Total Factor Productivity in Tunisian Agriculture: Measurement and Determinants

BOUBAKER DHEHIBI*, ROBERTO TELLERIA*, AND ADEN-AW-HASSAN*

Jel Classification: C8, O13, O14

Abstract

The paper analyses the patterns of agricultural productivity in Tunisian agriculture during the period 1981-2007. To undertake this analysis we examined own and cross price elasticities of different production factors using a translog production function which provides a convenient framework for analysing output reaction to changes in prices. Moreover, a regression approach was used to test the hypotheses that government-funded research, development and extension (RD&E), private and investment, terms of trade, and share of irrigated area are significant determinants of total factor productivity (TFP) in the agricultural sector.

We found significant negative cross-price elasticities between labor and capital suggesting that agricultural policies in the form of subsidies for agricultural machinery could be introduced without negatively affecting the agricultural labor force. Our results indicate that agricultural productivity experienced moderate annual growth between 1981 and 2007. Over the whole period, land and capital were found to be the most important contributors to productivity, followed by agricultural inputs and livestock, while labor was the least significant single contributor. The findings show that TFP growth was the result of investments in the agricultural sector, with the use of intensive irrigated production systems and the adoption of new production technologies.

Keywords: *Agricultural productivity; Translog production function; Total factor productivity (TFP), Elasticity of production factors; Tunisia.*

Résumé

Cet article analyse les tendances de la productivité et la croissance économique dans l'agriculture tunisienne au cours de la période 1981-2007. Pour entamer cette analyse, nous avons examiné les élasticités-prix directes ainsi que les élasticités croisées des différents facteurs de production en utilisant une fonction de production *translog* qui constitue un cadre idéal pour analyser la réaction de la production aux variations des prix. En outre, une approche de régression est utilisée pour tester les hypothèses que le financement du gouvernement en recherche et développement et en vulgarisation (RD&E), les investissements privés, les termes de l'échange et la part de la superficie irriguée sont des déterminants clés de la productivité globale des facteurs (PGF) dans le secteur agricole en Tunisie.

Des élasticités-prix croisées entre travail et capital négatives et significatives ont été mises en évidence. Ceci suggère que les politiques agricoles sous la forme de subventions pour les machines agricoles pourraient être introduites sans affecter négativement la main-d'œuvre agricole. Les résultats indiquent que la production agricole a connu une croissance annuelle modérée entre 1981 et 2007. Au cours de cette période, la terre et le capital ont été jugés les contributeurs les plus importants à la productivité suivie des intrants intermédiaires et de l'élevage, tandis que le travail était le contributeur le moins important. Les résultats montrent aussi que la croissance de la PGF a été le résultat d'investissements dans le secteur agricole, avec l'utilisation des systèmes irrigués intensifs et l'adoption de nouvelles technologies de production.

Mots clés: Productivité agricole, Fonction de production Translog; Productivité globale des facteurs (PGF), Elasticités des facteurs de production, Tunisie.

1. Introduction

The so-called 'Arab Spring' that started in Tunisia (January 2011) was the result of numerous social, economic and political issues. Street protests and social unrest were a response to many different grievances: poverty, lack of food security, rural and urban unemployment, government corruption, and human rights violations. The 'Arab Spring' reaffirmed the importance of the agricultural sector - not only for food security - but also for social, psychological, and political stability (Breisinger *et al.*, Ecker and Al-Riffai, 2011). In fact, agriculture assumes significant social and economic importance in the Tunisian economy. The main contribution of the agricultural sector is not in terms of GDP, around 8% in 2011, but as a source of employment engaging approximately 810,000 people in 2012 (FAOSTAT, 2013) or 19.5 percent % of the working population (FAOSTAT, 2013). Particularly important are the number of jobs the agricultural sector generates for the most vulnerable: women and the youth. In 2005 agriculture employed 38 percent of total female employment in rural areas (INS, 2008), while agriculture constituted 23% percent of the youth employment in 2010 (World Bank, 2013).

Given the importance of the agricultural sector, successive governments since the 1950s have sought strategies to increase production and productivity levels. After Tunisia obtained full independence from France in 1956, the newly independent government implemented a system of collective production which forced farmers to cultivate land through cooperatives. Under this system, the government was involved in all areas related to the production, transformation, and marketing of agricultural inputs and commodities. It also introduced a massive program of agricultural subsidies in the 1960s. Subsidies significantly lowered the costs of agricultural inputs (over 50 percent % in some cases) and were directly administered by the government which marketed subsidized fertilizers, seeds, irrigation systems, and chemical products through parastatal companies (Thabet *et al.,* 2002; and Laajimi *et all.,* 2012)). Output prices were also subject to government intervention. In the 1960s,

* Social, Economics and Policy Research Program (SEPRP) - International Center for Agricultural Research in the Dry Areas (ICARDA) – Amman (Jordan).

the government fixed agricultural prices (e.g. cereals, oils, milk, sugar, and meats) aiming at lowering the costs of sensitive commodities and guaranteeing food security in Tunisia. During the same period, an import substitution policy was also introduced (Nabli, 1980) which basically meant that domestic industry and agricultural sectors were protected with increased import tariffs. Most imports (e.g. wheat, milk, vegetable oil and sugar) and exports (e.g. olive oil, wine and dates) were channeled through state specialized agencies.

Some researchers (Thabet *et al.,*2002; and Dhehibi and Lachaal, 2006) claim that these policies were not successful and cite various reasons: input subsidization schemes provided few incentives for resource conservation; price support programs distorted the domestic market allocation of resources; and heavy border protection made food more expensive for consumers. Thus, such policies were increasingly recognized as inefficient ways to achieve higher levels of production and productivity, and consequently, food security (Dhehibi and Lachaal, 2006). In addition, food subsidies seriously compromised government budgets, forcing the government to constantly demand more taxes and other sources of income to support an ever-growing subsidy bill that was inflated due to increased international prices. Moreover, Thabet *et al.,* (2002) found that approximately 80 percent % of food subsidies went to urban areas, despite the fact that more than 40 percent % of the Tunisian population lived in rural areas. This suggests that food subsidies were inefficiently administrated and unevenly distributed between rural and urban consumers.

