Agricultural Productivity Analysis of European Union and Eastern Regions

Amilcar Serrao
Evora University,
Largo dos Colegiais,
7000 Evora, Portugal
amilcar-serrao@clix.pt

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Amílcar Serrão *

Abstract:

This research work uses stochastic frontier analysis (SFA) and data envelopment analysis (DEA) to examine the sources of agricultural productivity growth over time and of productivity differences among countries and regions in European Union over the period 1980-1998.
A comparison of the mean productivity scores obtained by the two approaches show that DEA results are higher than in SFA results, because DEA fits a tighter (more flexible) frontier than the translog frontier.
This study is a valuable warning for people to be carefully about the effects of the methodology choice upon their results and to use more than one approach if they suspect that it may have some influence.

Key words: Data Envelopment Analysis, Stochastic Frontier Analysis, Technical Efficiency Change, Technical Change, Total Factor Productivity Change, European Union.

JEL classification: Q12, D24

* Associate Professor in Management Department at Evora University, Largo dos Colegiais, 7000 Evora, Portugal
E-mail: amilcar-serrao@clix.pt

1. Introduction

The European Union's policy on agriculture began in 1960, when six countries adopted the mechanisms of the Common Agricultural Policy and its influence has become manifest in the competitiveness and in the growth of the productivity of the European Union's countries. The effects of the Common Agricultural Policy on the agriculture of these countries have been reinforced by other decisions and measures, specially the third reform of the Common Agricultural Politics (Agenda 2000) in 1999. These decisions and measures have had effects on the agriculture of the fifteen countries that constitute the European Union and the other countries that have already applied for European Union membership such as Bulgaria, Romania, Hungary and Poland.

Productivity growth, technical efficiency and technical change have been studied over the last decades. Agricultural economists have examined the sources of productivity growth over time and of productivity differences among countries and regions over this period. Some of the studies that have analysed cross-country differences in productivity growth include Hayami and Ruttan (1970, 1971), Kawagoe and Hayami (1983, 1985), Kawagoe, Hayami and Ruttan (1986), Lau and Yotopoulos (1989), Capalabo and Antle (1988), Bureau et. al (1995), Fulginiti and Perrin (1993, 1997) and Rao and Coelli (1998).

These studies refer to a small number of countries and span the period 1960 to 1980. They report results of the less developed countries that exhibit technological regression, countries which appear to be in sharp contrast to the developed countries that show technological progress. Some recent studies, Fulginiti and Perrin (1997), examine 18 developing countries and find that 14 of these countries show a decline in agricultural productivity over the period 1961-1985. Rao and Coelli (1998) examine the agricultural productivity growth in 97 countries over the period 1980 and 1995 and the results show an annual growth in total factor productivity growth of 2.7 percent, a major contributing factor being technical efficiency change.

This research work presents some results from a project, which examines agricultural productivity trends based on data from the fifteen European Union countries and four countries belonging to Eastern Europe covering the period 1980 to 1998. The present study analyses total factor productivity change, technical efficiency change and technical change among countries over the period of study, and focuses on issues of catch-up and convergence. The parametric and non-parametric Malmquist total factor productivity index methods are employed here to examine global agricultural productivity in those European countries.

2. Methodology

This section presents the Malmquist index methods research to measure total factor productivity (TFP). These indices can be estimated by using both parametric and non-parametric frontier estimation methods. There are a number of different approaches that can measure the distance functions that make up the Malmquist total factor productivity index. The first one is the DEA-like programming methods suggested by Färe et al (1994). The second one is the stochastic frontier methods.

