Measurement of the total factor productivity and its determinants: the case of the wheat sector in Tunisia[1]

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Jel codes: Q12, C23

Abstract

The main objectives of the current study are to quantify the Total Factor Productivity (TFP) growth of durum wheat sector in Tunisia and to identify its main determinants. The Malmquist index approach was applied for the calculation of TFP growth using one output (annual production) and four inputs (land, seeds, nitrogen, and phosphate fertilizers) for the period 1980-2012. Variables used to identify the main determinants of the TFP growth include expenditures on agricultural research and extension, share of irrigated durum wheat area with respect to its total cultivated area, drought index, and infrastructure development in rural areas. Almon distributed lag model is used to assess the impact of the research expenditures variable. Empirical results show that TFP grew by 1.9% per year, on average, during the study period 1980-2012. This average growth rate was highly variable: 5.9% for the period 1980-1991; 2.2% for the period 1992-2002; and 2.07% for the period 2003-2012. TFP growth was mainly generated by technical change during the first period (1980-1991) and by technical efficiency change during the last period 2003-2012. Results also show that changes in the TFP growth have been mainly related to the R&D expenditure lags, and drought.

Keywords: *total factor productivity, Malmquist index, Almon distributed lag model, wheat, Tunisia.*

Résumé

Les principaux objectifs du présent travail sont la mesure de l'indice de productivité globale des facteurs (PGF) et ses composantes (efficacité technique et progrès technique) pour la culture du blé dur en Tunisie, et l'identification des déterminants majeurs de cet indice. Pour ce faire, l'approche Malmquist avec un output (production nationale) et quatre inputs (superficie, semences, ammonitre, engrais phosphatés) a été utilisée pour l'estimation du PGF sur la période 1980 - 2012. Les résultats montrent que les taux annuels moyens de croissance sont de l'ordre de 1,9 % pour la PGF, 0,7 % pour l'efficacité technique et de 1,2 % pour le progrès technique. Le taux de croissance de la PGF varie selon les périodes. Il est de l'ordre de 5,9% pendant 1980-1991, de -2,2% entre 1992 et 2002 et 2,07% durant 2003-2012. Les résultats de l'estimation économétrique moyennant le modèle à retard échelonné « Almon model » ont montré que la PGF du secteur blé en Tunisie est affectée principalement par l'investissement en recherche et développement (R&D) retardé et par les différentes périodes de sécheresse.

Mots-clés: productivité globale des facteurs, approche Malmquist, modèle à retard échelonné, blé, Tunisie.

1. Introduction

Cereals are among the main crops in Tunisia. The sector plays an undeniable social and economic role. It provides major staple food commodities for most communities and households. Moreover, cereal cultivations occupy a considerable share of the arable land, and the majority of cereal growers are resource-poor smallholders. Currently, it covers about 1.5 million hectares or one third of the total arable land available in Tunisia. It also generates 13% of the total agricultural added value (MA, 2012). These cereal areas cover a wide range of soil types and mainly grown under rainfed conditions. However, over the past few years, the use of supplemental irrigation has become widespread in this country.

Among cereals, wheat is the most important in Tunisia in terms of both production and consumption. It occupies more than 50% of the cereals area and contributes with more than 40% to the cereal production (MA, 2012). Wheat is grown in different locations in Tunisia; but the humid and semi-arid Northern regions are particularly the most specialized in this crop. Average wheat yields are about 1.4 tons/ha, which is considered low compared to a world average of about 3.6 tons/ha (Laajimi *et al.*, 2013). According to the same author, this low yield is explained by many production and environmental factors; including low and uncertain rainfall with frequent droughts, common diseases such as septoria, root rots and insects, limited availability of inputs and high production costs, and the limited adoption of improved production packages.