In the 1980s, the Tunisian economy suffered serious structural imbalances due to slow economic growth, inflation, unemployment, and balance of payment deficits. In 1986, the government responded with the Structural Adjustment Program (SAP), recommended by the IMF and the World Bank, which coupled with Tunisia's Agricultural Sector Adjustment Program (ASAP), represented the most important economic milestone in the past 25 years, and a new policy paradigm for the domestic economy. The ASAP aimed at: (i) removing the major sources of price distortions that adversely affected efficiency and productivity; (ii) transferring marketing functions that were under state control to the private sector; and (iii) improving public and private investment and management, including efforts to increase privatization. These far-reaching reforms in the late 1980s and throughout the 1990s, involved a gradual disengagement from price fixing, the removal of input subsidies, and the expansion of private investments. Tunisian society expected these reforms to pay-off in terms of higher productivity and enhanced food security. However, food production has never been able to meet domestic needs. Tunisia is currently a food-deficit country for key staples such as cereals, vegetable oil and sugar – although it has almost achieved self-sufficiency in dairy products, meat, and various vegetables and fruits (WFP, 2011).

Currently, markets for the majority of agricultural products are governed by free market forces. However, some price control policies remain in place such as prices for cereals, olive oil, and meats. These products can only be marketed through specific channels namely the *Office des Céréales* for grains and the *Office National de l'Huile* for olive oil. Farmers, on the one hand, benefit from price stabilization since they can sell products with guaranteed fixed prices and no limitations on quantity. On the other hand, they are unable to take advantage of increased international prices which would increase their profits. Obviously, the government has to keep storage houses at public cost. The Tunisian agricultural sector faces an imperative challenge that is meeting increasing domestic food demand without degrading the country's natural resource base.

Thus, the objective of this paper is to identify the main determinants of Total Factor Productivity (TFP) that have been contributing to growth in the Tunisian agricultural sector. Our interest in measuring agricultural productivity is because it is acknowledged as one of the major factors contributing to the sustained economic growth of a nation (Huffman, 1993). As such, measuring agricultural productivity becomes important to analyze competitiveness in the agricultural sector, efficient in the distribution of scarce resources, agricultural technology adoption, and strategies to improve domestic food security (Ball, 1985; Hayami and Ruttan, 1985; Ball, 1985). Productivity analysis also helps in accounting for different sources of growth related to various changes in the production process, including technical efficiency and technological change (Capalbo, 1988; Fan, 1991; Capalbo, 1988).The only study on agricultural productivity exclusively focusing in Tunisia was made by Dhehibi and Lachaal (2006) who assessed agricultural productivity based on capital, inputs and labor variables, using information updated to the year 2000. This research provides a more comprehensive assessment of agricultural productivity by adding land and livestock variables, and by using the latest available data from the Tunisian bureau of statistics (updated to 2007).The remaining sections of the paper are structured as follows. Section 2 describes the theoretical foundation for measuring agricultural productivity. Section 3 specifies the methodology followed in this research. Section 4 discusses data sources and procedures followed for model estimation. Section 5 discusses results. And Section 6 presents the conclusion and policy implications drawn from this study.

2. Theoretical background

The literature proposes two main formal approaches to measure agricultural productivity: non-parametric and parametric. Non-parametric approaches involve Data Envelopment Analysis (DEA), while parametric approaches comprise the index number and econometric methods (Lachaal, 1998, provides a detailed review of the literature on methods related to productivity growth measurement). While parametrical procedures are based on central tendencies, non-parametric approaches or DEA are external processes. The DEA measures the relative efficiency with respect to the entire set being evaluated, and is thus more suitable for comparing agricultural productivity among countries. More generally, the DEA is a methodology directed to frontiers rather than central tendencies. The Malmquist index has been most commonly used by non-parametric methods (Telleria and Aw-Hassan, 2011).The parametric approach has widely used the Laspeyres Index to measure agricultural productivity through value added per unit of production factor. This index confirms whether an economy in the current period can afford to produce the same quantity as it consumed in the previous period. However, the Theil-Tornqvist Index is preferred to the Laspeyres Index because it not only uses prices from both the base and the comparison period but also rejects the unrealistic assumption that all production factors are perfect substitutes in production. Nevertheless, the Theil-Tornqvist Index does not satisfy transitivity conditions, making it inapplicable for cross-country comparisons.

The econometric approach to the measurement of agricultural productivity is based on an econometric estimation of the production function. This estimation proposes a functional form of the production function to characterize the underlying technology, using the resulting system of equations to estimate the unknown parameters. The major weakness of this approach is the assumption of an explicit functional form for the technology which could make it difficult to identify the sources of inefficiency accurately (Berndt and Christensen, 1973). However, a very important advantage of this method is that it allows for statistical inference and estimations of TFP indicators. Given that the primary objective of this study is the assessment of productivity in the Tunisian agricultural sector, the parametric criterion, particularly the econometric approach, is the model of choice.

Econometric estimation for measuring agricultural productivity is not a new approach; there have been many publications applying econometric formulations to estimate agricultural productivity and compare technology and efficiency indicators. However, a review of the literature on agricultural productivity in Tunisia reveals only one study Dhehibi and Lachaal (2006) that analyses patterns of productivity and economic growth in Tunisian agriculture during the period 1961-2000. There is another study by Telleria and Aw-Hassan (2011) which does not focus on Tunisia, but provides a cross-country comparison of agricultural productivity across twelve West Asian and North African countries (including Tunisia). None of these provide an estimate of the aggregate production model for Tunisian agriculture that simultaneously identifies substitution elasticities, input demand elasticities, rate of productivity growth, or the impact of agricultural research, development and extension (RD&E) investments. By furthering our understanding of the factors driving agricultural productivity in Tunisia as well as their policy implications, this paper will help to fill this gap.