The Malmquist index is defined using distance functions. These functions allow one to describe a multi-input and multi-output production technology without the need to specify a behavioural objective (such as cost minimization or profit maximization). One may define input distance functions and output distance functions. An input distance function characterizes the production technology by looking at a minimal proportional contraction of the input vector, given an output vector. An output distance function considers a maximal proportional expansion of output vector, given an input vector. This paper assumes a constant returns to scale technology and selects an output orientation, because it is fair to assume that agricultural activities in each country attempt to maximize output from a given set of inputs, rather than the converse. So, this research work only considers an output distance function as follows:

$$m_o(y_s, x_s, y_t, x_t) = \left[\frac{d_o^s(y_t, x_t)}{d_o^s(y_s, x_s)} x \frac{d_o^t(y_t, x_t)}{d_o^t(y_s, x_s)} \right]^{1/2} \tag{1}$$

A value of m_o greater than one will indicate a total factor productivity growth increase from period s to period t, while a value less than one indicates a total productivity growth decline. The equation 1 is the geometric mean of two indices. The first index is evaluated with respect to period s technology and the second one with respect to period t technology. An equivalent way of writing this productivity index is as follows:

$$m_o(y_s, x_s, y_t, x_t) = \frac{d_o^t(y_t, x_t)}{d_o^s(y_s, x_s)} \left[\frac{d_o^s(y_t, x_t)}{d_o^s(y_s, x_s)} x \frac{d_o^t(y_t, x_t)}{d_o^t(y_s, x_s)} \right]^{1/2} \tag{2}$$

This ratio has two parts. The part outside the square brackets measures efficiency change between period s and t, while the remaining part is a measure of technical change.

The distance measures required for the Malmquist TFP index calculations can be calculated using DEA-like linear programming models. For the i-th country, four distance functions are calculated to measure total factor productivity change, technical efficiency change and technical change between two periods. This requires the solving of four linear programming models.

$$\left[d_o^t(\mathrm{y_t}, x_t)\right]^{-1} = \max \ \phi$$
$$s.a.$$
$$-\phi y_{it} + Y_t\lambda \ \geq 0 \qquad (3)$$
$$x_{it} - X_t\lambda \ \geq 0$$
$$\lambda \ \geq 0$$

$$\left[d_o^s(\mathrm{y_s}, x_s)\right]^{-1} = \max \ \phi$$
$$s.a.$$
$$-\phi y_{is} + Y_s\lambda \ \geq 0 \qquad (4)$$
$$x_{is} - X_s\lambda \ \geq 0$$
$$\lambda \ \geq 0$$

$$\left[d_o^t(\mathrm{y_s}, x_s)\right]^{-1} = \max \ \phi$$
$$s.a.$$
$$-\phi y_{is} + Y_t\lambda \ \geq 0 \qquad (5)$$
$$x_{is} - X_t\lambda \ \geq 0$$
$$\lambda \ \geq 0$$

$$\left[d_o^s(\mathrm{y_t}, x_t)\right]^{-1} = \max \ \phi$$
$$s.a.$$
$$-\phi y_{it} + Y_s\lambda \ \geq 0 \qquad (6)$$
$$x_{it} - X_s\lambda \ \geq 0$$
$$\lambda \ \geq 0$$

Note that in linear programming models 5 and 6, where production points compared to technologies from different periods, the ϕ parameter need not be greater than or equal to one, as it must be when calculating Farrell output-oriented technical efficiencies. The data point could lie above the feasible production set. This will most likely occur in linear programming model 6, where a production point from period t is compared to technology in earlier period s. If technical progress has occurred, a value of $\phi<1$ is possible. Note that it could also possibly occur in linear programming model 5 if technical regress has occurred, but this is less likely. Furthermore, note that the above four linear programming models must be solved for each country in the sample.

The distance measures for the Malmquist TFP index can also be measured by Stochastic Frontier methods. This research work considers a stochastic (translog) production function defined as:

$$\ln(y_{it}) = f(x_{it}, t, \beta) + v_{it} - u_{it} \qquad i = 1,2,...,N \quad t = 1,2,....,T \qquad (7)$$

where:

ln represents the logarithm

y_{it} represents the output of the i-th firm the t-th year;

x_{it} is a (1xK) vector of inputs;

f(.) denotes a suitable functional form (translog function);

t is a time trend representing technical change;

β represents a vector of unknown parameters to be estimated;

the v_{it}'s are random errors, assumed to be i.i.d. and have N(0, σ_v) - distributions, independent of the u_{it}; and

the u_{it}'s are the technical inefficiency effects.

