Spanish Journal of Agricultural Research
15(2), e0111, 11 pages (2017)
eISSN: 2171-9292
https://doi.org/10.5424/sjar/2017152-10548
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria, O.A., M.P. (INIA)

RESEARCH ARTICLE

OPEN ACCESS

Global Malmquist indices of productivity change in Egyptian wheat production

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Abstract

This study aims to measure the total factor productivity of the main governorates of wheat production in Egypt during the time period 1990-2012 and decompose it into technical change, efficiency change and scale change. We used Global Malmquist TFP index as a non-parametric approach. The results indicated that the contribution of technical change component is more important than the efficiency change component. In fact technical change rose, 25.7%, while efficiency change presented a little decline, 3.7%. The decomposition of efficiency change indicated that the main problem of wheat production in Egypt was scale efficiency that worsened by 5.5%.

Additional keywords: total factor productivity; data envelopment analysis; Egypt.

Abbreviations used: BCC (Banker, Charnes and Cooper model); CCR (Charnes, Cooper and Rhodes model); DEA (Data Envelopment Analysis); EC (Efficiency Change); Efficiency Change (EC); FDH (Free Disposal Hull model); PC (Global Malmquist Total Factor Productivity Change); PEC (Pure Efficiency Change); SBM (Slacks Based Model); SEC (Scale Efficiency Change); TC (Technical Change); TFP (Total Factor Productivity

Authors' contributions: Conception and data search: YHE. Design and conceptualization, quantitative analysis and writing: YHE and SA.

Citation: Elasraag, Y. H.; Alarcón, S. (2017). Global Malmquist indices of productivity change in Egyptian wheat production. Spanish Journal of Agricultural Research, Volume 15, Issue 2, e0111. https://doi.org/10.5424/sjar/2017152-10548

Received: 30 Sept 2016. **Accepted:** 26 May 2017

Funding: This work was supported by Ministry of Economy and Competitiveness, Spain (AGL2015-65897-C3-1-R)

Competing interests: The authors have declared that no competing interests exist.

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Introduction

Egypt is located on the northeast corner of the African continent. It is bordered by Libya to the west, Sudan to the south, the Red Sea to the east, and the Mediterranean Sea to the north. Egypt has the largest, most densely settled population among the Arab countries. The total area of the country covers approximately one million square kilometers (El-Zanaty & Way, 2015). In Egypt rainfall is negligible and no crop can be grown without irrigation. Irrigation is almost universal in Egyptian agriculture, allowing the cultivation of summer and winter crops. In the frontier, irrigation water comes from wells (Tyner *et al.*, 1999; Kherallah *et al.*, 2000). Wheat is the most important cereal crop and a staple food of the vast majority of the human population (Tiwari & Shoran, 2009). It is a cool-season crop, widely cultivated under varied agro-ecologic conditions and cropping systems throughout the world. Wheat contributes more calories and proteins to the world diet than any other cereal crops (Abd-El-Haleem *et al.*, 1998; Adams *et al.*, 2002; Shewry, 2009). It is nutritious, easy to store and transport and can be processed into various types of food. Wheat is considered a good source of protein, minerals, B-group vitamins and dietary fiber (Simmonds, 1989; Shewry, 2007), although the environmental conditions can affect nutritional composition of wheat grains with its essential coating of bran, vitamins and minerals; it is an excellent health-building food.

In Egypt wheat is the most important winter crop. It is produced widely in both the older farming lands of the Delta and in the newly-farmed lands reclaimed from the desert. The vast majority of Egyptian wheat farms are small, irrigated, and owner-operated. Winters are without frost, but sufficiently cool for wheat. The mean daily temperature during the wheat growing period range from 15.7°C to 21.4°C. Wheat plays an important role in farmers' crop rotations. The most common winter-summer rotations are wheat-rice, clover-cotton, wheat-maize, and clover-maize (Tyner *et al.*, 1999; Kherallah *et al.*, 2000).

Two major factors are seriously increasing the rate of change in domestic wheat consumption, the rate of population growth and the rate of growth in wheat consumption per capita. These two factors are, consequently, affected by numerous other factors such as the adopted economic policies, income and its distribution among individuals, and the rate of change in prices (Tyner *et al.*, 1999). The Government of Egypt does continue to intervene in several markets, including the wheat market. Government intervention aimed at increasing self-sufficiency in wheat, thus reducing dependency on imports through support prices provided to wheat farmers and expansion of wheat area (Croppenstedt *et al.*, 2006). Wheat planted area grew due mainly to the implementation of more productive cultural practices and more liberal policy environment, an increase in government procurement prices, and improved profitability of wheat-based rotation. These factors reinforced each other in making investment in wheat production a more attractive and lucrative enterprise (USDA, 1997; Kherallah *et al.*, 2000).

The study of total factor productivity (TFP) of wheat production in Egypt is a crucial issue as it provides more precise information about what happen in the production process. Agricultural policy-making could be improved through identifying the sources of productivity change (O'Donnell, 2010). The objective of this study was to measure the TFP of the main governorates of wheat production in Egypt during the time period 1990-2012 and decompose it into technical change (TC), pure efficiency change (PEC) and scale efficiency change (SEC).