Tunisia is being faced to severe challenges in increasing wheat production in order to enhance the self-sufficiency ratio for wheat production. During the last three decades, durum[2] wheat import in Tunisia has increased by 5.1% (FAO, 2014). Hence, the wheat sector is characterized by a large deficit between domestic needs and productions. This gap keeps growing due to many factors including urbanization and higher living standards, migration from rural to urban area, population growth, limited land and water resources to extend the wheat areas, and the low productivity increasing rates. This

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[1] This paper is an improved version of a preliminary paper presented at the Economic Research Forum in 2015.

[2] Durum wheat is the most important wheat variety in Tunisia in terms of production and consumption. On average, more than 85% of wheat production is durum wheat.

growing gap has considerably led to increased reliance on imports. During the last decades, almost the half of wheat consumption has generally been imported every year. With the increase of wheat prices on the international market, the cost of wheat importation is becoming more expensive, which, in turn, increases the volume of government subsidies to the sector especially during the so-called international "food crisis" period (Laajimi *et al*., 2013). Thus, enhancing wheat productivity growth in Tunisia became a necessity for increasing the self-sufficiency ratio of wheat (Chebil *et al*., 2014).

Productivity is a crucial aspect of economic performance; it is affecting both the producers' and consumers' welfare. However, gains in output stemming from improvements in productivity are mostly important for farmers considering the opportunities to increase rural income.

Many existing studies have been dealing with TFP calculation of single crops using time series data (Kumar and Rosegrant, 1994; Ahmad and Ahmad, 1998; Mittal and Lal, 2001; Chieko *et al*., 2003; Liu and Li, 2010). In Tunisia, many studies have been interested in quantifying the TFP growth of the agriculture sector as a whole (Lachaal *et al*., 2005; Dhehibi *et al*., 2014). However, at our knowledge, there are no studies which were interested in evaluating TFP growth of single strategic crops in Tunisia, as wheat, olive oil, dates, etc. As productivity is expected to be different across diverse subsectors, and considering the social and economic importance of the wheat sub-sector in Tunisia, we believe that an investigation of TFP growth in the wheat sector will be highly valuable for impact assessment, policy making and development planning. Based on this, the objectives of our paper will be to calculate and decompose (into scale efficiency, pure technical efficiency and technological change) the TFP growth of the wheat sector (including soft and durum wheat) in Tunisia between 1980 and 2012; and to assess the role of research and development investments on the productivity gains of this sector.

The rest of this paper is organized as follows: the second section discusses data and the Malmquist TFP index methodology; the third section presents our empirical results and discussion, and the final section draws the conclusions.

2. Methodology and data

2.1. Approaches to TFP measurements

TFP change is defined as the ratio of change in weighted combination of output to change in weighted combination of input. It is a variable which accounts for effects in total output not caused by inputs. Technical change (TC) and efficiency change (EC) are regarded as two of the biggest sub-sections of TFP. TC is defined as an upward shift of the production function frontier. It corresponds to a shift of the maximum attainable (potential) output for given constant input levels over time. Efficiency improvement is however defined as the decrease in the distance between current and potential outputs, without considering changing the production technology.

In general, the TFP measurement methods that have been used in empirical productivity studies can be grouped into two main approaches: parametric and nonparametric methods. The nonparametric method does not impose a specific functional form, whereas the parametric method imposes a functional form and employs econometric techniques in estimating a production function, a cost function or a profit function. For a more detailed discussion and strengths and weaknesses of each approach, see Grosskopf (1993) and Coelli *et al.* (2005).

For the purpose of this study, the measure of TFP is nonparametric (output oriented) Malmquist index as explained in Cave *et al*. (1982), popularized by Fare *et al*. (1994). The main advantage of Malmquist approach does not require prices, does not impose a specific functional form, and is suitable to decompose change in factor productivity on TC component and EC component (pure and scale) .