This parametric approach permits to determine the measures of technical efficiency and technical change to calculate the Malmquist total factor productivity index.

The technical efficiency change measures are obtained as

$$TE_{it} = E(\exp(-u_{it}) \mid e_{it}) \tag{8}$$

where

$e_{it} = v_{it} - u_{it}$ can be used to calculate the technical efficiency change component, that is, $d_0^t(x_{it}, y_{it}) = TE_{it}$ *and* $d_0^s(x_{it}, y_{it}) = TE_{is}$ and the technical efficiency change (TEE) is calculated as:

$$TEE_{it} = TE_{it} / TE_{is} \tag{9}$$

The technical change index between period s and t for the i-th country can be calculated directly from the estimated parameters. If technical change is non-neutral, the technical change index may vary for estimate different input vectors. A geometric mean is used to estimate the technical change index between adjacent period s and period t (Coelli et al, 1998).

The technical change index (TEC) is calculated as:

$$TEC_{it} = \left\{ \left[1 + \frac{\partial f(x_{is}, s \ , \beta \ )}{\partial s} \right] * \left[1 + \frac{\partial f(x_{it}, t \ , \beta \ )}{\partial t} \right] \right\}^{0,5} \tag{10}$$

The Malmquist total factor productivity index (MI) is calculated by multiplying the indices of technical efficiency change and technical change using equations 9 and 10 as follows:

$$MI_{it} = TEE_{it} * TEC_{it} \tag{11}$$

3. Data and information

This research work collected data exclusively from the AGROSTAT system of the Statistics Division of the Food and Agricultural Organization in Rome. All necessary data and information were downloaded from the Web site of the Food and Agriculture Organization of the United Nations (FAO). The data was collected for European Union countries and four countries from Eastern Europe over the period 1980 to 1998. These four Eastern European countries have already applied for European Union membership.

The output variable includes crops and livestock values ($1.000). The base year is 1989-91.

The study considers only three input variables. The first variable collected is land (hectares), which includes permanent crops as well as the area under permanent pasture. The second one is tractors (units), which covers the number of wheel and crawler tractors used in agriculture, without allowance being made as to their horsepower. The third one is labor (units), which refers to the economically active population in agriculture, including all economically active persons engaged in agriculture, forestry, hunting or fishing. This variable overstates the labor input used in agricultural production, and the extent of overstatement depends upon the level of development of the country.

4. **Results**

The results of this research work are presented in this section. Table 1 shows the geometric mean values of technical efficiency change, technical change and total factor productivity change for the 18 countries over the period 1980 to 1998. European countries in this table are presented in a descending order of the magnitude of the total factor productivity changes.

Country	effch	techch	tfpch
France	1,005	1,037	1,042
Germany	1,013	1,028	1,041
Denmark	1,005	1,031	1,036
Bel-Lux	1,000	1,033	1,033
Bulgaria	1,023	1,004	1,027
Austria	0,990	1,028	1,018
Sweden	0,990	1,027	1,017
Ireland	0,989	1,028	1,017
Netherland	1,000	1,015	1,015
Finland	0,989	1,026	1,015
UK	0,988	1,026	1,014
Geomean	0,995	1,017	1,012
Spain	0,991	1,018	1,009
Italy	0,988	1,019	1,007
Greece	0,991	1,009	1,000
Portugal	0,986	1,004	0,990
Romania	1,007	0,977	0,984
Poland	0,969	1,014	0,983
Hungary	0,996	0,981	0,977
Geomean	0,995	1,017	1,012

Table 1. Efficiency and productivity changes for the countries - DEA Results
Notes: effch - technical Efficiency Change, techch - technical Change
tpfch - total factor productivity change, Geomean - geometric mean

The results in table 1 show France and Germany as the two countries with the maximum total factor productivity growth. France shows a 4.2 percent average growth in total factor productivity change, which is due to 3.7 percent growth in technical change. The Eastern countries, Bulgaria, Romania, Poland, Hungary, exhibit the lowest total factor productivity growth. Hungary has the lowest total factor productivity growth decline over the whole period of study.

