope for significant increases in production through more effective use of available inputs. Sissoko et al. (2018) used data from the national surveys data from the living standards measurement study and the integrated surveys on agriculture for Mali at 2014 to analyze socio-economic, pedagogical and climate determinants for cereals crops and cash crops. The study used the stochastic production frontier. The technical efficiency score on average is 0.66, implying that the level of technical efficiency can be improved by 0.34 without additional cost. We did not find sufficient empirical works that estimate the technical efficiency of maize production on the level of Nile basin countries, therefore, the contribution of this work is important.

METODOLOGY

Technical efficiency (TE) represents the capacity and willingness of an economic unit to produce the maximum attainable output from a given set of inputs and technology (Koopmans, 1951). Technical efficiency can be estimated by employing different approaches and these include stochastic production frontier (parametric approach) and data envelopment analysis (nonparametric approach). Data envelopment analysis works under the assumption of no random shocks in the data set. Farmers always operate under uncertainty and therefore, the present study employs a stochastic production frontier approach introduced by Aigner et al. (1977); and Meeusen and van den Broeck (1977). The original specification involved a production function which had an error term that had two components, one to account for random effects and another to account for technical inefficiency. For the panel data, a stochastic frontier production function can be expressed as follows:

$$Q_{it} = f(X_{it}, t; \alpha) e^{v_{it} - u_{it}} \tag{1}$$

where Q_{it} is the production of the *i-th* firm in the *t-th* time period; X_{it} is a vector of input quantities of the *i-th* firm in the *t-th* time period; t is the time trend index that serves as a proxy for technical change; α is a vector of unknown parameters to be estimated; v_{it} is a vector of random variables which are assumed to be iid. $N(0, \sigma_v^2)$ and independent of u_{it}; and u_{it} is a vector of non-negative random variables which are assumed to account for technical inefficiency in production and are often assumed to be iid. $\left|N(0, \sigma_u^2)\right|$. Specifically, u_{it} is a vector of random disturbances that measures the extent to which actual production falls short of maximum attainable output. From an empirical perspective, we use the stochastic frontier production function for the maize production in the Nile basin countries:

$$Q_{it} = f\,(X_{Ait}, X_{Sit}, t; \alpha) e^{v_{it} - u_{it}} \tag{2}$$

Where Q_{it} is the maize production of *i-th* country at *t-th* time period; X_{Ait}, X_{Sit} are the inputs of *i-th* country at *t-th* time period; t is the time variable; α is a vector of unknown parameters to be estimated; v_{it} is the error component, and u_{it} is the inefficiency error. The translogarithmic function and the Cobb-Douglas function are the two most common functional forms which have been used not only in empirical studies on frontier production but in the studies on production behavior in general. The Cobb-Douglas production function can be defined as:

$$\ln Q_{it} = \alpha_0 + \sum_{j=1} \alpha_j \ln \mathrm{x}_{jit} + \alpha_t\, t + v_{it} - u_{it} \tag{3}$$

Following the previous literature (Coelli et al. 2003; Lambarraa et al. 2007), the stochastic frontier production function is specified as a Translog function that takes the form:

$$\ln Q_{it} = \alpha_0 + \sum_{j=1} \alpha_j \ln \mathrm{x}_{jit} + \alpha_t t + \frac{1}{2} \sum_{j=1} \sum_{l=1} \alpha_{jl} \ln \mathrm{x}_{jit} \ln \mathrm{x}_{lit} + \frac{1}{2} \alpha_{tt} t^2 + \sum_{j=1} \alpha_{jt} (\ln \mathrm{x}_{jit})(t) + v_{it} - u_{it} \tag{4}$$

Where Q_{it} is the maize production of *i*-th country at *t-th* time period, x_{jit} is the *j-th* input of *i-th* country at *t-th* time period, t is the time variable, u is the efficiency error (representing production loss due to technical inefficiency and thus always greater than or equal to zero, $u \geq 0$), and v is the statistical error. All variables appearing in natural logarithms and the time trend was at zero in 2004. In this study we used the two specifications of Battese and Coelli (1992 and 1995). In Battese and Coelli (1992) specification, the statistical error ν is assumed to be independently and identically distributed as $N(0,\sigma_v^2)$. The efficiency error u is assumed to be independent of ν with the following definition:

$$u_{it} = u_i \exp(-\eta[t-T]) \qquad (5)$$

Where the distribution of u_i is taken to be the non-negative truncation of the normal distribution $N(\mathrm{u},\sigma_u^2)$ and η is a parameter that represents the rate of change in technical inefficiency. The positive value (negative) is associated with improvements (deterioration) in the technical efficiency for maize production over time. In Battese and Coelli (1995) specification, the statistical error ν is assumed to be independently and identically distributed as $N(0,\sigma_v^2)$ an independent of the efficiency error u. The efficiency error u is a non-negative random variable which is assumed to account for technical inefficiency in production and is assumed to be independently distributed as truncations at zero of the $N(\mathrm{m}_{it},\sigma_u^2)$ distribution. The technical inefficiency model defined by Battese and Coelli (1995) is specified as follows:

$$u_{it} = \delta_0 + \sum_{j=1} \delta_j D_{jit} + \delta_t t \qquad (6)$$

Where u_{it} is the technical inefficiency of the *i-th* country at *t-th* time period; δ is a vector of parameters to be estimated; and D_{jit} is a vector of variables which expected to influence the level of technical inefficiency of the *i-th* country at *t-th* time period. In this study we have two dummy variables (D_{jit}), one dummy variable for the country area within the basin and the other dummy variable for the annual rainfall in the basin area; D_1 equal to 1 if the area of the country within the basin higher than the mean of the countries area within the basin and zero otherwise; D_2 equal to 1 if the mean annual rainfall in the basin area of the country higher than the mean annual rainfall in the basin area and zero otherwise. Additionally, we incorporate the time variable to verify if the inefficiency increase or decrease in the analyzed period. The Maximum Likelihood estimates for the parameters of the stochastic frontier models, defined by equations (3), (4), (5) and (6) can be obtained by using the Frontier 4.1 program, in which the variance parameters are expressed in terms of (Coelli, 1996):

$$\sigma_s^2 = \sigma_u^2 + \sigma_v^2 \, ; \gamma = \frac{\sigma_u^2}{\sigma_s^2} \textit{ and } 0 \leq \gamma \leq 1 \qquad (7)$$

The technical efficiency level of the *i-th* country at the *t-th* time period (TE_{it}) is defined as the ratio of the actual output to the maximum potential output as follows: $TE_{it} = \exp(-u_{it})$.

Data

The Nile river with an estimated length of over 6800 km, is the longest river flowing from north over 35 degrees of latitude. It is fed by main river systems: The White Nile, with its sources on the equatorial lake plateau (Burundi, Tanzania, Kenya, DR Congo and Uganda), and the Blue Nile, with its sources in the Ethiopian highlands. The total area of the Nile basin represents 10.3% of the area of the continent (FAO, 1997) and spreads over than ten countries: Burundi, DR Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda (table 1).

Table 1. Nile basin: Areas and rainfall by country

Country	Total area of the country (km²)	Area of the country within the basin (km²)	As % of total area of basin (%)	As % of total area of the country (%)	Annual rainfall in the basin area (mm)		
					Min.	Max.	Mean
Burundi	27834.00	13260.00	0.40	47.60	895.00	1570.00	1110.00
DR Congo	2344860.00	22143.00	0.70	98.10	875.00	1915.00	1245.00
Egypt	1001450.00	326751.00	10.50	32.60	0.00	120.00	15.00
Eritrea	121890.00	24921.00	0.80	20.40	240.00	665.00	520.00
Ethiopia	1100010.00	365117.00	11.70	33.20	205.00	2010.00	1125.00
Kenya	58037.00	46229.00	1.50	8.00	505.00	1790.00	1260.00
Rwanda	26340.00	19876.00	0.60	75.50	840.00	1935.00	1105.00
Sudan	2505810.00	1978506.00	63.60	79.00	0.00	1610.00	500.00
Tanzania	945090.00	84200.00	2.70	8.90	625.00	1630.00	1015.00
Uganda	235880.00	231366.00	7.40	98.10	395.00	2060.00	1140.00
Mean	836720.10	311236.90	9.99	50.14	458.00	1530.50	903.50

Sources: FAO and own elaboration

In this study we used panel data on the country level. The data was obtained from FAOSTAT and consider the time period 1993-2016. The data include the Nile basin countries: Burundi, DR Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda. The data consists of one agricultural output variable, which is the maize production in the Nile basin countries, and the input variables consists of area and seed.