3. Methodology

Following Ruttan (2002), this research on productivity measurement was implemented in three stages. In the first stage, we aimed at obtaining own and cross-price elasticities of production factors affecting agricultural output. To this end, we used the transcendental logarithmic (*translog*) production function which can be considered a second-order Taylor series approximation for any arbitrary production function (Christensen *et al.,*1973). The *translog* was used to obtain TFP growth estimates as well as to analyze production factor demands, substitution between production factors, and TFP growth rates. To avoid strong restrictions on the technology, the six-factor *translog* production function was used with the following specification:

$$
\begin{aligned}
&Y = f(X, K, L, La, Li, T)\\
&Ln\, Y = \alpha_0 + \alpha_X Ln\, X + \alpha_K Ln\, K + \alpha_L Ln\, L + \alpha_{La} Ln\, La + \alpha_{Li} Ln\, Li + \alpha_T T\\
&+ \tfrac{1}{2}\beta_{XX} Ln\, X^2 + \beta_{XK} Ln\, X\, Ln\, K + \beta_{XL} Ln\, X\, Ln\, L + \beta_{XLa} Ln\, X\, Ln\, La +\\
&\quad \beta_{XLi} Ln\, X\, Ln\, Li + \beta_{XT}\, Ln\, X\, T\\
&+ \tfrac{1}{2}\beta_{KK}\, Ln\, K^2 + \beta_{KL} Ln\, K\, Ln\, L + \beta_{KLa} Ln\, K\, Ln\, La + \beta_{KLi} Ln\, K\, Ln\, Li\\
&\quad + \beta_{KT}\, Ln\, K\, T\\
&+ \tfrac{1}{2}\beta_{LaLa} Ln\, La^2 + \beta_{LaLi} Ln\, La\, Ln\, Li + \beta_{LaT} Ln\, La\, T\\
&+ \tfrac{1}{2}\beta_{LiLi} Ln\, Li^2 + \beta_{LiT} Ln\, Li\, T\\
&+ \tfrac{1}{2}\beta_{TT}\, T^2
\end{aligned}
\tag{1}
$$

Where Y is the value of agricultural output, (X)inputs, (K)capital, (L)labor, (La)land, and (Li)livestock. T represents the time trend proxy and Ln is the natural logarithm. The αs and βs are parameters to be estimated. The function is symmetric so that $\beta_{ij} = \beta_{ji}$. We assumed that the production function is characterized by constant returns to scale. Under this assumption, the share of each production factor in the value of output is equal to the elasticity of output with respect to that factor, and the value shares sum up to unity. Given the functional form defined in equation (1), and applying the Shepard's Lemma, the value shares for each production factor is estimated as follows:

$$
\begin{aligned}
S_X &= \alpha_X + \beta_{XX} Ln\, X + \beta_{XK} Ln\, K + \beta_{XL} Ln\, L + \beta_{XLa} Ln\, La + \beta_{XLi} Ln\, Li + \beta_{XT} T\\
S_K &= \alpha_K + \beta_{XK}\, Ln\, X + \beta_{KK} Ln\, K + \beta_{KL} Ln\, L + \beta_{XLa} Ln\, La + \beta_{KLi} Ln\, Li + \beta_{KT} T\\
S_L &= \alpha_L + \beta_{XL}\, Ln\, X + \beta_{KL} Ln\, K + \beta_{LL} Ln\, L + \beta_{LLa} Ln\, La + \beta_{LLi} Ln\, Li + \beta_{LT} T\\
S_{La} &= \alpha_{La} + \beta_{XLa} Ln\, X + \beta_{KLa} Ln\, K + \beta_{LLa} Ln\, L + \beta_{LaLa} Ln\, La + \beta_{LaLi} Ln\, Li + \beta_{LaT} T\\
S_{Li} &= \alpha_{Li} + \beta_{XLi} Ln\, X + \beta_{KLi} Ln\, K + \beta_{LLi} Ln\, L + \beta_{LaLi} Ln\, La + \beta_{LiLi} Ln\, Li + \beta_{LiT} T
\end{aligned}
\tag{2}
$$

Equation (1), and the set of equations contained in (2), form a simultaneous equation whose parameters, to be estimated, must satisfy production technology characterized by constant returns to scale, as follows:

$$
\begin{aligned}
&\alpha_X + \alpha_K + \alpha_L + \alpha_{La} + \alpha_{Li} + \alpha_T = 1\\
&\beta_{XX} + \beta_{XK} + \beta_{XL} + \beta_{XLa} + \beta_{XL} = 0\\
&\beta_{XK} + \beta_{KK} + \beta_{KL} + \beta_{KLa} + \beta_{KLi} = 0\\
&\beta_{XL} + \beta_{KL} + \beta_{LL} + \beta_{LLa} + \beta_{LLi} = 0\\
&\beta_{XLa} + \beta_{KLa} + \beta_{LLa} + \beta_{LaLa} + \beta_{LaLi} = 0\\
&\beta_{XLi} + \beta_{KLi} + \beta_{LLi} + \beta_{LaLa} + \beta_{LiLi} = 0\\
&\beta_{XT} + \beta_{KT} + \beta_{LT} + \beta_{LaT} + \beta_{LiT} = 0
\end{aligned}
\tag{3}
$$

The main reason for choosing Christensen *et al*., Jorgenson and Lau's (1973) *translog* production function was that it allows measurement of TPF growth and examination of its differentials across time with a single stage estimation procedure. With the assumption of identically distributed TFP effects in the transcendental function, which is necessary in the *Maximum Likelihood* (ML) estimation, the commonly applied two-stage estimation procedure has been recognized as inconsistent (Christensen *et al.,*1973). However, the two-stage estimation procedure can be used for identifying the determinants affecting TFP growth within a given timeframe since TFP is calculated from the parameters estimated in the set of equations (2).