Table 2 shows a 1.2 percent growth in total factor productivity change over the period 1980 to1998. These results also show that over the whole period there has been no technological regression. This means advances in technology which may be represented by an upward shift in the production frontier. The productivity improvement has mainly been due to technical change over the period of study. This is in contrast to the study of Rao and Coelli (1998), who report that a major contributing factor for productivity growth is technical efficiency.

Year	effch	techch	tfpch
1981	0,967	1,018	0,984
1982	0,828	1,39	1,151
1983	1,227	0,743	0,912
1984	1,013	1,068	1,082
1985	0,977	0,995	0,972
1986	0,944	1,039	0,981
1987	1,03	0,996	1,026
1988	0,991	1,02	1,011
1989	1,037	1,005	1,042
1990	1,014	0,999	1,013
1991	1,018	0,973	0,991
1992	0,922	1,049	0,967
1993	1,02	0,993	1,013
1994	0,97	1,037	1,006
1995	0,981	1,052	1,032
1996	1,017	1,015	1,032
1997	1,023	1,001	1,024
1998	0,984	1,015	0,999
Geomean	0,995	1,017	1,012

Table 2. Annual mean efficiency and productivity change - DEA Results
Notes: effch - technical Efficiency Change, techch - technical Change
tpfch - total factor productivity change, Geomean - geometric mean

Table 3 provides a measure of technical efficiency change, technical change and total factor productivity change by five regions. The North region consists of Denmark, Finland and Sweden; the Central region Austria, Bel-Lux, France, Germany and the

Netherlands; the Western region Ireland and United Kingdom; the South region Portugal, Spain, Italy and Greece; and the Eastern region Bulgaria, Hungary, Poland and Romania. The Central region has the highest total factor productivity growth of 3.0 percent, followed by the North and Western regions. The Central region growth is explained mainly by the technical change growth of 2.8 percent. The Eastern region has a negative growth rate of 0.8 percent in total factor productivity change. All regions, except the Central region, have a negative growth in technical efficiency change.

Regions	Effch	Techch	Tfpch
North	0,995	1,028	1,022
Central	1,002	1,028	1,030
Western	0,988	1,027	1,015
South	0,989	1,012	1,001
Eastern	0,999	0,994	0,992
Geomean	0,995	1,017	1,012

Table 3. Efficiency and productivity changes for each region - DEA Results
Notes: effch - technical Efficiency Change, techch - technical Change
tpfch - total factor productivity change, Geomean - geometric mean

A surprising result is that, over the period 1980-1998, these results show no evidence of regional technological regression in European Countries, excluding the Eastern region. This is in contrast to the work of Fulginiti and Perrin (1997), who report technical regression over the period 1960-1985. Another interesting result is that technical efficiency change (or "catch-up") is not a source of total factor productivity change over the period of study, as Rao and Coelli (1998) report it.

Coefficient	Estimate	t-ratio
b0	35,3324	3,109
b1	-6,2636	-2,864
b2	-0,5107	-0,796
b3	2,6349	2,762
b11	0,2904	2,144
b22	0,0239	0,789
b33	-0,2481	-3,078
b12	0,0272	0,249
b13	0,1390	0,879
b23	-0,0184	-0,189
b1t	0,0001	0,588
b2t	0,0005	2,487
b3t	-0,0011	-4,277
bt	0,0128	0,108
btt	0,0009	1,160
sigma-squa	0,3846	2,891
gamma	0,9662	80,853
LR test		713,301

Table 4 - Estimates of the Translog Production Frontier Model

Notes: 1 - land; 2 - tractor; 3 - Labor; t - time; and, b0 - intercept.