2.2. Malmquist TFP index

The Malmquist index measures the TFP change between two data points by calculating the ratio of the distance of each data point relative to a common technological frontier. The Malmquist TFP index was first introduced by Caves *et al*. (1982). They defined an output-based productivity index relative to a single technology t as:

$$M^t = \frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \tag{1}$$

And for (t+1) as:

$$M^{t+1} = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)} \tag{2}$$

(Following Färe et al. (1994), the Malmquist index as the geometric mean of the two-period *t* and *t + 1* is given by:

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

Färe *et al.* (1994) has suggested using simple arithmetic manipulation, the equation (3) can be rewritten as:

$$M_o(x^{(t+1)}, y^{t+1}, x^t, y^t) = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}\left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}} \tag{4}$$

Where Efficiency change = $\dfrac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}$ (5)

$$\text{Technical change} = \left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})} \right) \left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)} \right) \right] \quad (6)$$

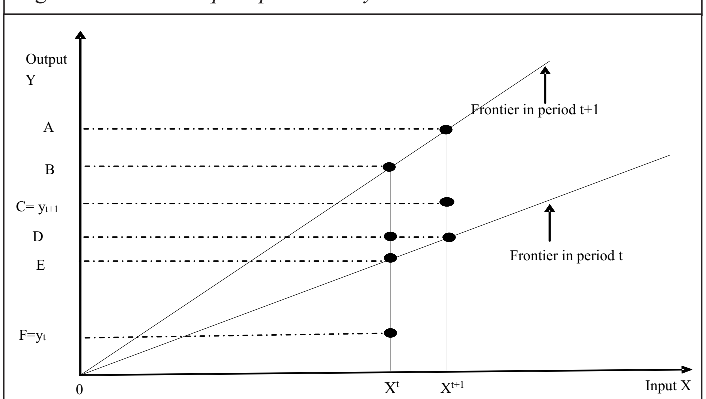
Hence the Malmquist productivity index is simply the product of the change in relative efficiency that occurred between period *t* and *t+1*, and the change in technology that occurred between period *t* and *t+1*.

This decomposition is illustrated in Figure 1 where we have depicted a CRS technology involving a single input and a single output. In terms of distances along the y axis, the index (6) becomes:

$$M_o(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{OC/OA}{OF/OE} \left[\left(\frac{OC/OD}{OC/OA} \right) \left(\frac{OF/OE}{OF/OB} \right) \right]^{\frac{1}{2}} \quad (7)$$

The ratios inside and outside the square bracket measure the TC and EC, respectively. Malmquist indexes greater than one indicate growth in productivity. Malmquist indexes less than one indicate decline in productivity.

Figure 1. *The Malmquist productivity index*.



2.3. Determinants of TFP

Based on the empirical studies, the explanatory variables are: expenditure on agricultural research and extension, percentage of irrigated land with respect to total cultivated land of wheat (%), drought (dummy variable derived from Standard Precipitation Index SPI[3]); infrastructure (Rural road length per 1000 Km^2 of agricultural land). Their expected signs are indicated in parenthesis. The econometric model is given by:

$$TFP = f(R\ \&\ D, IF, IR, W) \quad (12)$$

Where:
TFP: total factor productivity index
R&D (+): real public agricultural and extension expenditures
IF (+): infrastructure (rural roads)
IR (+): irrigation (share of irrigated durum wheat area with respect to its total cultivated area)
D1 (-) and D2 (+): weather factor (dummy variables capturing the drought (D1): SPI <-1 and good years (D2): SPI>1). Normal years (-1<SPI<1) are considered as reference variable.

Concerning the R&D variable, we consider that there are long lags between R&D expenditures and agricultural productivity. In order to properly include such variable in the model, Almon distributed lag model (polynomial distributed lag PDL) is used for this variable. All quantitative variables used in the model are in natural logarithms.