In the second stage, we estimated the total productivity growth for Tunisian agriculture. This estimation was based on the concept of the *Divisia index* which allows for multifactor productivity calculations, using quantity indexes that incorporate changes in shares. The resulting index number series are unit less like other index numbers. However, the *Divisia index* has an operational problem since it only works with exact data generated continuously. To make this index operational, we used a discrete approximation given by the *Törnqvist* index. Mathematically, the *Törnqvist index* is calculated (in log form) between any two consecutive time periods, *t* and *t+1*, as follows:

$$TFP_{t,t+1} = Ln\ Y_{t+1} - Ln\ Y_t - \sum ½\ [S_{i,t+1} + S_{i,t}][Ln\ X_{i,t+1} - Ln\ X_{i,t}] \quad (4)$$

Where LnY_{t+1} is the natural logarithm (*log*) of agricultural output in periods *t* and *t+1*, S_i denotes the respective production factor value shares in periods *t* and*t+1* and $Ln\ X_{i,t+1}$ is the natural log of factor *i* at periods *t* and *t+1*. The *Törnqvist index* requires that the shares result in perfect aggregation. This is ensured by the assumption of constant returns to scale.

In the third stage, we conducted an econometric estimation of the relationship between TFP growth and different factors, including agricultural research and development investments. In a stylized form, we used the following regression model (expected signs in parentheses):

$$TFP = f\,(R, PR, PI, TT, IA) \quad (5)$$

Where:

TFP = Total Factor Productivity in the agricultural sector;
R (+) = Share (in percentage) of public investment in agricultural research, development and extension (RD&E) with respect to Total Government Investment;
PR (+) = Share (in percentage) of private investment in the agricultural sector with respect to Total Government Investment (e.g. share of private investment on working capital, assets, private infrastructure and equities);
PI (+) = Share (in percentage) of public investment in agriculture with respect to Total Government Investment (i.e. public investment in agriculture such as water technologies, other than public investment in RD&E);
TT (+) = Terms of Trade defined as Export – import value ratio (in percentage);
IA (+) = Share (in percentage) of irrigated land with respect to total cultivated land.

The log-linear form of equation (5) allows for estimating coefficients that can be directly interpreted as elasticities. In addition, as pointed out in the pioneering work by Jud and Joseph Hyman (1974), equation (5) contains a weak residual variance relative to other functional forms for the same data set and adjusts the data better than the linear specification for both forecasted parameter signs and statistical significance. The standard Ordinary Linear Squared (OLS) method, if applied to non-stationary data series, can produce spurious regression. That is, the OLS regression can give high R^2, low Durbin-Watson (DW) statistics, and significant t-values of the estimated coefficients, suggesting a significant relationship between dependent and explanatory variables, when in fact they are completely unrelated. Conventionally, the factors explaining TFP have been studied by expressing variables in logarithmic form. This is similar to the first differencing of variables in time series analysis. Provided that the original series are integrated of order 1, as is normally the case, expressing the variables in logarithmic terms ensures a stationary data series and means that the OLS method can safely and directly be used (Hendry, 1995).

4. Data sources and estimation procedure

To implement the above-specified model, we used annual agricultural data covering the period from 1981 to 2007. That is, annual data on the value of agricultural outputs, inputs, capital, labor, land, livestock (proxied by investment in livestock sector), private agricultural investment, public agricultural investment, terms of trade and total government investments in agricultural RD&E were used. All these data were collected from the Yearly Statistics Data of the Ministry of Agriculture, Irrigation Resources and Fisheries of the Tunisian Government (MAIRF), except labor and input data that were collected from the Tunisian *Institut National de la Statistique* (TINS), and capital stock data collected from the Tunisian *Institut de la Compétitivité et des Etudes Quantitatives* (ITCEQ). All these variables were measured in Tunisian Dinars valuated at 1990 constant prices. Although information on the price of land is unavailable in Tunisia, this variable is necessary to estimate TFP. In order to estimate the value of land, we used the value-added approach to estimate GDP. That is, estimating the contribution of land value added by deducting from agricultural GDP the value added of labor, capital and inputs.

The system of equations, as outlined in (3), consists of the agricultural output equation (1) and five value-share equations (2) that are set up to be solved as a simultaneous equations system. The set of seemingly unrelated equations (1) and (2) is solved using Zellner's iterative seemingly unrelated regression (ITSUR) procedure. This allows us to estimate several regression equations, i.e. LnY in equation (1) and S_X, S_K, S_L, S_{La}, and S_{Li} in equation (2), each having its own dependent variable and exogenous explanatory variables. Note that the value shares in equation (2) have to add up to one, and hence only n−1 of the value shares are linearly independent. This implies that the covariance matrix is singular and non-diagonal (Berndt, 1991). To solve the singularity problem, the livestock equation (S_{Li}) was arbitrarily dropped from the estimation. The parameter estimates and their variances can be derived from the parameter estimates of the remaining equations based on the adding-up and symmetry restrictions.

As part of the estimation procedure, we first tested for auto-correlation. The resulting DW statistics from preliminary estimations suggested that auto-correlation was not a problem. Furthermore, an important part of the estimation was to calculate price elasticities. These provide a measure of the effects of a percentage change in the price of factor i on the demand for factor j. The price elasticities are defined as $\varepsilon_{ij} = S_j\ \sigma_{ij}$, where S_j is the estimated value-share of the j^{th} factor, and σ_{ij} is the Allen partial elasticity of substitution. Allen elasticity is defined as follows:

$$\sigma_{ij} = \sum\nolimits^{n}{}_{h=1} \sum_{h=1}^{n} F_h X_h \mid F_{ij} \mid / X_i X_j \mid \overline{F} \mid \qquad (6)$$

Where $|F|$ is the determinant of the bordered Hessian, and $|F_{ij}|$ is the cofactor of F_{ij} in F. The price elasticities are crucial when analyzing the effects of price changes on factor demand, especially if public commodity pricing policies are involved.

5. Results and discussion

Parameter estimates of the aggregated production function for Tunisian agriculture indicate that 18 out 24 variables were significant at five percent level (Annex 1), indicating that the variables used in the *translog* model (Equation 1) are significant determinants of output growth variability of the Tunisian agriculture for the period of analysis (1981-2007). One of the key objectives of this study was the estimation of own price elasticities of production factors for the period of analysis as they provide inferences of the changes in agricultural output due to changes prices and production factors. Estimates for own price elasticities of capital, inputs, labor, and livestock indicate that changes in production factor prices have triggered minor changes in demand for these factors in the Tunisian agricultural sector.