The main novelty of this work was the use and comparison of different techniques for measuring and decomposing TFP: contemporaneous Malmquist (Färe *et al.*, 1994), Global Malmquist (Pastor & Lovell, 2005) and Färe-Primont indices (O'Donnell, 2011). In addition, to gain robustness several distance functions were employed: well-known Data Envelopment Analysis (DEA) efficiency measures (Charnes *et al.*, 1978; Banker *et al.*, 1984), slacks-based (SBM) non-radial (Tone, 2001) and free disposal hull (FDH) measures of efficiency (Deprins *et al.*, 1984).

The results showed that the problems of wheat production in Egypt were related more with the farms' size and the efficiency of their resources than with the technology they used. Indeed, we concluded that scale issues hindered technical progress in Egyptian wheat production during the period 1990-2012. These findings leaded to suggest and prioritize political actions (land consolidation processes, agricultural extension activities, more resources in agricultural research and development) by Egyptian governorates.

Material and methods

Literature review

The terms productivity and efficiency are often used interchangeably but they are not precisely the same things (Coelli & Rao, 2005). Productivity is an absolute concept and is measured by the ratio of outputs to inputs while efficiency is a relative concept and is measured by comparing the actual ratio of outputs to inputs with the optimal ratio of outputs to inputs (Javed, 2009). Agricultural productivity growth can be defined as agricultural outputs growth at a sufficiently rapid rate to meet the growth of demand for food and raw materials arising out of steady population growth (Kaliji *et al.*, 2013). Researchers and policy makers are interested in measuring not only the levels and trends in agricultural productivity but also what sources are attributed to the agricultural productivity growth. In early studies of the measurement of productivity growth, a number of techniques were employed to construct productivity growth indices to measure the productivity growth. However, the index numbers have disadvantages because it requires data on prices and quantities as well as assumptions concerning the behavior of producers and the structure of technology. Moreover, it cannot provide what sources attributing to productivity growth which is of broad interest of researchers. These problems lead to the development of new empirical techniques known as non-parametric and parametric approaches to measure the productivity growth. The production frontier represents the maximum output attainable from each input level. Hence it reflects the current state of technology. Firms operate either on that frontier, if they are technologically efficient or beneath the frontier if they are not technically efficient. When we consider productivity comparisons through time, an additional source of productivity change, called TC, is possible. When we observe that a firm has increased its productivity from one year to the next, the improvement not from efficiency improvements alone, but may have occurred due to TC or the exploitation of scale economies or from some combination of these three factors.

Many studies on productivity in the field of agricultural production have used DEA approach, which was become popular for several reasons (Headey *et al.*, 2010): DEA is a nonparametric technique that does not require a prior specific functional form for the production frontier; DEA is capable of handling multiple outputs and multiple inputs and does not require them to be aggregated; DEA is based on linear programming techniques, and it is possible to identify the best practice for every firm; DEA provides information about the peers that can offer insights into how efficiency of the firm concerned can be improved; DEA provides a simple framework to measure efficiency change (EC) and TC for each firm in the sample along with measures of TFP growth.

In recent years several studies have been conducted on TFP based on DEA, which provides an indicator to compare productivity performance between firms and over time. Bushara & Barakat (2010) carried out a study to decompose TFP change of cotton cultivars (Barakat-90 & Barac(67)B) in the Gezira scheme, Sudan during the time period 1991-2007 into two components, TC and EC, and the latter was further divided into SEC and PEC. The study was based on the DEA program using model of Malmquist indices. The output was the cotton cultivars while the inputs were land, water, capital, material, and labor. The results indicated that TFP change was -1.3% for the period 1991 to 2007, the contribution of EC -1.6% and TC 0.30%. The main problem was the EC and this was mainly due to scale inefficiency. Barac(67)B contributed to this negative at an average annual rate -3.3%; this implying that Barac(67)B was ailing due to EC.

Bushara & Dongos (2010) conducted a study to decompose TFP index of wheat production in Sudan into two components the TC and the EC. The study was based on the DEA using model of input-oriented Malmquist index. The output was the wheat value while inputs were land, water, capital, material, and labor. The results revealed that the EC was equal to zero, implying no significant effect on the productivity of wheat crop. TC was between 0.46 and -1.42, which implies that fluctuation in wheat crop yields were attributed mainly to poor application of the full technological package.

Korkmaz (2011) carried out a study to determine the TFP changes between the years 2006 and 2010 at the state forest enterprises bound to Isparta regional forest directorate located at the Western Mediterranean region in Turkey. The Malmquist productivity index as a non-parametric approach was used in the study. Malmquist productivity index was evaluated based on the DEA. Input factors were the actual capital of forest enterprises, production costs, and amount of employees while the output factors were the total amount of production of logs, mine poles, and the value added. EC value reached its highest level in 2007-2008 with an increase of 11.5%. TC value showed increases in the first and the last periods and decreases during the other periods. PEC value obtained its maximum level in 2007-2008 but then was subject to decrease in the following years. There was no change seen in the SEC values. For the TFP changes values, besides the increase seen in the first period with a rate of 0.2%, the following periods experienced decrease. The reason for the increase in such period was due to the contribution of the TC values with a rate of 12.3%.