Table 2 shows the maize production (thousand ton) in the Nile basin countries during the time period 1993-2016. The minimum mean of maize production in the studied period is 13.55 thousand tons in Eritrea, while the maximum mean of maize production is 6511.00 thousand tons in Egypt. The mean of maize production for the Nile basin countries during the time period 1993-2016 is 2032.40 thousand tons. The minimum annual average percentage growth rate (1993-2016) for maize production is 0.19% in DR Congo, while the maximum annual average percentage growth rate (1993-2016) for maize production is 7.60% in Ethiopia. The mean of the annual average percentage growth rates for maize production in the studied period is 3.60%.

Table 3 shows the maize area (thousand hectare) in the Nile basin countries during the time period 1993-2016. The mean of maize area in the Nile basin countries during 1993-2016 varying from 20.34 thousand hectares in Eritrea to 2609.00 thousand hectares in Tanzania. The mean of maize area for the Nile basin countries during 1993-2016 is 961.46 thousand hectares. The annual average percentage growth rate (1993-2016) for maize area varying from -3.45% in Sudan to 7.01% in Rwanda. The mean of the annual average percentage growth rates for maize area in the studied period is 1.98%.

Table 4 shows the maize yield (ton/hectare) in the Nile basin countries during the time period 1993-2016. The mean of maize yield in the Nile basin countries during 1993-2016 varying from 0.65 ton/hectare in Eritrea to 7.43 ton/hectare in Egypt. The mean of maize yield for the Nile basin countries during 1993-2016 is 2.32 ton/hectare. The annual average percentage growth rate (1993-2016) for maize yield varying from -0.43% in Rwanda to 6.59% in Eritrea. The mean of the annual average percentage growth rates for maize yield in the studied period is 1.62%.

Table 2. Maize production (thousand ton) in the Nile basin countries (1993-2016)

Year	Burundi	DR Congo	Egypt	Eritrea	Ethiopia	Kenya	Rwanda	Sudan	Tanzania	Uganda	Min.	Max.	Mean
1993	172.10	1130.19	5039.08	5.54	1455.92	2089.00	87.00	40.00	2282.20	804.00	5.54	5039.08	1310.50
1994	122.76	1184.43	5112.00	18.53	1396.23	3060.00	67.00	48.00	1485.80	850.00	18.53	5112.00	1334.47
1995	153.02	1007.58	4535.18	5.35	1989.70	2698.86	56.00	21.00	2874.40	913.00	5.35	4535.18	1425.41
1996	144.46	1101.13	5165.34	6.76	3164.18	2160.00	66.60	54.00	2822.00	759.00	6.76	5165.34	1544.35
1997	144.99	1167.31	5806.07	6.41	2986.50	2214.00	83.43	52.00	1831.20	740.00	6.41	5806.07	1503.19
1998	131.83	1215.34	6336.80	28.99	2344.30	2464.10	58.62	42.00	2684.60	924.00	28.99	6336.80	1623.06
1999	128.71	1199.00	6143.36	15.90	2832.07	2322.14	54.91	37.00	2420.94	1053.00	15.90	6143.36	1620.70
2000	117.84	1184.00	6474.45	5.32	2682.94	2160.00	62.50	53.00	1965.40	1096.00	5.32	6474.45	1580.14
2001	124.40	1169.19	6093.58	9.05	3298.33	2790.00	80.98	53.00	2652.81	1174.00	9.05	6093.58	1744.53
2002	126.80	1154.57	6430.96	3.01	2825.56	2408.60	91.69	53.00	4408.42	1217.00	3.01	6430.96	1871.96
2003	120.58	1154.80	6530.43	4.46	2743.88	2710.85	78.89	53.00	2613.97	1300.00	4.46	6530.43	1731.08
2004	123.20	1155.03	6236.14	2.29	2906.31	2607.14	88.21	60.00	4651.37	1080.00	2.29	6236.14	1890.97
2005	125.67	1155.26	7085.19	13.58	3911.87	2905.56	97.25	10.00	3131.61	1237.00	10.00	7085.19	1967.30
2006	116.83	1155.49	6374.30	28.40	4029.63	3247.20	96.66	109.00	3423.02	1258.03	28.40	6374.30	1983.86
2007	115.51	1155.72	6243.22	13.69	3336.80	2928.79	101.66	70.00	3659.00	1261.80	13.69	6243.22	1888.62
2008	117.68	1155.95	7401.41	4.15	3776.44	2367.24	166.85	62.00	5440.71	2314.91	4.15	7401.41	2280.73
2009	120.38	1156.18	7686.09	16.65	3897.16	2439.00	286.95	66.00	3326.20	2354.66	16.65	7686.09	2134.93
2010	126.41	1155.96	7041.10	18.00	4986.13	3464.54	432.40	35.00	4733.07	2373.50	18.00	7041.10	2436.61
2011	128.48	1156.11	6876.47	20.04	6069.41	3376.86	525.68	42.00	4340.82	2551.00	20.04	6876.47	2508.69
2012	140.54	1375.00	8093.65	22.00	6158.32	3749.88	573.04	51.00	5104.25	2734.00	22.00	8093.65	2800.17
2013	162.42	1373.00	7956.59	20.00	6491.54	3592.69	667.83	43.00	5356.35	2748.00	20.00	7956.59	2841.14
2014	127.83	1400.00	5800.00	18.04	7234.96	3513.17	480.00	48.00	6737.20	2763.00	18.04	7234.96	2812.22
2015	160.71	1177.39	7803.18	20.00	7882.44	3825.00	370.14	48.00	5902.78	2647.45	20.00	7882.44	2983.71
2016	243.74	1179.28	8001.41	19.10	7847.18	3339.00	374.27	50.00	5875.56	2663.03	19.10	8001.41	2959.26
Mean	137.40	1184.10	6511.00	13.55	4010.30	2851.00	210.40	50.00	3738.00	1617.30	13.55	6511.00	2032.40
Rate[a]	1.53	0.19	2.03	5.53	7.60	2.06	6.55	0.98	4.20	5.35	0.19	7.60	3.60