Assuming a regression that is a log-linear form of the equation (12) with some lag, the empirical model employed is:

$$\ln TFP_t = \beta_0 + \beta_1 \ln IR_1 + \beta_2 \ln IF_{t-1} + \beta_2 \ln TFP_{t-1} + \beta_4 D1 + D2 + \sum_{j=0}^{L} \alpha_j R\&D_{t-j} + \varepsilon_t \quad (13)$$

Where:

ε_t = random error term

$$\alpha_j = \alpha_0 + \alpha_1 J + \alpha_2 J^2 \qquad j = 0,1,..., L \quad (14)$$

The Almon method implies that it is only necessary to estimate three parameters (i.e., a_0, a_1, and a_2). The respective parameters of the lag distribution (αj) can be derived from these estimates using equation 13.

2.4. Data sources and variables construction

To implement the above specified models, an annual time series from 1980 to 2012 was used for durum and soft wheat using two crops in the same subsector to construct frontier. Hence, this approach was used for the US Food and Kindred Products Industry (Fousekis, 2003).

Disaggregated data of output and inputs for the two types of wheat was used for the empirical analysis. Wheat production (in tons) for each crop is used as output. Four other inputs were considered (land (in ha), seeds (in tons), nitrogen fertilizers (ammonium nitrate in tons), phosphate fertilizers (superphosphate 45% in tons)) and included in the estimation of Malmquist TFP index. Land refers to the cultivated areas for each year. Seeds refer to the amount of certified seeds and the fertilizers input refer to the quantity of applied nitrogen and phosphate**.** All of this data has been collected from national statistical sources, including the Ministry of Agriculture. Since durum wheat represents more than 85% of wheat production, our average weighted TFP as well as the results of the econometric regression will be particularly relevant and interpreted in relation to this subsector.

The summary statistics of the data used for durum wheat

[3] See Khan *et al.* (2008) for SPI calculation.

in the modeling is presented in Table 1. This table indicates large variations in the output as well as the input variables across time.

Table 1: *Summary statistics for variables in Malmquist index analysis.*

Variable	Units	Min	Max	Mean	St. deviation
Durum wheat production	Tons	167100	1705600	982082	399584
Cultivated land	Ha	596300	1109000	783056	108974
Certified seeds	Tons	77000	275000	128318	50647
Nitrogen fertilizers	Tons	27128	126526	77903	29603
Phosphate fertilizers	Tons	29149	125154	5539	15710

Explanatory variables, used as determinants of the TFP growth, have been collected from different sources. The amount of annual expenditures on agricultural research and extension (R&D) and the annual share of irrigated durum wheat area with respect to its total cultivated area have been collected from yearly statistic books of the Ministry of Agriculture. Rainfall data, which have been used to calculate the drought index, was obtained from the 'National Climate Institute of Tunisia'; and finally, rural road density (expressed in Km/Km^2) was collected from the database of the International Road Federation. All the variables which were expressed in current Tunisian National Dinar (TND) have been converted to constant values using the year 1980 as base year.

3. Empirical results

3.1. Malmquist TPF index and its decomposition

The calculation of the Malmquist TFP index for durum wheat sector in Tunisia was done using the DEAP 2.1 computer program written by Coelli (1996). Results are reported in Table 2. The calculation was done for the entire sample period and for different sub-periods 1980-1991, 1992-2002, and 2003-2012. The empirical results show that TFP grew with 1.9% per year, on average, during the study period 1980-2012. The contribution of TC and EC to this growth during the whole period was 0.7% and 1.2%, respectively. The average growth rate of TFP was highly variable: 5.9% for the period 1980-1991; -2.2% for the period 1992-2002; and 2.07% for the period 2003-2012. TFP growth was mainly generated from TC during the first period (1980-1991) and from technical EC during the last period 2003-2012.