Chaudhary (2012) conducted a study to estimate TFP in Indian agriculture at state-level for the years 1983-1984 to 2005-2006. Changes in TFP were estimated by using the non-parametric sequential Malmquist TFP index based on DEA. The study used the index of agricultural production as the measure of output while the inputs were land, water, fertilizer, tractors, and livestock. The results indicated that the contribution of TC was greater than that of EC to overall productivity changes in all the states.

Hajian *et al*. (2013) accomplished a study to measure the technical, allocative, and economic efficiency and the TFP for the strategic agronomy products including wheat, barley, rice, cotton and sugar beet during 1995 to 2009 in Iran by Malmquist index and DEA method. The output was the production of wheat, barley, rice, cotton and sugar beet while the inputs were seed, chemical fertilizer, antipest, labor and land. The results showed that productivity for these products had generally risen in this period. Technical efficiencies were in high levels but allocative and economic efficiencies were in lower levels.

Kaliji *et al*. (2013) conducted a study to gauge TFP of wheat production and its components in three Northern provinces, Iran. The study estimated Malmquist index using DEA. The output was the production quantity of wheat while the inputs were land, seed, poison, fertilizer, labor, and machineries. The results showed that during the study period (2000-2011) TFP changes in Golestan Province was more effected by TC, while in Gilan and Mazandran provinces the TFP is more affected by EC. Changes in TFP for the whole country presented large fluctuations. These changes were due to variations in EC and TC.

Rahman & Salim (2013) estimated agriculture TFP in 17 regions of Bangladesh over the year period 1948–2008. They used the Färe–Primont index (O'Donnell, 2010, 2011) with six outputs (food grains, sugarcane, jute, potatoes, pulses and oilseeds) and seven inputs (land, labor, animal power, N, P and K fertilizers and irrigation). It was decomposed into six components, TC, technical-, scale- and mix-efficiency changes, residual scale- and residual mix-efficiency changes. Results revealed that TFP growth was due mainly to technological progress, whereas technical efficiency improvement is very small and mix efficiency declined. The conclusion was that Bangladesh agriculture experiments a technical growth but decreases in mix-efficiency change in the later years.

We did not find empirical works that estimate TFP of wheat production on the level of governorates in Egypt. Therefore, from this perspective this is a novel work. From the point of view of establishing an agricultural policy for Egypt, the contributions of this work are important because it provides recommendations for improvement.

Methodology

The nonparametric approach has been extensively applied to estimate TFP growth. Firstly, DEA models are running with linear programming methods to measure the distance from one decision unit, a province in our case, to the frontier. In a second step TFP growths are estimated through Malmquist indices. They do not require any assumptions regarding efficiency and functional form, and are therefore able to distinguish between the factors causing changes in productivity. In addition, Malmquist TFP index (DEA model) may be used to decompose the productivity change into TC and EC in the presence of panel data.

The Malmquist TFP index is introduced as a theoretical index by Caves *et al*. (1982) and popularized as an empirical index by Färe *et al*. (1994). They define the TFP index using Malmquist input and output distance functions, and thus the resulting index is known as the Malmquist TFP index (Chaudhary, 2012). The period t Malmquist productivity index is given by Eq. [1]:

$$M_o^t = \frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \quad [1]$$

i.e., they define the productivity index as the ratio of two output distance functions taking technology at time t as the reference technology. Instead of using period t's technology as the reference technology it is possible to construct output distance functions based on period (t+1)'s technology and thus another Malmquist productivity index can be laid down as Eq. [2]:

$$M_o^{t+1} = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)} \quad [2]$$

Färe *et al.* (1994) specify Malmquist productivity change index as the geometric mean of two-period indices that is [3]:

$$M_o(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \times \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)}\right]^{1/2} \quad [3]$$

Eq. [3] can be written as the product of two distinct components, TC and EC (Färe *et al*. 1994), as it is shown in Eq. [4]:

$$M_o(x^{t+1}, y^{t+1}, x^t, y^t) = \underbrace{\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}}_{\text{efficiency change}} \underbrace{\left[\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right]^{1/2}}_{\text{technical change}} \quad [4]$$

Hence the Malmquist productivity index is simply the product of the change in relative efficiency that occurred between periods t and t+1, and the change in technology that occurred between periods t and t+1. A value of Malmquist TFP index equal to one implies there has been no change in TFP across the two time periods, greater than one implies a growth in TFP and a value less than one is interpreted as deterioration in TFP. A similar interpretation applies to the two components as well.

The value of EC measures the overall change in relative efficiency, and is a measure of the distance between observed production and the maximum possible production level between the two time periods t and t+1. The component of TC, calculated as the geometric mean of two ratios, measures the shift in production technology. This ratio represents the relative change in the input technologies over the time period t and t+1 (*i.e.* change in x^t and x^{t+1}).