In the case of inputs, the estimated own-price elasticity parameter had the expected sign and was significant (ε_{XX}= −0.184, p= 0.075) indicating that changes in prices did not affect significantly the demand for agricultural inputs. This finding can explain that the demand for inputs (e.g. fertilizers, seeds and pesticides) did not decrease substantially when the process of subsidy removal took place in Tunisia from the early 1990s onwards. That is, since the late 1980s the agricultural sector has been driven by the Agricultural Sector Adjustment Program (ASAP) which, funded by the International Monetary Fund and the World Bank and implemented by the Tunisian government, implemented a gradual discontinuation of input subsidies advocating for the increased involvement of the private sector in the agricultural sector, and emphasizing on the cultivation of export crops. Given the inelastic characteristic of demand for inputs, the policies for removing input subsidies have not critically affected the capacity of the Tunisian agricultural sector in the use of agricultural inputs. In addition to the gradual elimination of input subsidies, the ASAP moved the economy towards liberalization and integration of the economy into the global market. Measures undertaken included input price liberalization and reductions in both tariff and non-tariff trade barriers. These policies further exposed the domestic input market to changes in international market prices. With the removal of input subsidies and elimination of input tariffs, domestic prices of inputs changed in line with international prices, but the changes in demand of inputs remained moderate due to its intrinsic inelastic demand attribute.

As expected, own price elasticity of capital (ε_{KK}= −0.367, p= 0.009) was found to be negative and inelastic indicating that when the price of capital factors increased, the use of these factors (e.g. transportation equipment, tractors, harvesters, water pumps, milking machines, milk coolers, hay cutters and storage facilities) decreased at a rate that was less than proportional to the augmentation. This is an interesting finding as it shows that the demand for capital has not substantially been affected over time due to capital price increases, which could have contributed to agricultural production growth in Tunisia.

Table 1 - *Mean values of own-price elasticities of the aggregate production function for Tunisian agriculture, 1981-2007.*

Parameters	Mean	Standard error	T-statistics	P-value
ε_{XX} (inputs)	-0.184	0.141	-1.77	0.075
ε_{KK} (capital)	-0.367	0.140	-2.61	0.009
ε_{LL} (labor)	-0.366	0.236	-1.54	0.122
ε_{LaLa} (land)	0.023	0.137	0.172	0.863
ε_{LiLi} (ivestock)	-0.636	0.347	-1.829	0.067

With respect to the livestock sector, the government has been encouraging animal production to increase national self-sufficiency in meat and milk products in the past two decades. Livestock production has increased steadily both in quantity and value and become an important contributor to agricultural GDP (40%). This favorable trend can be explained by increasing prices for meats (beef and sheep), which given the inelastic demand for livestock (ε_{LiLi}= -0.636, p = 0.067), have meant increased benefits for livestock producers. Furthermore, the extension of irrigated lands produced larger amounts of fodder which encouraged livestock growth. From the early 1990s onwards, the private sector found it profitable to import pregnant heifers, fatten and slaughter, and finally supply the meat to a mostly domestic market.

Own price elasticity of labor ($\varepsilon_{LL}= -0.366$, $p = 0.122$) was also estimated to be inelastic and significant at 10 percent. This reflects the fact that the Tunisian labor market is characterized by youth migration from rural to urban areas, many leaving agricultural farms (most of them family run) in the hands of women and elderly workers. Thus, even when wages increased in the agricultural labor market, particularly during the harvesting season when labor is scarce and a young workforce is needed to undertake physically-demanding agricultural work, demand did not decrease significantly. The estimation of all of these parameters corresponds reasonably close to those estimated by Dhehibi and Lachaal (2006).

In relation to cross-price elasticities, all of them were less than one in absolute values (2). A negative value for the partial elasticity of substitution indicates that the pairs of factors of production are complementary, while a positive value indicates that they are substitutes. In fifteen out of twenty cases, pairs of production factors exhibit substitutability, with the largest positive cross-price elasticities between livestock and capital ($\varepsilon_{KLi}= 0.413$, $p= 0.038$) and livestock and labor ($\varepsilon_{LLi}= 0.37$, $p= 0.074$). This suggests that a percentage change in the price of livestock had a positive effect on demand for capital and labor. An interesting finding was a negative cross-price elasticity between labor and capital (and *vice-versa*) ($\varepsilon_{LK}= -0.49$, $p= 0.064$; $\varepsilon_{KL}= -0.185$, $p = 0.136$). This indicates complementarity in the use of these production factors when their relative prices change. In the case of Tunisia, this is explained by the low wages and underemployment that have prevailed in the agricultural sector, which increased demand for capital goods along with demand for labor. A useful policy implication is that measures oriented to capital-intensive use in the agricultural sector (such as subsidies for mechanization and equipment) can be introduced without negatively affecting the demand for labor used in agriculture.

This is an important finding as it undermines fears that small farm mechanization is a substitute for manpower. Some old and new policy papers (Smith and Gascon, 1979; Rahman *et al.,* 2011) conclude that mechanization of agricultural production has displaced agricultural labor, particularly in countries like Tunisia where labor is abundant and farm operations are labor intensive. However, the experience of olive production in Tunisia demonstrates that mechanization allows for higher production and the intensification of land cultivation which actually increases the requirement and demand for labor. Thus, small farm mechanization does not necessarily displace labor. In fact, harvesting and post-harvesting labor can have an offsetting effect on the amount of labor displaced by mechanized land preparation.

In relation to total factor productivity growth in Tunisia, we estimated TFP grew at different rates in the three periods in which we divided the analysis (Table 3). That is, in the first one, TFP grew at 1.2 percent % per year during the period 1981-1990. This growth rate decelerated in 1991-2000 to 0.76 percent % per year and accelerated again in 2001-2007 to 1.82 percent % per year. The ANOVA analysis was used to test significance for difference in TFP growth between the three periods indicating that the mean real average TFP growth rates for the three periods were statistically different.