Sources: FAOSTAT and own elaboration

([a]) Annual average percentage growth rates (1993-2016)

Table 3. Maize area (thousand hectare) in the Nile basin countries (1993-2016).

Year	Burundi	DR Congo	Egypt	Eritrea	Ethiopia	Kenya	Rwanda	Sudan	Tanzania	Uganda	Min.	Max.	Mean
1993	120.00	1368.79	829.07	24.00	838.45	1343.50	50.00	81.00	1824.00	503.00	24.00	1824.00	698.18
1994	100.00	1432.90	865.48	24.10	1242.74	1500.00	40.00	100.00	1203.00	563.00	24.10	1500.00	707.12
1995	120.00	1280.93	735.87	15.89	1464.08	1438.74	50.00	36.54	1368.00	571.00	15.89	1464.08	708.11
1996	110.00	1377.37	742.97	17.01	1880.58	1489.00	60.00	83.16	1580.00	584.00	17.01	1880.58	792.41
1997	115.00	1427.43	814.34	25.68	1718.27	1504.82	76.48	80.00	1564.00	598.00	25.68	1718.27	792.40
1998	115.00	1460.96	876.99	38.49	1449.30	1475.74	71.21	63.84	2088.00	616.00	38.49	2088.00	825.55
1999	115.00	1500.63	817.22	20.08	1651.35	1567.24	72.67	63.42	957.55	608.00	20.08	1651.35	737.32
2000	112.00	1481.85	843.03	22.54	1655.75	1500.00	89.05	71.82	1017.60	629.00	22.54	1655.75	742.27
2001	115.00	1463.31	873.04	11.53	1892.69	1640.00	105.56	71.82	845.95	652.00	11.53	1892.69	767.09
2002	116.00	1482.12	828.13	14.49	1506.76	1592.32	104.63	63.42	1718.20	676.00	14.49	1718.20	810.21
2003	113.00	1482.41	834.10	13.36	1791.12	1670.91	102.82	71.82	3462.54	710.00	13.36	3462.54	1025.21
2004	114.00	1482.71	788.52	9.51	1801.57	1351.33	115.00	58.38	3173.07	750.00	9.51	3173.07	964.41
2005	116.00	1483.00	868.21	27.69	1950.12	1771.12	109.40	9.80	3109.59	780.00	9.80	3109.59	1022.49
2006	115.00	1483.30	761.52	29.12	1526.13	1888.19	113.31	104.17	2570.15	819.00	29.12	2570.15	940.99
2007	105.62	1483.59	775.91	16.45	1694.52	1615.30	141.17	36.67	2600.34	844.00	16.45	2600.34	931.36
2008	117.20	1483.89	936.25	19.53	1767.39	1700.00	144.90	30.67	3980.97	862.00	19.53	3980.97	1104.28
2009	120.00	1484.19	983.08	19.16	1772.25	1884.37	147.13	37.08	2961.33	942.00	19.16	2961.33	1035.06
2010	125.60	1484.78	968.52	20.00	1963.18	2008.35	184.66	26.46	3050.71	1032.00	20.00	3050.71	1086.42
2011	128.00	1480.00	888.33	20.56	2054.72	2131.89	223.41	31.08	3287.85	1063.00	20.56	3287.85	1130.88
2012	119.48	1745.00	1041.35	21.00	2013.05	2159.32	253.70	30.66	4118.12	1094.00	21.00	4118.12	1259.57
2013	122.87	1750.00	1030.34	20.00	1994.81	2123.14	292.33	26.88	4120.27	1101.00	20.00	4120.27	1258.16
2014	97.24	1800.00	750.00	18.84	2114.88	2116.14	250.00	45.20	4200.00	1105.00	18.84	4200.00	1249.73
2015	121.18	1514.25	1061.00	20.00	2111.52	2098.24	241.71	38.64	3787.75	1125.17	20.00	3787.75	1211.95
2016	184.82	1518.26	1082.77	19.07	2135.57	2337.59	237.66	36.12	4037.00	1148.99	19.07	4037.00	1273.78
Mean	118.30	1498.00	874.80	20.34	1749.60	1746.00	136.50	54.11	2609.00	807.34	20.34	2609.00	961.46
Rate[a]	1.90	0.45	1.17	-1.00	4.15	2.44	7.01	-3.45	3.52	3.66	-3.45	7.01	1.98