This approach presents some problems, such as possible infeasibility in DEA models and lack of circularity. To overcome this, Pastor & Lovell (2005) propose the Global Malmquist index:

$$M_o^G(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_o^G(x^{t+1}, y^{t+1})}{D_o^G(x^t, y^t)} \quad [5]$$

where the output distance indices are measures respect to a global benchmark technology, defined as the convex hull of the set of all period's technologies. M_o^G can be also decomposed into EC and TC:

$$M_o^G(x^{t+1}, y^{t+1}, x^t, y^t) = \underbrace{\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}}_{\text{efficiency change}} \underbrace{\left[\frac{D_o^G(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_o^t(x^t, y^t)}{D_o^G(x^t, y^t)}\right]}_{\text{technical change}} \quad [6]$$

The EC index of [4] or [6] can be decomposed into PEC and SEC, comparing the distance functions under constant and variable returns of scale (Färe *et al.*, 1994; Ray & Desli, 1997). Thus Malmquist productivity indices, either traditional (Färe *et al.*, 1994) or global (Pastor & Lovell, 2005) can be split into PEC, SEC and TC.

In this work distance functions were obtained through well-known DEA efficiency measures such as CCR model (Charnes *et al*., 1978) for constant and

BCC (Banker *et al.*, 1984) for variable returns to scale. Moreover, to gain robustness other procedures have been implemented: contemporaneous Malmquist indices (Färe *et al.*, 1994); Global Malmquist indices with SBM non-radial measures of efficiency (Tone, 2001), which provide more appropriate measures since they account of slacks (or shortages) of inputs and outputs; Global Malmquist indices with FDH (Deprins *et al.*, 1984), which ensure that only observed production possibilities are considered to obtain efficiency scores; and Färe-Primont indices (O'Donnell, 2014), which are not based on any strong assumptions about the production technology, the input/output market, firm's optimising behaviour and returns to scale, and in addition can be decomposed in a further driver of productivity change, such as the mix efficiency change that is related to economies of scope. Following Cooper et al. (2007) advise, we preferred to try different models and compare their results before drawing final conclusions, given that it is difficult to recognize the features of the wheat production frontier in Egypt. We used the R software (R Core Team, 2015) and a modified version of the nonparaeff package (Oh & Suh, 2013) to estimate Global Malmquist indices and its components.

Data

Table 1 shows the wheat production, area, and yield of the main governorates in Egypt. The wheat production increased 92.80% from 3600.71×10^3 t in 1990 to 6942.14×10^3 t in 2012. The annual average percentage growth rate of wheat production for the time period 1990-2012 was 3.35%. The wheat area increased 59.90% from 643.36×10^3 ha in 1990 to 1028.71×10^3 ha in 2012. The annual average percentage growth rate of wheat area for the time period 1990-2012 was 2.40%. Labor and machinery grew respectively 58.85% and 65.98%. Since the inputs grew less than the outputs, productivity increased, *i.e.* the wheat yield increased 20.58% from 5.60 t/ha in 1990 to 6.75 t/ha in 2012. The annual average percentage growth rate of wheat yield for the time period 1990-2012 was 1.02%.

Egypt is divided for administrative purposes into 27 governorates. Figure 1 shows the main governorates of wheat production in Egypt. The data employed for this study were obtained from the Ministry of Agriculture and Land Reclamation (MALR, 1990-2012), Egypt. The panel data composed of eleven governorates represents the main governorates of wheat production in Egypt during the time period 1990-2012. Table 2 shows the main governorates of wheat production in Egypt. During the time period 1990-2012 there was an increasing in the wheat production, area, and yield at the main governorates. The annual average percentage growth rates for the time period 1990-2012 indicate increasing in wheat production, area,

Table 1. Wheat production, area, and yield in Egypt (1990-2012)

Year	Wheat production (10^3 t)	Wheat area (103 ha)	Wheat yield (t/ha)
1990	3600.71	643.36	5.60
1991	3672.85	698.00	5.26
1992	3727.47	648.61	5.75
1993	3923.32	647.18	6.06
1994	3608.59	634.70	5.69
1995	4402.37	741.64	5.94
1996	4580.06	728.78	6.28
1997	4612.58	770.45	5.99
1998	4777.30	741.22	6.45
1999	4997.55	741.97	6.74
2000	5353.24	805.06	6.65
2001	5033.90	754.24	6.67
2002	5149.46	782.96	6.58
2003	5573.68	814.42	6.84
2004	5752.93	837.69	6.87
2005	6455.69	953.53	6.77
2006	6321.60	987.68	6.40
2007	5841.98	871.27	6.71
2008	6347.98	984.63	6.45
2009	6913.73	1043.20	6.63
2010	5775.31	979.91	5.89
2011	6673.45	999.15	6.68
2012	6942.14	1028.71	6.75
Rate[a]	3.35	2.40	1.02

[a] Annual average percentage growth rate (1990-2012). Source: MALR (1990-2012) and own elaboration.