In the first period (1981–1990), TFP growth increased due to increases in capital and livestock growth (0.02 percent % per year each) which prompted output growth in Tunisian agriculture. In the period 1991-2000, land and capital growth (0.41 and 0.27percent 27% per year respectively) were the most important contributors to productivity growth, while in 2001-2007, land and capital (0.17 and 0.03% per year respectively) were the most important contributors to productivity growth. It does not come as a surprise that capital and land turn out to be the main driving forces behind agricultural productivity in Tunisia in the last 30 years. Tunisia has historically been an importer of capital equipment for the agricultural sector. Already in the 1960s the Tunisian government undertook capital-intensive investments in irrigation to improve land productivity and

Table 2 - *Mean values of cross-price elasticities of the aggregate production function for Tunisian agriculture, 1981-2007.*

Parameters		Mean	Standard error	T-statistics	P-value
ε_{XK}	(inputs / capital)	0.064	0.101	0.63	0.524
ε_{XL}	(inputs / labor)	0.060	0.156	0.38	0.700
ε_{XLa}	(inputs / land)	0.014	0.069	0.198	0.843
ε_{Xli}	(inputs / livestock)	0.045	0.174	0.259	0.795
ε_{KX}	(capital / inputs)	0.061	0.096	0.636	0.524
ε_{LX}	(labor / inputs)	0.057	0.149	0.385	0.700
ε_{LaX}	(land / inputs)	0.012	0.062	0.198	0.843
ε_{LiX}	(livestock / inputs)	0.041	0.158	0.259	0.795
ε_{KL}	(capital / labor)	-0.185	0.130	-1.49	0.136
ε_{KLa}	(capital / land)	0.057	0.056	1.02	0.305
ε_{KLi}	(capital / livestock)	0.433	0.208	2.079	0.038
ε_{LK}	(labor / capital)	-0.49	0.267	-1.85	0.064
ε_{LaK}	(land / capital)	-0.19	1.26	-0.15	0.879
ε_{LiK}	(livestock / capital)	0.413	0.198	2.07	0.038
ε_{LLa}	(labor / land)	0.103	0.103	1.00	0.316
ε_{LLi}	(labor / livestock)	0.39	0.21	1.78	0.074
ε_{LaL}	(land / labor)	0.603	0.72	0.833	0.404
ε_{LiL}	(livestock / labor)	0.37	0.208	1.78	0.074
ε_{LaLi}	(land / livestock)	-0.18	0.137	-1.47	0.071
ε_{LiLa}	(livestock / land)	-0.18	0.138	-1.46	0.072

Source: Author's calculation, based on coefficient estimates of the *translog* production function.

Table 3 - *Average annual growth rates of output and weighted growth rates of production factors and productivity growth for Tunisian agriculture (percent).*

Period	Output growth	Weighted growth rate of production factors: Inputs	Capital	Labor	Land	Livestock	TFP grow
1981–1990	1.38	0.04	0.02	0.003	0.05	0.02	1.20*
1991–2000	1.62	0.11	0.27	0.003	0.41	0.07	0.76*
2001–2007	2.04	0.04	0.03	0.007	0.17	0.03	1.82*
Mean	1.68	0.06	0.11	0.004	0.21	0.02	1.20

* The ANOVA analysis, used to test significance for difference in TFP growth between the three periods, indicates the mean real average TFP growth rate for the three periods that are statistically different.
Source: Author's calculation, with computed values of the *Törnqvist index.*

raise wellbeing of rural households. Some of these investments consisted of building about 40 dams, mostly in the Medjerda River, and constructing over 1,000 new wells particularly in the southern regions. In the 1980s additional capital investments in irrigation were allocated to the Medjerda River basin. In this decade the government fostered direct inflow of capital into the agricultural sector by creating the National Agricultural Development Bank (NADB) and the Agricultural Investment Promotion Agency (AIPA).

The NADB, created in 1989, provided more than two-thirds of all formal agricultural credit (Jessop *et. al*., 2012) which was capital investments in transportation equipment, tractors, etc. The AIPA, created in 1983, has been promoting private investment in order to improve land productivity in the agriculture sector. As such AIPA has been providing technical support not only to local farmers, but also to foreign investors and young entrepreneurs in areas of olive oil, fruits, vegetables, poultry products, red meats, and fish. This support has included assistance to benefit from financial and fiscal incentives (e.g. tax-free) for capital investments in areas such product transformation, post-harvest agricultural produce and agro-industry. In 1991-2000 large publically-funded development projects such as *Projets de Développement Rural Intégrés* I and II (PDRI) were implemented as part of Tunisia's ASAP that promoted the widespread use of irrigation technologies. Between 2001 and 2007, the PDRIs programs gradually discontinued their activities and were replaced by large government-driven extension projects under the umbrella of the Ministry of Agriculture.

Livestock growth was an important contributor of productivity growth in the periods 1981–1990 and 1991-2000, but slowed down between 2001 and 2007 due to increased feed prices in international markets and low productivity within the small ruminant sector (Elloumi *et al.*, 2008).The annual growth rate of labor during all periods was the lowest (0.004% percent per year), reflecting restrictions in labor productivity, low returns to labor from 1980s onwards and insufficient training to raise productivity of farmers with respect to competing imports of cheaper agricultural commodities that came along with the liberalization of agricultural markets. Likewise, the annual growth rate of inputs (such as fertilizers) during the period 1981–2007 was relatively low (0.06% percent per year), reflecting import restrictions that the Tunisian government applied to imported inputs during the 1980s. Subsequently in the 1990s, with the liberalization of input markets, the growth of inputs increased (0.11% per year), though it decreased in the period 2000-2007 probably reflecting the increased international input prices and lack of foreign exchange.