Sources: FAOSTAT and own elaboration

([a]) Annual average percentage growth rates (1993-2016)

Table 4. Maize yield (ton/hectare) in the Nile basin countries (1993-2016).

Year	Burundi	DR Congo	Egypt	Eritrea	Ethiopia	Kenya	Rwanda	Sudan	Tanzania	Uganda	Min.	Max.	Mean
1993	1.43	0.83	6.08	0.23	1.7	1.55	1.74	0.49	1.25	1.60	0.23	6.08	1.94
1994	1.23	0.83	5.91	0.77	1.12	2.04	1.68	0.48	1.24	1.51	0.48	5.91	1.93
1995	1.28	0.79	6.16	0.34	1.36	1.88	1.12	0.57	2.10	1.60	0.34	6.16	1.97
1996	1.31	0.80	6.95	0.40	1.68	1.45	1.11	0.65	1.79	1.30	0.40	6.95	2.07
1997	1.26	0.82	7.13	0.25	1.74	1.47	1.09	0.65	1.17	1.24	0.25	7.13	2.02
1998	1.15	0.83	7.23	0.75	1.62	1.67	0.82	0.66	1.29	1.50	0.66	7.23	2.12
1999	1.12	0.80	7.52	0.79	1.72	1.48	0.76	0.58	2.53	1.73	0.58	7.52	2.26
2000	1.05	0.80	7.68	0.24	1.62	1.44	0.70	0.74	1.93	1.74	0.24	7.68	2.15
2001	1.08	0.80	6.98	0.79	1.74	1.70	0.77	0.74	3.14	1.80	0.74	6.98	2.27
2002	1.09	0.78	7.77	0.21	1.88	1.51	0.88	0.84	2.57	1.80	0.21	7.77	2.27
2003	1.07	0.78	7.83	0.33	1.53	1.62	0.77	0.74	0.75	1.83	0.33	7.83	2.12
2004	1.08	0.78	7.91	0.24	1.61	1.93	0.77	1.03	1.47	1.44	0.24	7.91	2.20
2005	1.08	0.78	8.16	0.49	2.01	1.64	0.89	1.02	1.01	1.59	0.49	8.16	2.28
2006	1.02	0.78	8.37	0.98	2.64	1.72	0.85	1.05	1.33	1.54	0.78	8.37	2.45
2007	1.09	0.78	8.05	0.83	1.97	1.81	0.72	1.91	1.41	1.50	0.72	8.05	2.40
2008	1.00	0.78	7.91	0.21	2.14	1.39	1.15	2.02	1.37	2.69	0.21	7.91	2.40
2009	1.00	0.78	7.82	0.87	2.20	1.29	1.95	1.78	1.12	2.50	0.78	7.82	2.49
2010	1.01	0.78	7.27	0.90	2.54	1.73	2.34	1.32	1.55	2.30	0.78	7.27	2.48
2011	1.00	0.78	7.74	0.97	2.95	1.58	2.35	1.35	1.32	2.40	0.78	7.74	2.58
2012	1.18	0.79	7.77	1.05	3.06	1.74	2.26	1.66	1.24	2.50	0.79	7.77	2.65
2013	1.32	0.78	7.72	1.00	3.25	1.69	2.28	1.60	1.30	2.50	0.78	7.72	2.66
2014	1.31	0.78	7.73	0.96	3.42	1.66	1.92	1.06	1.60	2.50	0.78	7.73	2.62
2015	1.33	0.78	7.35	1.00	3.73	1.82	1.53	1.24	1.56	2.35	0.78	7.35	2.57
2016	1.32	0.78	7.39	1.00	3.67	1.43	1.57	1.38	1.46	2.32	0.78	7.39	2.54
Mean	1.16	0.79	7.43	0.65	2.21	1.64	1.33	1.07	1.56	1.91	0.65	7.43	2.32
Rate[a]	-0.36	-0.27	0.85	6.59	3.31	-0.37	-0.43	4.58	0.66	1.63	-0.43	6.59	1.62