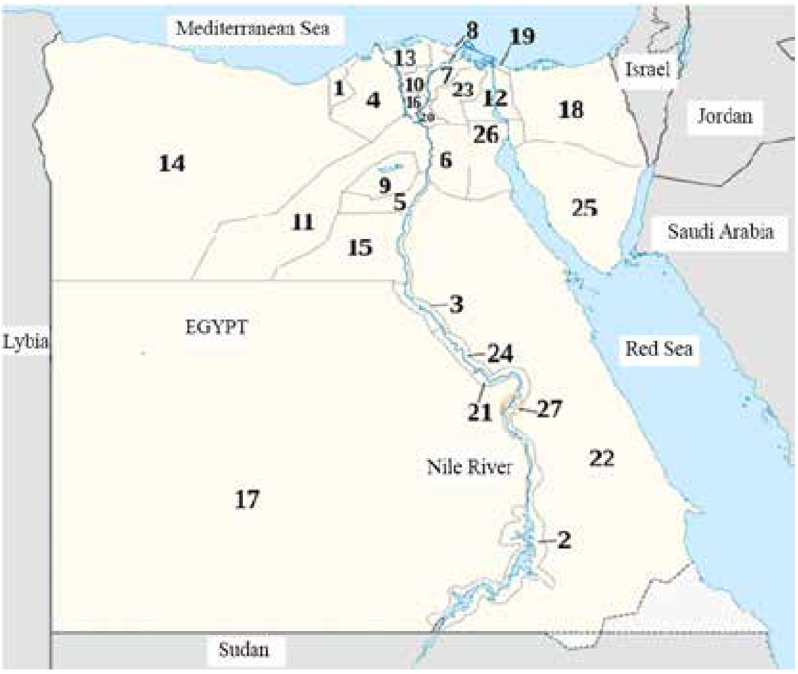

Figure 1. Main governorates of wheat production in Egypt: 3 Assuit; 4 Behairah; 5 Beni Suef; 7 Dakahlia; 9 Fayoum; 10 Gharbia; 13 Kafr Elshikh. 15 Menia; 16 Menoufia; 23 Sharkia; 24 Suhag; Sources: MAPS.com, Wikipedia, and own elaboration.

and yield of the main governorates. During the time period 1990-2012, Behairah governorate had the highest annual average percentage growth rate of wheat production (4.09%), Sharkia had the highest annual average percentage growth rate of wheat area (3.11%), and Suhag had the highest annual average percentage growth rate of wheat yield (1.44%).

The summary statistics for the variables used in the analysis are presented in Table 3. The production inputs comprised three input variables (land, labor and machinery) while there was only one output (wheat production). Wheat production was estimated in thousand tons, land in thousand hectares, and labor and machinery in thousand hours.

Results

General results

Table 4 shows a decomposition of the Global Malmquist total factor productivity change (PC) for

Table 2. Main governorates of wheat production in Egypt (1990-2012)

Governorate[1]	Wheat production[2] (10^3 t)		Wheat area[2] (10^3 ha)		Wheat yield[2] (t/ha)	
	1990	2012	1990	2012	1990	2012
Assuit [3]	291.80	537.84 (2.82)	51.07	80.18 (2.07)	5.71	6.71 (0.73)
Behairah [4]	385.80	930.94 (4.09)	75.60	135.04 (2.67)	5.10	6.89 (1.38)
Beni Suef [5]	220.00	360.26 (2.27)	36.20	52.97 (1.75)	6.08	6.80 (0.51)
Dakahlia [7]	519.00	879.14 (2.42)	87.74	127.38 (1.71)	5.92	6.90 (0.70)
Fayoum [9]	228.70	491.25 (3.54)	41.33	73.43 (2.65)	5.53	6.69 (0.87)
Gharbia [10]	266.30	436.94 (2.28)	45.74	63.43 (1.50)	5.82	6.89 (0.77)
Kafr Elshikh [13]	367.00	639.85 (2.56)	63.00	99.24 (2.09)	5.83	6.45 (0.46)
Menia [15]	328.70	618.68 (2.92)	56.49	91.84 (2.23)	5.82	6.74 (0.67)
Menoufia [16]	211.40	406.06 (3.01)	35.41	53.17 (1.87)	5.97	7.64 (1.13)
Sharkia [23]	487.31	1144.62 (3.96)	90.97	178.52 (3.11)	5.36	6.41 (0.82)
Suhag [24]	294.70	496.56 (2.40)	59.81	73.52 (0.94)	4.93	6.75 (1.44)
Total	3600.71	6942.14 (3.03)	643.36	1028.71 (2.16)	62.06	74.87 (0.86)

[1]Figures in square brackets indicate numbers on Figure 1. [2]Figures in parentheses are annual average percentage growth rates (1990-2012). Sources: MALR (1990-2012) and own elaboration.

Table 3. Summary statistics for the variables (1990-2012)

Variables	Units	Maximum	Minimum	Mean	Std. Dev.
Output (y_{it})	(10^3 t)	1144.62	195.00	474.46	192.47
Land (x_{1it})	(10^3 ha)	178.52	20.92	74.46	29.22
Labor (x_{2it})	(10^3 h)	110466.20	13191.72	46973.43	18421.22
Machinery (x_{3it})	(10^3 h)	12321.23	1045.38	4325.39	1799.44

Source: Own elaboration from the sample data (MALR, 1990-2012).

wheat production in Egypt during the time period 1990-2012 into two components, TC and EC. Furthermore, EC decomposes into PEC and SEC.

PC of wheat production in Egypt has grown up with an average annual rate of 0.87%. The accumulative PC during the time period 1990-2012 was slightly over 21%, but this growth mainly occurred in the first half, and more specifically between 1995 and 1999. The accumulative PC rise was 19.55% by 1999, almost the same figure that in 2012. Thus TFP barely rose during the 2000s.