We conclude that for the overall period (1981-2007) TFP grew at an annual rate of 1.2% percent per year. This figure was below the country's population growth, 2.03 (FAOSTAT) per year for the same period, prompting concerns about Tunisia's ability to feed its growing population. From 1981 to 1990, TFP grew at a rate of 1.2% percent per year. This rate slowed down in 1991-2000 to 0.76% percent per year, and increased again in 2001-2007 to 1.82% percent per year on average. In 1991–2000 slowdowns in TFP growth was due to inefficiencies in the use of technology and know-how which were exacerbated by unfavorable drought throughout the 1990s. Supporting this finding, Latiri (2005) reports low productivity in the cereal sector in the 90s, one of the most important crops in Tunisian agriculture. Saï and Msallem (2005) also report low productivity in the olive sector in the 90s, particularly in the Northern part of the country, where although technical production conditions are the most favorable in Tunisia, but yet experienced poor performance.

To analyze the contribution of agricultural research to TFP, the regression model specified in equation 5 was used. In this model TFP was proposed as a function of agricultural research, development and extension (RD&E), irrigated land, private investment, public investment and terms of trade. Based on F-statistics, results indicate that the overall model was significant (4). The share of irrigated land, private investments, and irrigation infrastructure were the most important drivers of TFP growth, implying that a 1% increase in these factors, with respect to national investment, would lead to increases in TFP growth of 0.11, 0.08, and 0.063% percent respectively (since all variables are measured in logarithms, the regression coefficients are elasticities and the size of the coefficients indicate the magnitude of their relative influence on TFP).

The agricultural RD&E coefficient was positive but not significant (0.0055, p= 0.9043). This may be due to the low share of RD&E investments in agricultural GDP (which represent 0.5% percent, on average, for the 1981-–2007 period). However, this positive relationship is consistent with empirical studies that find a direct correlation between investments on agricultural RD&E and TFP (Fuglie, 1999; Ruttan, 2002; and Thirtle *et al.,* Lin and Piesse, 2003). Private investment was found to be statistically significant (p= 0.1534). Both findings, i.e. investments in RD&E and private investments, could support the private public partnership (PPP) development paradigm (Quiggin, 1996; Hartwich *et al*., 2007; Moszoro and Gasiorowski, 2008; IF-

Table 4 - *TFP determinants in agricultural sector (1981-2007).*			
Parameters	Estimated coefficients	t-ratios	p-value
Constant	0.409	2.14	0.0445
LnR_t (investment in agricultural RD&E)	0.0055	0.121	0.9043
$LnIRR_t$ (irrigated land)	0.115	1.561	0.1340
$LnPR_t$ (private investment)	0.081	1.502	0.1534
$LnPI_t$ (public investment)	0.063	1.800	0.1228
$LnTT_t$ (terms of trade)	0.064	0.9239	0.3665
T	27		
F-statistic	1.1948 (p<0.347)		
Log likelihood	59.35		

Source: Author's calculation based on coefficient estimates of the linear regression model.

PRI, 2007; and Quiggin, 1996), which for the case of Tunisia would be a different and novel approach advocating for a joint research system to foster technical and efficiency improvements in the domestic agricultural sector. Investment in agricultural RD&E induces productivity growth, offering a potential solution to the challenge of maintaining a continuous increase in agricultural output in a manner that minimizes input use, protects the natural resource base, and enhances food security (CGIAR, 2009). For Tunisia, Elloumi and Dhehibi (2010) also found evidence indicating a positive relationship between investments in the agricultural sector and TFP growth. Productivity-enhancing investments in developed countries have encouraged public-private research partnerships which have achieved worldwide improvements in agricultural technologies (Pardey *et al.,* 2006). The new Tunisian government should consider encouraging not only Tunisian public-private alliances but also partnerships with other Mediterranean and worldwide research institutions (CGIAR, among others).

Our estimated coefficient of public investment (e.g. government expenditure in roads, bridges, railway tracks, harbors and airports) was significant (0.063, p= 0.1228). This reflects the fact that in Tunisia public investment has mostly benefited urban and rural sectors, with positive spillovers for agricultural development. Hermes and Lensink (2001) found that public investments can be development-oriented. They classify public investment into development and non-development expenditures, which combined with private investments, can have mixed results for national economic growth. Non-development government expenditures affect private investment positively via demand channels but may also affect it negatively in terms of budget deficits, future taxes, and the absence of complementary effects on investments. A significant coefficient of public investment indicates that in Tunisia public investment has favored rural and agricultural sectors. This finding is consistent with several studies (Greene and Villanueva, 1991; Munnell, 1992; Oshikaya, 1994; Ghura and Goodwin, 2000; and Mamatzakis, 2001) that also found positive relationship between public investment and agricultural development.

As expected the estimated coefficient of the terms of trade was positive, but not significant (0.064, p= 0.3665). This may be due to the deterioration of the terms of trade that Tunisia has experienced in the past 30 years. According to UNCTAD (2010) estimates, the value of the net barter terms of trade index (2000 = 100)[11] Net barter terms of trade index is calculated as the percentage ratio of the export unit value indexes to the import unit value indexes, measured relative to the base year 2000.

in Tunisia decreased from 123.60 in 1980 to 89.65 in 2007. This means depreciation in the terms of trade which compels the economy to decrease its final demand as the cost of imported goods increase, a development that does not favor TFP growth. Indeed, our results are in accordance with Schiff and Valdéès (1992) findings. These authors have indicated that trade policies that lowered agriculture's terms of trade have been a major cause of the slow growth in developing countries-—precisely the opposite of the intended effect from industry-led growth strategies. Cleaver's work in 1984 also points to this predominant view that in sub- Saharan Africa trade and exchange rate policies had a negative impact on agricultural production though his analysis suggested that these were not the most important factors impeding agricultural growth.

The coefficient estimate of irrigated land with respect to total agricultural land was significant (0.115, p= 0.1340), suggesting that government investment in irrigation schemes has been a positive determinant of TFP in Tunisian agriculture.

6. Conclusions and policies implications

The objective of this paper has been to identify the main determinants of TFP that have contributed to growth in the agricultural sector. To meet this objective, we first analyzed own and cross price elasticities of different production factors using a *translog* production function which provides a convenient framework for analyzing output reaction to changes in prices. We then analyzed the performance of Tunisia's agricultural sector during the period 1981–2007 by examining average annual growth rates of output and weighted growth rates of production factors and productivity growth for the Tunisian agriculture. Finally we used a regression approach to empirically test whether government-funded RD&E, private investment, public investment, terms of trade, or share of irrigated area in total cultivated land were significant determinants of TFP.