Even though we cannot establish a direct link of causality, it is worth mentioning that the 70s and 80s correspond to periods in which Tunisia invested in research, development, and promotion of new high yielding varieties, intensification of the mechanisation, and the use of chemical fertilizers. The TFP growth observed in the period 1980-1991 could be a normal result of these investments. Moreover, the period 1997-2000 corresponds to a period where several droughts events happened in Tunisia, which may affect negatively the TFP growth of the period 1992-2002. During the previous decade, Tunisian investments in R&D for the wheat sector have been mainly focusing on the promotion of the good use of the available technologies through enhanced agronomic practices, including crop rotations, irrigation and fertilizers scheduling, etc. that period also corresponds to the elimination of farms subsidies on production factors. Many studies showed that the elimination of subsidies improves technical efficiency of crops production (Lachaal, 1994, Fulginiti and Perrin, 1997). Our results also revealed that there was no change in scale efficiency during the 1980-2012 study period. The score of scale efficiency was found to be constant all over this period.

Table 2. *Annual average changes in TFP and its components (%).*

Period	Efficiency change	Technical change	TFP
1980-1991	0	5.92	5.92
1992-2002	0	-2.2	-2.2
2003-2012	2.1	-0.03	2.07
Average 1980-2012	0.7	1.2	1.9

3.2. Sources of TFP growth

After calculating the productivity index and its components, we examined a set of potential explicative factors of the TFP, through the econometric regression described in section 2.3. Equation (13) was estimated using the E-views (version 5) software package. Results of the model estimation are presented in Table 3.

Table 3. *Estimation results of TFP determinants*

Variables	Coefficient	*T*-value
Constant	-1.612	-0.399
IR	0.047	0.267
IF(-1)	0.066	0.425
TFP(-1)	-0.297	-2.964*
Dummy1	-0.989	-5.935*
Dummy2	0.654	3.197*
PDL01	-0.102	-1.045
PDL02	-0.100	-2.783*
PDL03	0.056	2.408*
Lag coefficients of R&D		
0	0.708	3.579*
1	0.325	2.928*
2	0.054	0.572
3	-0.102	-1.045
4	-0.147	-1.786*
5	-0.078	-0.944
6	0.102	0.598
Sum of lags	0.863	1.870*
R^2	0.815	
Adjusted R^2	0.733	
F-statistic	9.992* (p=0.0003)	
Breuch-Godfrey LM (1)	2.385 (p=0.242)	
Breuch-Godfrey LM (2)	2.833 (p=0.122	
Jarque-Bera (JBN) test	1.211 (p=0.545	
White test	15.932 (p=0.317	

All of the estimated coefficients have a plausible sign. The R^2 has a quite high value (0.78), which indicates that 78% of the variation in TFP is explained by the regressed variables. F-statistics also shows that the estimated model is statistically significant. The residual diagnostic tests of serial correlation (Breuch-Godfrey LM), normality (Jarque-Bera JBN), and heteroscedasticity (White) are satisfactory.

Results indicate that the change in the TFP was mainly due to the R&D expenditure lags, and to the drought periods which the country experienced during the study period. The coefficient associated with R&D variable is positive and statistically significant at 5%. Expenditures for public agronomic research appear to be the major factor which is positively influencing the wheat sector productivity in Tunisia. This positive and significant impact of public research on TFP is actually consistent with other theoretical and empirical findings from the literature (Ruttan, 2002, Thirtle *et al*., 2003, Ali, 2005). Therefore, the significant coefficient of the current expenditures and some lag on R&D could be explained by the extension expenditures as well as by the fast track wheat variety development strategy which allowed to quickly releasing varieties in less than two seasons.

Moreover, as expected, the dummy variable representing the drought index was found to be negatively affecting the wheat TFP. Its coefficient is also statistically significant at the 5% level. This result stresses the dependency of wheat sector performance on the variable climate conditions in Tunisia. Climate variability is mainly effecting the wheat production in the North of the country where the share of irrigated wheat is lower.

The infrastructure coefficients was found to be positively, but not significantly, correlated to the wheat TFP. The variable representing the share of irrigated wheat was also positive but not significant. The possible explanation of this latter result is that this share is in most cases not exceeding 7.6%, which means that the production from irrigated wheat is not significant, compared to the overall wheat production in the country. The lagged dependent variable is negative and significant at 5%, implying that TFP decline after an important increase of TFP in previous period.