Table 4. Global Malmquist Indices by year and its components

Year	PEC	SEC	EC	TC	PC
1990-1991	0.9854	0.9810	0.9667	0.9697	0.9374
1991-1992	1.0173	1.0130	1.0305	1.0599	1.0923
1992-1993	0.9681	1.0036	0.9716	1.0744	1.0439
1993-1994	1.0387	0.9780	1.0159	0.9356	0.9504
1994-1995	0.9818	1.0103	0.9919	1.0455	1.0371
1995-1996	0.9621	0.9762	0.9392	1.1216	1.0534
1996-1997	1.0490	0.9771	1.0250	0.9394	0.9629
1997-1998	1.0217	1.0281	1.0504	1.0241	1.0757
1998-1999	1.0029	1.0282	1.0312	1.0085	1.0399
1999-2000	0.9783	0.9943	0.9728	1.0171	0.9894
2000-2001	1.0276	1.0067	1.0344	0.9726	1.0061
2001-2002	0.9583	1.0050	0.9631	1.0164	0.9788
2002-2003	1.0245	0.9782	1.0022	1.0501	1.0524
2003-2004	1.0115	1.0328	1.0447	0.9574	1.0002
2004-2005	0.9984	0.9841	0.9825	1.0003	0.9828
2005-2006	0.9650	1.0061	0.9709	0.9811	0.9526
2006-2007	1.0232	0.9953	1.0185	1.0296	1.0486
2007-2008	0.9531	0.9623	0.9172	1.0531	0.9659
2008-2009	1.0561	1.0025	1.0587	0.9675	1.0243
2009-2010	0.9982	1.0234	1.0216	0.8614	0.8800
2010-2011	1.0043	0.9772	0.9814	1.1731	1.1512
2011-2012	1.0020	0.9845	0.9865	1.0171	1.0034
Average annual rate	1.0008	0.9974	0.9983	1.0105	1.0087
Accumulative 1990-2012	1.0188	0.9451	0.9629	1.2573	1.2107

Source: Own elaboration. PEC (Pure Efficiency Change), SEC (Scale Efficiency Change), EC (Efficiency Change), TC (Technical Change), PC (Global Malmquist Total Factor Productivity Change).

The decomposition of PC shows that the contribution of TC component is more important than the EC component. In fact, TC rose while EC presented a little decline. The average annual rate of TC was 1.05%, with an accumulative growth of 25.73% in the last period year. Here again, it seems that the bulk of this advance occurred during the first half, since the accumulative TC reached almost 20% by 2000. In contrast, the accumulative EC was 0.963 in 2012 which indicates a regression of 3.7% respect to 1990 in terms of efficiency.

The decomposition of the latter index shows that pure efficiency faintly increases but scale efficiency suffers a decrease. PEC increased at an average annual rate of 0.08%, with an accumulative progress of 1.88%. On the other hand, SEC decreased and took a value in 2012 94.51% lesser than in 1990. Therefore, the main problem of wheat production in Egypt is scale efficiency. This means that wheat production within Governorates does not work with its optimal size.

Productivity change by governorates

Table 5 presents accumulative (or 1990-2012) Global PC Malmquist indices of wheat production in the main governorates and their decomposition. Figure 2 shows the evolution of accumulative Global PC Malmquist indices (jointly with TC, PEC and SEC) by governorate. The highest increase in PC occurred at Suhag governorate by 39.40% rate, followed by Behairah (34.89%), Menoufia (27.69%), and Assuit and Fayoum (21.71%). The remainder governorates are below the PC mean, with Kafr Elshikh obtaining the minimum (11.33%).

TC governorate indices point to low spatial variability of TC. Indeed, 9 out of 11 indices range between 25-30%, being the exception Assuit, 19.09% and Suhag, 15.27% (the lowest). These figures highlight that agriculture modernization has been a rather widespread and ubiquitous phenomenon in Egypt. On the contrary, EC indices were very different among governorates and followed a rather similar pattern that PC. That is governorates with advances in EC, such as Suhag

Table 5. Global Malmquist indices 1990-2012 by governorate

	PEC	SEC	EC	TC	PC
Assuit	1.0394	0.9630	1.0009	1.1909	1.1920
Behairah	1.1404	0.9181	1.0470	1.2884	1.3489
Beni Suef	1.0000	0.8905	0.8905	1.2684	1.1295
Dakahlia	0.9969	0.9198	0.9170	1.2712	1.1657
Fayoum	1.0189	0.9526	0.9705	1.2541	1.2171
Gharbia	0.9284	0.9715	0.9019	1.2948	1.1678
Kafr Elshikh	0.9333	0.9436	0.8806	1.2641	1.1133
Menia	0.9850	0.9287	0.9148	1.2768	1.1679
Menoufia	1.0000	1.0000	1.0000	1.2769	1.2769
Sharkia	1.0000	0.9041	0.9041	1.3009	1.1762
Suhag	1.1951	1.0119	1.2093	1.1527	1.3940

Source: Own elaboration. PEC (Pure Efficiency Change), SEC (Scale Efficiency Change), EC (Efficiency Change), TC (Technical Change), PC (Global Malmquist Total Factor Productivity Change).