Results indicate that TFP experienced moderate annual growth between 1981 and 2007 of 1.2% percent per year, which has been below the country's population growth (2.03 per year for the same period), suggesting that intensification of production systems is needed to improve food security. International trade has been supplementing food gaps, though stakes can be high if world food prices sky up as they did in 2007–2008. Regarding the contribution of production factors to agricultural productivity, empirical findings show that over the whole period, capital and land were the most important contributors. In particular, land growth was high in 1991–2000 but later decreased in 2001–2007. Productivity growth has occurred because of investments in the agricultural sector, particularly in the last decade with the use of intensive production systems, water resource mobilization (i.e. irrigation), and the adoption of new production technologies. These findings have important policy implications for promoting further growth in Tunisian agriculture. Increased productivity is important for Tunisia's competitiveness as the country looks to take further advantage of existing bilateral and multilateral trade partnerships (e.g. World Trade Organization, Euro-Med Free Trade Area, and the Arab Maghreb Union). Mean growth rates of inputs and livestock subsequently decreased in 2001–2007. Labor was the least significant source of growth for agricultural output.

The positive impact of public investment suggests that Tunisia should now invest more comprehensively in its own agricultural infrastructure, especially in efficient water management technologies. Furthermore, if the significance of public agricultural investment is fully recognized, and it is to be used effectively as a policy tool to improve agricultural output and consequently food security using fewer resources, then a greater policy commitment is needed to strength public-private partnership investments in the agricultural sector. The empirical findings indicate that private investment in the agricultural sector was one of the major determinants of TFP growth. The corresponding coefficient was statistically significant, suggesting that policymakers should encourage such investments in the agricultural sector through the implementation of well-targeted public-private partnerships that channel funding to infrastructural projects.

Agricultural policies such as subsidies to agricultural machinery or equipment can also be introduced without negatively affecting the rural labor force. This policy recommendation is supported by cross-price elasticities between capital and labor, indicating complementarity between these two production factors when used in agriculture. Thus, the adoption of farm mechanization will not displace agricultural labor since mechanization intensifies production (i.e. more output), offsetting possible effects on labor displacement. For example, the mechanization of olive production in Tunisia caused an increment in the requirement of agricultural labor.

This is the first study that has estimated the impact of agricultural RD&E on TFP in Tunisia. Even though we did not find the estimated coefficient to be significant, we did find a positive correlation. As indicated above, the reason for this may be the limited financial resources allocated to RD&E, in comparison to total agricultural public investment. However, this positive correlation could indicate to the national government the need to strengthen its domestic agricultural research system. For example, public RD&E could be allocated to the improvement of research for farm systems that are not of interest to the private sector. By definition, the nature of public goods tends to generate uncertainty in obtaining profitable results, making the private sector generally reluctant to invest in overall farm system research programs. In addition, the level of government spending on public RD&E is insufficient to compensate the underinvestment of the private sector. Instead, policymakers could play a more active role encouraging increased investments, not only in production systems, but also in RD&E through a variety of policy tools that induce joint public-private co-investments.

This paper elucidates that intensification of production systems through improved productivity is key to improve food security in the country. We showed that over years modernization of agriculture, in the form of land and capital investments coming from both public and private sources, has been determinant to agricultural productivity growth. Therefore, better food security has been achieved in Tunisia, particularly in strategic food staples such as cereals, vegetables, oil and livestock products. Yet this paper covers productivity analysis until 2007 (latest comprehensive set of data available), and thus the recent events related to the 2011 Tunisian revolution are not included in the analysis. Further research might wish to look at how the Tunisian farmers have been affected by food price instability that characterized the Tunisian economy from 2011 to 2013. Analysis might include evaluating how the productivity of agricultural sector has been affected by the domestic crises, including scarcity in food supply and ability of consumers to purchase food and implications for food security.

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Annex 1

Parameter estimates of the aggregate production function for Tunisian agriculture, 1981–2007

#	Parameters	Estimate	Standard error	P-value	#	Parameters	Estimate	Standard error	P-value
1	α_0	0.177	0.092	0.056	15	β_{XL}	-0.025	0.029	0.382
2	α_X	0.189	0.026	0.000	16	β_{XLa}	-0.036	0.013	0.005
3	α_K	0.124	0.039	0.002	17	β_{XLi}	-0.030	0.032	0.352
4	α_L	0.166	0.031	0.000	18	β_{XT}	0.0009	0.0016	0.575
5	α_{La}	0.213	0.015	0.000	19	β_{KL}	-0.075	0.025	0.003
6	α_{Li}	0.158	0.117	0.177	20	β_{KLa}	-0.029	0.011	0.007
7	α_T	-0.029	0.011	0.008	21	β_{KLi}	0.044	0.041	0.278
8	β_{XX}	0.118	0.026	0.000	22	β_{KT}	0.0047	0.0026	0.066
9	β_{KK}	0.085	0.027	0.002	23	β_{LLa}	-0.02	0.020	0.309
10	β_{LL}	0.086	0.046	0.065	24	β_{LLi}	0.036	0.043	0.402
11	β_{LaLa}	0.17	0.028	0.000	25	β_{LT}	0.0019	0.002	0.335
12	β_{LiLi}	0.032	0.072	0.653	26	β_{LaLi}	-0.082	0.028	0.004
13	β_{TT}	0.0021	0.0006	0.001	27	β_{LaT}	-0.0008	0.001	0.394
14	β_{XK}	-0.025	0.019	0.191	28	β_{LiT}	-0.056	0.023	0.014

Source: Own elaboration, with computed values of the Christensen transcendental logarithmic function based on figures from the Yearly Statistics Data - Ministry of Agricultural, Irrigation Resources and Fisheries of the Tunisian Government, the Tunisian *Institut National de la Statistique*, the *Institut Tunisien de la Compétitivité et des Etudes Quantitatives*, and the FAO-AGROSTAT system (online database).