The parameter estimates of the translog production frontier model are reported in Table 4, where some of the coefficients of individual inputs are positive and significant at 5% level.

The estimate for γ is 0.9662 with estimated standard error of 0.01195. The results are consistent with the conclusion that the true γ-value must be greater than zero. Here, the γ-estimate is different from one, so the stochastic frontier model is different from the deterministic frontier, in which they are random errors in the production function.

Another interesting hypothesis is whether the Cobb-Douglas production function is an adequate representation of the data, given the specifications of the translog model. Here, the test of the null hypothesis requires that the second-order coefficients of the translog frontier model must be simultaneaously zero. So all the bij coefficients should be deleted to obtain the required data set for the Cobb-Douglas model. The value of the generalised likelihood-ratio statistic for testing the null hypothesis, $H_0 : \beta_{ij} = 0$, is calculated to be equal to 713,301. This value compared with the upper five percent point for the χ^2_{10} -distribution, which is 18.31. The conclusion is that the null hypothesis is rejected and the Cobb-Douglas is not a good representation of the data, given the specification of the translog model.

The estimates of technical change parameters show little technical progress during the period. The estimate of bt indicates an average annual technical progress of 1.28 percent per year.

The technical efficiency change, technical change and the Malmquist total factor productivity index for European countries and the four Eastern countries are reported in table 5. The geometric mean values of the technical efficiency change, technical

Country	effch	techch	tfpch
France	1,001	1,028	1,029
Bel-Lux	0,999	1,028	1,027
Denmark	1,002	1,024	1,026
Germany	1,009	1,011	1,020
Netherland	0,999	1,015	1,014
Sweden	0,990	1,024	1,014
Austria	0,988	1,024	1,012
Finland	0,985	1,026	1,011
Ireland	0,983	1,028	1,011
Spain	0,988	1,014	1,002
Greece	0,986	1,016	1,002
UK	0,985	1,017	1,002
Italy	0,981	1,015	0,996
Portugal	0,986	1,005	0,991
Bulgaria	0,991	0,993	0,984
Romania	0,998	0,972	0,970
Hungary	0,991	0,977	0,968
Poland	0,963	0,994	0,957
Geomean	0,990	1,013	1,003

Table 5. Efficiency and productivity changes for the countries - Translog Results
Notes: effch - technical Efficiency Change, techch - technical Change
tpfch - total factor productivity change, Geomean - geometric mean

change and the Malmquist Total Factor Productivity index are 0.990, 1.013 and 1.003, respectively.

The results of the translog model show that France, Belgium-Luxembourg and Denmark have the highest total factor productivity change. France shows a 2.9 percent average growth in total factor productivity change due to technical change. The Eastern countries, (Bulgaria, Romania, Hungary and Poland) have the lowest total factor productivity change explained by a negative growth in technical efficiency change and technical efficiency change.

Unlike the results calculated by DEA model, the results of the translog model over the period 1980 to 1998 are much lower (Table 6).

Year	effch	techch	tfpch
1981	0,957	1,016	0,972
1982	0,823	1,385	1,140
1983	1,222	0,737	0,901
1984	1,009	1,078	1,088
1985	0,957	0,992	0,949
1986	0,94	1,037	0,975
1987	1,028	0,994	1,022
1988	0,988	1,015	1,003
1989	1,033	1,001	1,034
1990	1,014	0,996	1,010
1991	1,015	0,967	0,982
1992	0,912	1,042	0,950
1993	1,019	0,991	1,010
1994	0,969	1,029	0,997
1995	0,976	1,048	1,023
1996	1,014	1,011	1,025
1997	1,018	0,996	1,014
1998	0,980	1,012	0,992
Geomean	0,990	1,013	1,003

Table 6. Annual mean efficiency and productivity change - Translog Results
Notes: effch - technical Efficiency Change, techch - technical Change
tpfch - total factor productivity change, Geomean - geometric mean

The total factor productivity change is 0.3% over the period of study. During the period of study, most of the periods exhibit positive technical change growth although these values are lower than the results displayed by DEA approach. However, the results indicate an upward shift in the production frontier and they do not confirm the study of Rao and Coelli (1998), which reports that a major contributing factor for productivity growth is technical efficiency change.