(20.93%) and Behairah (4.70%), presented also the highest increases in PC; meanwhile governorates with the highest regress in EC, *i.e.* Beni Suef (89.05%) and Kafr Elshikh (88.06%), were the same with the lowest growths in PC. Thus the highest growths of productivity occurred when both factors, efficiency and technical growth, came together. When the efficiency diminished, productivity growth was lower than technical growth, as was the case of seven governorates, Beni Suef, Dakahlia, Fayoum, Gharbia, Kafr Elshikh, Menia and Sharkia. This can also be appreciated in Figure 2 by looking at TC lines that appear above PC lines in these latter governorates.

The decomposition of EC shows that there was a common regress in scale efficiency, this may be due to the farm size average in Egypt is small. Apart from Suhag, with a slight scale efficiency increase, 1.19%, and Menoufia, 0%, SEC indices decreased. In Figure 2 SEC lines remain below or equal to 1 in most cases. At the end of the period the major decline in scale efficiency can be observed (Table 5) in Beni Suef (89.05%) followed by Sharkia (90.41%), Behairah (91.81%), and Dakahlia (91.98%).

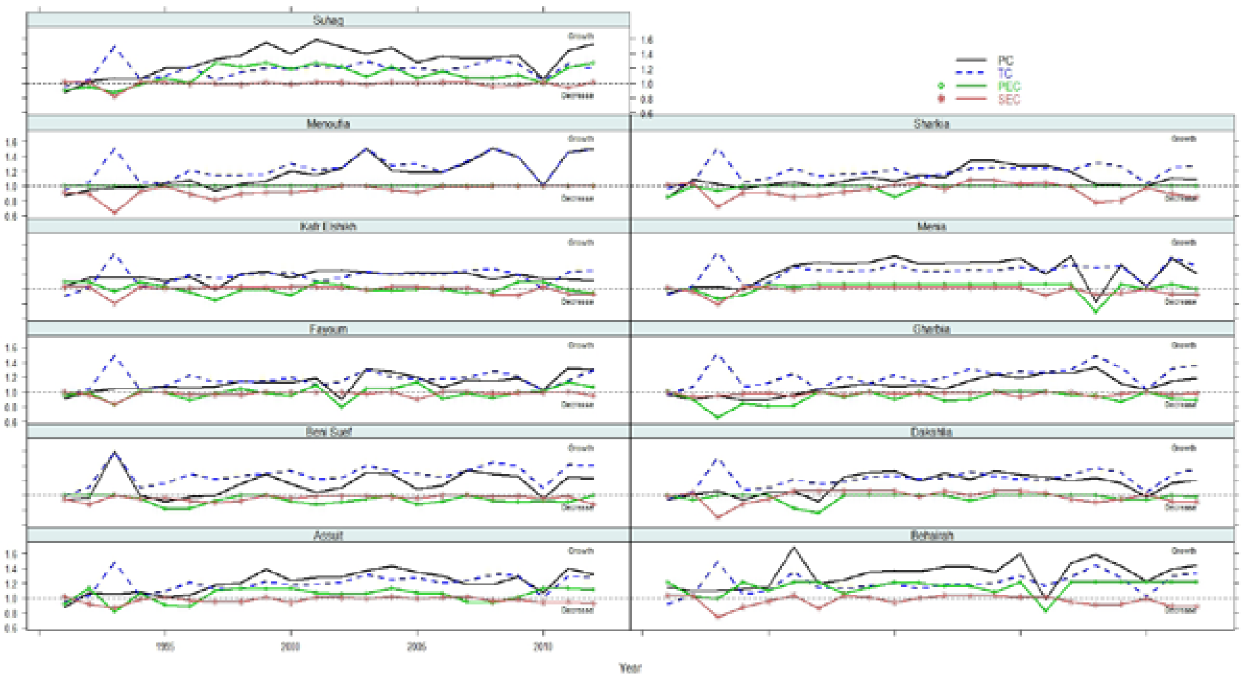

Figure 2. Evolution of accumulative PC (Global Malmquist total factor productivity change), TC (technical change), PEC (pure efficiency change) and SEC (scale efficiency change) by governorate.

Table 6. Other alternative indices

	Malmquist[1]	Global Malmquist		Färe-Primont[4]
		SBM[2]	FDH[3]	
Residual mix efficiency change				0.9999
Efficiency change	1.0188[5]	1.0383[5]	1.0039	1.0148
Scale efficiency change	0.9451	0.9299		0.9437
Technical change	1.2704	1.3214	1.1781	1.2670
Total factor productivity change	1.2232	1.2758	1.1826	1.2131

Source: Own elaboration. [1]Färe *et al.* (1994). [2]Tone (2001) and Pastor & Lovell (2005). SBM: Slacks Based Model. [3]Deprins *et al.* (2001) and Pastor & Lovell (2005). FDH: Free Disposal Hull. [4]: DPIN 3.0 software (O'Donnell, 2011). [5]pure efficiency change.

Some governorates, such as Behairah and Assuit increased enough in PEC so as to compensate scale efficiency decrease. Behairah and Assuit PEC values were frequently above 1 (Fig. 2). Some other, Dakahlia, Gharbia, Kafr Elshikh and Menia, drop in both, which in turn mitigates advances in TC. Suhag is the unique governorate that succeeds in growing all indices.

