A Comparison of Agricultural Productivity among European Countries

AMÍLCAR SERRÃO

Abstract

This research work examines levels and trends in global agricultural productivity in fifteen European Union countries and four Eastern European countries that have already applied for European Union membership.

An approach based on Data Envelopment Analysis is used to provide information on the peers of the (inefficient) i-th country and to derive the Malmquist productivity indices. Model results show the Eastern European region is the major performer region over the period of study. These results 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 four Eastern European countries.

Résumé

Ce travail de la recherche examine des niveaux et des tendances dans la productivité agricole globale dans quinze pays de l' Union européenne et quatre pays européens de l'Est qui ont déjà sollicité l'adhésion dans l'Union européenne.

Une approche basée sur la 'Data Envelopment Analysis' est utilisée pour fournir de l'information sur les 'peers' de l'inefficient dans les pays et dériver le Malmquist productivité indices. Les résultats du modèle montrent que la region de l'Est est la région avec majeure accomplissement sur la période d'étude. Ces résultats indiquent qu'il n'y a pas un degré de 'catch-up' dû à l'amélioration de l'efficient technique avec augmentation dans la changement technique dans les pays de l'Union Européenne et dans les quatre pays européens de l'Est.

1. Introduction

The European Union's policy on agriculture began in 1960, when six countries adopted the mechanisms of the Common Agricultural Policy. This was only really applied in 1962, when those countries created the first organizations of common agricultural markets that had a strong influence on the agriculture of the six countries. This influence has become manifest in the competitiveness and in the growth of productivity of European Union countries. The effects of the Common Agricultural Policy on the agriculture of these countries have been reinforced by other decisions and measures. Reference is here made only to the first reform of the Common Agricultural Policy (Mansholt Plan) in 1971, the introduction of socio-structural policies in 1971, the accession of the United Kingdom in 1972, Ireland and Denmark in 1973, Greece in 1981 and Portugal and Spain in 1986, the reform of structural funds in 1987, the second reform of the Common Agricultural Policy under Commissary Mac Sharry in 1992, the entrance of Finland, Sweden and Austria in 1995 and the third reform of the Common Agricultural Policy (Agenda 2000) in 1999.

These decisions and measures have had effects on the agriculture of the fifteen countries that constitute the European Union and on the other countries that have already applied for European Union membership, such as Bulgaria, Romania, Hungary and Poland. These four countries belong to Eastern Europe, whose agriculture is different from the remaining fifteen countries of the European Union. 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. In 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, the results showing 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 global 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 non-parametric Malmquist total factor productivity

* Department of Management, Evora University, Largo dos Colegiais, 7000-554 Evora, Portugal.

index methods discussed in Färe et al (1994) are employed here to examine global agricultural productivity in these countries.

2. Methodology

This section describes the data envelopment analysis and the Malmquist index methods research to measure total factor productivity (TFP). These methods are described by Färe et al (1994), Coelli, Rao and Battese (1997) and Rao and Coelli (1998). The data envelopment analysis (DEA) constructs a piece-wise linear production frontier for each year in the sample. This methodology has been applied to firms which use data on input and output quantities to construct a piece-wise linear surface over the data points. This frontier surface is constructed by the solution of a sequence of linear programming problems. The degree of technical inefficiency of each firm (the distance between the observed data point and the frontier) is produced as a by-product of the frontier construction method.

DEA can be either input-orientated or output-orientated. The input-orientated case requires that the DEA approach defines the frontier by seeking the maximum possible proportional reduction in input usage, with output levels held constant for each firm. For the output-orientated case, the DEA approach seeks the maximum proportional increase in output production, with input levels held constant. The two cases provide the same technical efficiency scores when a constant returns to scale (CRS) technology applies, but the scores are unequal when variable returns to scale are assumed to measure global agricultural productivity. This research work applies this approach to countries. Firstly, the study presents a DEA model to provide information on the peers of the (inefficient) i-th country, before describing the Malmquist total factor productivity calculations.

A DEA model is solved for the i-th country as follows:

max ϕ, λ^{ϕ}

st

$\Phi y i + Y \lambda \geq 0$

$x i - x \lambda 0$

$\lambda 0$

Where

y_i is an Mx1 vector of output quantities for the i-th country;

χ_i is an Kx1 vector of input quantities for the i-th country;

Y is an Nxm matrix of output quantities for all N countries;

X is an NxK matrix of input quantities for all N countries;

λ is an Kx1 vector of weighs; and

Φ is a scale.