Regions	Effch	Techch	Tfpch
North	0,992	1,025	1,017
Central	0,993	1,024	1,017
Western	0,984	1,022	1,006
South	0,985	1,009	0,994
Eastern	0,993	0,991	0,984
Geomean	0,990	1,013	1,003

Table 7. Efficiency and productivity changes for each region - Translog Results
Notes: effch - technical Efficiency Change, techch - technical Change
tpfch - total factor productivity change, Geomean - geometric mean

Table 7 presents three measures for five European regions. Again the results of translog model for technical efficiency change, technical change and total factor productivity change are lower than the same results calculated by DEA model. The Eastern region has a negative growth rate of 1.6 per cent in total factor productivity change. These results show that DEA Approach fits a tighter (more flexible) frontier than the translog frontier.

5. Conclusions

This research work examines the sources of productivity growth over time, and of productivity differences among countries and regions over the period 1980-1998. The growth in agricultural productivity is examined in fourteen European countries and four East European countries such as Bulgaria, Poland, Hungary and Romania that have already applied for European Union membership. Five European regions are defined in this research work such as the North region, the Eastern region, the Central region, the Western region and the South region.

Stochastic frontier analysis (SFA) and data envelopment analysis (DEA) are used to provide information on the Malmquist productivity total factor productivity indices. The study utilizes a panel data sample of 18 countries observed between 1980 and 1998 and collected from the database of Food and Agriculture Organization of the United Nations.

The SFA results show that the estimates of the technical change parameter indicate very little technical progress during the sample period. The estimates also suggest that there has been a mixture of both increases and declines in the technical efficiency change of the different regions of European regions. These results show a decline in technical efficiency change of 1.0 percent during the sample period. The technical change rose slightly over the period of study. The technical change has risen only 1.3 % over the 19 year period of study. When this small amount of technical change is combined with the above technical efficiency change there is a net increase of 0.3% in total factor productivity change over the sample period. The North region is the major performer and the Eastern region has a total factor productivity growth decline of 1.6 % followed by the South region.

An alternative approach based on Data Envelopment Analysis also used to compute the Malmquist productivity indices. DEA results show an annual growth in total factor productivity of 1.2 percent, where major contributing factor is technical change. Negative growth in efficiency change is observed in DEA analysis. France posts the most spectacular performance, with an average annual growth of 4.2 percent in total factor productivity change over the study period. Germany and Belgium-Luxembourg have a good performance, while Hungary has the lowest total factor productivity growth decline.

Turning to the performance of five European regions defined in this research work, the Central region is the major performer, with an annual total factor productivity growth of 3.0 percent. The Eastern European region seems to be the weakest performer, with a growth in total factor productivity decline of 1.8 percent.

A comparison of the mean productivity scores obtained by the two approaches show that DEA results are higher than in SFA results. This may be because DEA fits a tighter (more flexible) frontier than the translog frontier. This is most likely due to the piece-wise nature of the DEA frontier. These results also indicate that there is not a degree of catch-up due to improved technical efficiency along with growth in technical change in European Union countries and the four Eastern European countries. This is a valuable warning for people to be carefully about the effects of the methodology choice upon their results and to use more than one approach if they suspect that it may have some influence. These results should shed some light on the relative importance of the functional form issue in explaining the SFA/DEA differences found in this research work and to develop in future other approaches to accommodate less restrictive functional forms.

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