Robustness

Table 6 presents other alternative TFP indices and their decomposition. We can observe that previous TFP change (21.07%) is rather close to traditional Malmquist (22.32%) and Färe-Primont (21.31%) indices, and something further from Global Malmquist-FDH (18.26%) and Global Malmquist-SBM (27.58%). However similar pattern decomposition arises: (1) TC component is by far more important than EC component; (2) scale efficiency problems are shown whatever the method used. Färe-Primont decomposition informs that mix EC lacks of importance in Egyptian wheat production.

Discussion

Wheat is one of the most important agricultural crops in Egypt. From 1990 to 2012 wheat production increased 92.80% but the main inputs grew in smaller proportions, between 58 to 66%. As a consequence partial and total productivity also experienced increases. TFP growth of wheat production in Egypt has grown up 21%. This advance mainly occurred in the first half, and more specifically between 1995 and 1999. During this decade a series of reforms were implemented, *i.e.* elimination of area restrictions, a floor price instead of a procurement price determined by the government and a more liberal framework for the trading of grain and flour (Kherallah *et al.*, 2000). Thus the expansion of wheat production and its higher productivity growth in this period are probably the consequences of the Agricultural Reform Program initiated in 1987 and aimed at improving food supply and increasing farm income.

The decomposition of productivity growth shows that the contribution of TC component is more important than the EC component. In fact, TC rises 25.7% while EC presents a little decline, 3.7%. The reforms of production and trade mentioned above undoubtedly provided a boost to the modernization of agriculture, that is reflected in the increase in TC. But despite this, continued to exist a series of structural deficiencies in transport, storage and access to information (Kherallah *et al.*, 2000), that explain the decline in the EC. The decomposition of EC indicates that the main problem of wheat production in Egypt is scale efficiency that worsens by 5.5%. This may be due to the small farm size average in Egypt. Bushara & Barakat (2010) also found how a regress in scale efficiency leads to a poor EC for cotton in Sudan.

The findings in some other recent studies reveal problems with both TC and EC. For example, Bushara & Dongos (2010) study of wheat production in Sudan concluded the main cause of TFP decline over the period 1980-2002 was the scarce use of appropriate technology; Kaliji *et al.* (2013) found that during the period 2001-2010 TFP changes in Iranian wheat production were more affected by TC in some provinces while in others was due to EC. This work is more in line with the results of Chaudhary (2012) that concluded that the contribution of TC was greater than that of EC to overall productivity changes in Indian agriculture. In a global context using FAO country data from 1970 to 2001, Headey *et al.* (2010) showed also that agricultural TC was more important than EC for Middle East and North African countries. But with similar data, Coelli & Rao (2005) study over the period 1980-2000 reported an annual TFP growth for the Egyptian agriculture of 1.2% due exclusively to TC, which is consistent with our results. In addition Coelli & Rao (2005) compared the decomposition of TFP with other surrounding countries, *i.e.* in Algeria, Tunisia and Iran the contribution of EC to TFP change takes a more relevant role, whereas Iraq and Syria exhibit a decline in EC.

TC by governorate confirms that the agriculture modernization process has been extended throughout Egypt, as is appreciated looking at the narrow variability of these indices, *i.e.* the bulk of them within the range 25-30%. This contrasts with the wide interval of the TFP change, 11-40%, and points out to other drivers, such as scale efficiency, as the factor that deteriorate productivity. Indeed the highest growth of productivity occurred when all indices increase together, as was the case of Suhag. A similar result was obtained by Rahman & Salim (2013), who reported that agricultural productivity in Bangladesh is led by Chittagong region that obtains improvements in all components of the TFP index.

On the other hand, scale efficiency decreased in 9 out of 11 governorates; two of them, Behairah & Assuit, increased enough in PEC so as to compensate scale efficiency decrease; but in the remaining seven governorates the efficiency indices diminished, and as a consequence total productivity growth was lower than technical growth. This is in consonance with Chaudhary (2012) that highlighted how the improvements in efficiency were observed to be low for most of the Indian states and efficiency decline was observed in several states implying huge potential increase in production even with the existing technology. Thus the production and productivity of wheat will rise in Beni Suef, Dakahlia, Fayoum, Gharbia, Kafr Elshikh, Menia and Sharkia if some political actions are taken in order to improve scale efficiencies, such as applying the land consolidation system.

From this work we suggest the following recommendations. Some measures to mitigate scale efficiency problems would include the increase of wheat production area through the reclaimed agricultural areas, as well as implementing land consolidation processes that would increase farm size and reduce production costs. PEC could be boosted by organizing agricultural extension activities that would improve the training of labor. Especially important are the skills of cultivation and irrigation techniques, as was stressed by Croppenstedt (2005). He found that support to improving irrigation practices would increase wheat output in Egypt. Our results identify which governorates need to be prioritized for implementing these actions.

Given that TC has maintained stagnant in last decade it would be advisable to put more resources in agricultural research and development. This would permit to take advantage of genetic improvements, which should enable the introduction of new wheat varieties with higher productivity.

The main limitation of this work is the lack of information on other variables to connect with the results. Future works need to carry out on the farm level through the use of surveys, in order to investigate the socio-economic factors such as age, education, sex, composition of labor, quality of land, property of land, etc. that affect the efficiency and productivity of wheat production in the different farms and governorates.

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