Sources: FAOSTAT and own elaboration

([a]) Annual average percentage growth rates (1993-2016)

The summary statistics for the variables used in the analysis are presented in table 5. The production inputs comprise two input variables (area and seed) while there is only one output (maize production). Maize production is expressed in thousand tons, the area in thousand hectares and seed have been estimated in thousand tons.

Table 5. Summary statistics for the variables

Variables	Units	Minimum	Maximum	Mean	Std. Dev.
Production (Q)	Tons (thousands)	2.29	8093.64	2032.40	2260.81
Area (X1)	Hectares (thousands)	9.51	4200.00	961.46	944.23
Seed (X2)	Tons (thousands)	0.29	91.09	28.53	25.30

Source: Own elaboration from the data (FAOSTAT)

RESULTS

The results of the Maximum Likelihood estimate (MLE) of Battese and Coelli (1992) and (1995) specifications for maize production in the Nile basin countries are presents in table 6. The coefficients of the Cobb-Douglas and Translog production functions illustrated the production elasticities of inputs in the production process. In the four models, the coefficient of maize area is positive and significant according to the prior expectations. In the four models, the coefficient of seed is positive and insignificant, this may be due to the use of seed is not used appropriately in the production process. The technical change coefficient is positive and significant for three models [models (1), (2) and (3)] this result indicates technical progress over time, while the technical change coefficient is negative and significant for model (4), this result probably suggests that there are other factors which are not considered in the production function and whose negative effects on output outweigh the positive effects of the possible technical progress, another possible reason is that the existent technology might not be used appropriately. We estimated the technical inefficiency model defined by equation (6), where technical inefficiency is a dependent variable. The coefficients of the dummy variables in model (3) are significant, while they are insignificant for model (4). In model (3), the negative and significant coefficient for (D1) suggests that technical inefficiency in maize production in the Nile basin countries tended to decrease with the increasing in the area of the country within the basin. The positive and significant coefficient for (D2) suggests that technical inefficiency in maize production in the Nile basin countries tended to increase with the increasing in the annual rainfall in the basin area of the country. The positive and significant coefficient for the dummy variable of time (t) in model (3) indicates that there is technical inefficiency in maize production during the studied period. In models (1) and (2), Eta value is statistically different from zero, this implies that technical inefficiency is time-variant. The variance parameter, gamma, is positive and significant for three models [models (1), (2) and (4)], which suggests the relevance of technical inefficiency in explaining output variability, while gamma is positive and insignificant for model (3). Table 7 shows the annual levels of technical efficiency for maize production in the Nile basin countries during the time period 1993-2016. The mean of technical efficiency for the four models during the time period 1993-2016 vary from a minimum level of 0.6812 in 1993 to a maximum level of 0.7254 in 2014, while the mean of technical efficiency for the studied period is 0.7020, this indicates improving in the levels of technical efficiency during the studied period. The annual average percentage growth rates for the four models during the time period 1993-2016 vary from a minimum rate of -0.8470% to a maximum rate of 1.7055%.