4. Conclusion and policy implications

This paper presented an empirical investigation of the Tunisian wheat sector TFP and its determinants in Tunisia. Both Malmquist index calculation and econometric regression were applied to annual data of the period 1980 to 2012. Results show that the TFP grew with 1.9% per year, in average, during the study period 1980-2012. This average growth rate was highly variable: 5.9% for the period 1980-1991; -2.2% for the period 1992-2002; and 2.07% for the, period 2003-2012. TFP growth was mainly generated from technical change during the first period (1980-1991) and from technical efficiency change during the last period 2003-2012. Results also show that changes in the TFP have been mainly due to the R&D expenditure lags, and drought. The dummy variable representing the drought period has a negative impact on TFP meaning that decreasing productivity during severe drought periods is a major problem of the wheat sector. Based on this specific result, further efforts can be recommended to develop new heat and drought tolerant wheat varieties in Tunisia, and encourage their adoption by farmers. It is actually worth mentioning that Tunisia has been mainly focusing on developing high yielding varieties. With climate change and the expected extreme weather events, more efforts have to be undertaken in order to ensure the genetic performances of the current cultivated wheat varieties in the country. Also, an integrated crop management strategy allowing for enhanced productivity and helping to reduce yield fluctuation over years is highly needed, especially in the current context of climate change. The government should consider policy initiatives for technology generation, seed market regulation, credit access and enhancement of the extension and training services. These policy initiatives are crucial for increasing the adoption of new technological packages especially by small farmers.

Finally, while this study constitutes a first attempt to analyse wheat TFP growth, disaggregated analysis including several regions could be considered for further future researches; and may provide accurate results about comparative regional performances. In this case, panel data model would be highly recommended.

Acknowledgements

The authors are most grateful to the “Economic Research Forum” (ERF) financial and intellectual support. Authors are also grateful to Dr. Randall Filer for his valuable comments that helped to widely improve the paper.

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Appendix: Linear programming problems of Malmquist TFP index

To construct the Malmquist TFP index four distance functions are to be calculated. This requires the solving of following four LP problems.

$$[D_o^{t+1}(y_{t+1},x_{t+1})]^{-1} = \max_{\phi,\lambda} \phi, \quad \text{s.t} \quad -\phi y_{i,t+1} + Y_{t+1}\lambda \geq 0, \quad x_{i,t+1} - X_{t+1}\lambda \geq 0, \quad \lambda \geq 0. \qquad \text{LP1} \qquad (8)$$

$$[D_o^{t}(y_t, x_t)]^{-1} = \max_{\phi,\lambda} \phi, \quad \text{s.t} \quad -\phi y_{it} + Y_t\lambda \geq 0, \quad x_{it} - X_t\lambda \geq 0, \quad \lambda \geq 0. \qquad \text{LP2} \qquad (9)$$

$$[D_o^{t+1}(y_t, x_t)]^{-1} = \max_{\phi,\lambda} \phi, \quad \text{s.t} \quad -\phi y_{it} + Y_t\lambda \geq 0, \quad x_{it} - X_{t+1}\lambda \geq 0, \quad \lambda \geq 0. \qquad \text{LP3} \qquad (10)$$

$$[D_o^{t}(y_{t+1},x_{t+1})]^{-1} = \max_{\phi,\lambda} \phi, \quad \text{s.t} \quad -\phi y_{i,t+1} + Y_t\lambda \geq 0, \quad x_{i,t+1} - X_t\lambda \geq 0, \quad \lambda \geq 0. \qquad \text{LP4} \qquad (11)$$

Where λ is a Nx1 vector of constant and ϕ is a scalar with $\phi \geq 1$. The term $(\Phi-1)$ is the proportional increase in outputs that could be achieved by the i-th unit, with input quantities held constant.