Table 6. Maximum Likelihood estimates of the stochastic frontier production models

Variables	Battese and Coelli (1992) Specification				Battese and Coelli (1995) Specification			
	Cobb-Douglas (1)		Translog (2)		Cobb-Douglas (3)		Translog (4)	
	Coefficients	Standard error	Coefficients	Standard error	Coefficients	Standard error	Coefficients	Standard error
Stochastic Frontier								
Constant	1.3792	(0.5158)**	-0.1172	(0.7779)	-1.1375	(0.3035)***	-1.1372	(0.9216)
ln (X1)	0.9253	(0.0608)***	1.2431	(0.3488)***	1.2432	(0.0765)***	1.0374	(0.4227)**
ln (X2)	0.0039	(0.0592)	0.5156	(0.3192)	0.0145	(0.0783)	1.1430	(0.7605)
t	0.0110	(0.0032)***	0.1056	(0.0333)***	0.0279	(0.0063)***	-0.1083	(0.0621)*
½ $[\ln(X1)]^2$			-0.0356	(0.0966)			0.1430	(0.1262)
½ $[\ln(X2)]^2$			0.2796	(0.1038)**			0.1546	(0.3374)
½ $[t]^2$			0.0023	(0.0009)**			0.0008	(0.0023)
(ln X1) (ln X2)			-0.1412	(0.0914)			-0.2665	(0.2518)
(ln X1) (t)			-0.0205	(0.0093)**			0.0300	(0.0168)*
(ln X2) (t)			0.0148	(0.0091)			-0.0294	(0.0192)
Technical Inefficiency								
Constant					-0.2905	(0.1974)	-0.0082	(0.5530)
D1					-0.5458	(0.2370)**	-0.6881	(0.5607)
D2					0.5181	(0.2035)**	0.6428	(0.5942)
t					0.0161	(0.0051)***	-0.0298	(0.0231)
Sigma-squared	1.1381	(0.2230)***	0.6794	(0.1180)***	0.2722	(0.0238)***	0.3291	(0.0794)***
Gamma	0.9246	(0.0184)***	0.8969	(0.0181)***	0.0126	(0.0128)	0.0200	(0.0039)***
Mu	-0.1606	(0.5827)	-0.2663	(0.6928)				
Eta	0.0130	(0.0038)***	-0.0028	(0.0052)				
Log likelihood function	-100.8417		-80.2846		-182.0455		-174.2729	
LR test of the one-side error	264.4669		261.0723		102.0592		73.0957	
Total number of observations	240		240		240		240	

Source: Own elaboration

***, ** and * indicates significance at 1, 5 and 10% level, respectively.

All the variables are in log form except dummies and time.

Table 7. Technical efficiency for maize production in the Nile basin countries by year (1993-2016)

Year	Battese and Coelli (1992) Specification		Battese and Coelli (1995) Specification		Minimum	Maximum	Mean
	Cobb-Douglas (1)	Translog (2)	Cobb-Douglas (3)	Translog (4)			
1993	0.5310	0.6577	0.9601	0.5761	0.5310	0.9601	0.6812
1994	0.5344	0.6570	0.9541	0.5891	0.5344	0.9541	0.6837
1995	0.5379	0.6563	0.9478	0.6002	0.5379	0.9478	0.6856
1996	0.5413	0.6557	0.9404	0.6119	0.5413	0.9404	0.6873
1997	0.5447	0.6550	0.9324	0.6225	0.5447	0.9324	0.6887
1998	0.5481	0.6543	0.9246	0.6363	0.5481	0.9246	0.6908
1999	0.5515	0.6537	0.9173	0.6496	0.5515	0.9173	0.6930
2000	0.5549	0.6530	0.9087	0.6596	0.5549	0.9087	0.6941
2001	0.5583	0.6524	0.9014	0.6740	0.5583	0.9014	0.6965
2002	0.5617	0.6517	0.8928	0.6839	0.5617	0.8928	0.6975
2003	0.5651	0.6510	0.8833	0.6952	0.5651	0.8833	0.6987
2004	0.5685	0.6504	0.8760	0.7078	0.5685	0.8760	0.7007
2005	0.5718	0.6497	0.8679	0.7184	0.5718	0.8679	0.7020
2006	0.5752	0.6490	0.8605	0.7298	0.5752	0.8605	0.7036
2007	0.5786	0.6484	0.8528	0.7410	0.5786	0.8528	0.7052
2008	0.5819	0.6477	0.8458	0.7521	0.5819	0.8458	0.7069
2009	0.5853	0.6470	0.8387	0.7641	0.5853	0.8387	0.7088
2010	0.5886	0.6463	0.8320	0.7764	0.5886	0.8320	0.7108
2011	0.5920	0.6457	0.8245	0.7880	0.5920	0.8245	0.7126
2012	0.5953	0.6450	0.8175	0.8000	0.5953	0.8175	0.7145
2013	0.5986	0.6443	0.8106	0.8123	0.5986	0.8123	0.7165
2014	0.6019	0.6437	0.8307	0.8252	0.6019	0.8307	0.7254
2015	0.6052	0.6430	0.7967	0.8378	0.6052	0.8378	0.7207
2016	0.6085	0.6423	0.7895	0.8500	0.6085	0.8500	0.7226

Mean	0.5700	0.6500	0.8753	0.7126	0.5700	0.8753	0.7020
Rate[a]	0.5941	-0.1030	-0.8470	1.7055	-0.8470	1.7055	0.3374

Source: Own elaboration
(a) Annual average percentage growth rate (1993-2016)

Table 8 shows the technical efficiency for maize production in the Nile basin countries during the time period 1993-2016. The mean of technical efficiency for the four models vary from a minimum level of 0.4910 in DR Congo to a maximum level of 0.9987 in Egypt.

Table 8. Technical efficiency for maize production in the Nile basin countries [a]

	Battese and Coelli (1992) Specification		Battese and Coelli (1995) Specification				
Country	Cobb-Douglas (1)	Translog (2)	Cobb-Douglas (3)	Translog (4)	Minimum	Maximum	Mean
Burundi	0.4193	0.5585	0.7970	0.5521	0.4193	0.7970	0.5818
DR Congo	0.3453	0.2866	0.7875	0.5447	0.2866	0.7875	0.4910
Egypt	1.0000	1.0000	1.0000	0.9949	0.9949	1.0000	0.9987
Eritrea	0.1755	0.3286	0.9874	0.9083	0.1755	0.9874	0.5999
Ethiopia	0.8820	0.9397	0.9889	0.9222	0.8820	0.9889	0.9333
Kenya	0.7088	0.7179	0.7939	0.5520	0.5520	0.7939	0.6931
Rwanda	0.4326	0.5931	0.7973	0.5532	0.4326	0.7973	0.5941
Sudan	0.3216	0.4448	1.0000	0.9941	0.3216	1.0000	0.6901
Tanzania	0.6646	0.8115	0.7925	0.5507	0.5507	0.8115	0.7048
Uganda	0.7503	0.8192	0.7969	0.5532	0.5532	0.8192	0.7299
Total sample	0.5700	0.6500	0.8753	0.7126	0.5700	0.8753	0.7020

Source: Own elaboration
([a]) Mean of the time period (1993-2016)

CONCLUSIONS

This study estimates the evolution of technical efficiency for maize production in the Nile basin countries. The data used in this study is a panel data at the countries level, it represents the time period 1993-2016 and taken from FAOSTAT. The specifications of Battese and Coelli (1992) and (1995) are employed. In the four models of stochastic frontier, the coefficient of maize area is positive and significant implying that increasing the maize area could significantly enhance maize production. In the four models, the coefficient of seed is positive and insignificant, this may be due to the use of seed is not used appropriately in the production process. The technical change coefficient is positive and significant for three models [models (1), (2) and (3)], while it is negative and significant for model (4). The coefficients of the dummy variables in technical inefficiency model are significant in model (3), while they are insignificant in model (4). The mean of technical efficiency for the four models during the time period 1993-2016 vary from 0.4910 in DR Congo to 0.9987 in Egypt, while the mean of technical efficiency for the Nile basin countries is 70.20%, this implying that potential exists to improve the level of technical efficiency in maize production.

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