The F will take a value greater than or equal to one and F - 1 is the proportional increase in outputs that could be achieved by the i-th country, with input quantities held constant. The linear programming model is solved N times, once for each country in the sample. Each solution of the linear programming model has a F and a l vector. The F parameter provides information on the technical efficiency score for the i-th country and the l- vector provides information on the peers of the (inefficient) i-th country. The peers of the i-th country are those efficient countries that define the facet on the frontier against which the (inefficient) i-th country is projected.

The second approach used in this research work is the Malmquist total factor productivity index. This is defined using distance functions. Distance functions describe a multi-input, multi-output production technology without the need to specify a cost minimisation or profit maximisation objective. The distance function can be either input distance function or output distance function. This paper only refers to output distance function in detail, since this function considers a maximal proportional expansion of the vector, given an input vector. The input distance function can be defined and used in a similar manner.

This research work considers that in time period t, producers are using inputs, $X^t \in R_+^m$ to produce outputs $Y^t \in R_+^m$. The input requirement set is defined as follows:

$$L^t(Y^t) = \{X^t : X^t \, can \text{ produce } Y^t\}$$

$L^t(Y^t)$ contains all input vectors that can produce output Y^t. This requirement set is non-empty, closed, convex, bounded from below by the input isoquant, that is:

$$IsoqL^t(Y^t) = \{X^t : X^t \in L^t(Y^t), \lambda X^t \notin L^t(Y^t), for \, \lambda < 1\}.$$

Isoq Lt(Yt) defines a boundary (frontier) to the input requirement set, and those input vectors that lie on it are efficient in the sense that any radial contraction of them within $L^t(Y^t)$ is not possible. Alternatively, with reference to the input requirement set, the technology of production is defined in terms of the input distance function (Shephard, 1953 and 1970) as:

$$D_i^t(Y^t, X)^t = \sup_{\theta}\{\theta : (X^t/\theta) \in L^t(Y^t), \theta > 0\}$$

where the subscript i denotes input orientation. $D^t_i(Y^t,X)^t$ characterises the technology of production completely in the sense that $D^t_i(Y^t,X)^t \geq 1$ is sufficient for $X^t \in L^t(Y^t)$ and if $D_i^t(Y^t,X)^t = 1 \, X^t \in Isoq \, L^t(Y^t)$. On the other hand, $D^t_i(Y^t,X)^t$ is reciprocal to Farrell's input-oriented measure of technical efficiency (Färe and Primont, 1995), which is:

$$TE_i^t(Y^t, X^t) = \min_{\phi}\{\phi : (\phi X^t) \in L^t(Y^t), \phi > 0\}.$$

Assuming two time periods t and t+1 respectively, and defining in each one of them technology and production as shown earlier, 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 minimisation or profit maximisation). One may define input distance functions and output distance functions. An input distance function characterises 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 that 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 maximise output from a given set of inputs, rather than the converse. So, this research work only considers an output distance function as follows:

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

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 above equation 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:

$$m_o(y_s, x_s, y_t, x_t) = \frac{d_o^t(y_t, x_t)}{d_o^s(y_s, x_s)}$$

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

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.

There are a number of different methods that could be used to measure the distance functions that make up the Malmquist index. Following Färe et al (1994), the required distances are calculated using DEA-like linear programming models. For the i-th country, four distance functions are calculated to measure total factor productivity change, technological change and technical change between two periods. This requires the solving of four linear programming models:

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

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

$$\left[d_o^t (y_s, x_s) \right]^{-1} = max \;\; \phi$$
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$$x_{is} - X_t \lambda \;\; \geq 0$$
$$\lambda \;\; \geq 0$$

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

Note that in linear programming models three and four, where production points are compared to technologies from different periods, the f 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 four, where a production point from period t is compared to technology in earlier period s. If technical progress has occurred, a value of $f<1$ is possible. Note that it could also possibly occur in linear programming model three, 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. Some authors have suggested that all the Malmquist Data Envelopment Analysis calculations must be done assuming variable returns to scale. Apart from interpretation difficulties associated with total factor productivity measures based upon variable returns to scale technology, this approach can experience computational difficulties because the distances may not always be defined in some inter-period DEA-linear programming models. Hence, for these two reasons, the use of constant returns to scale methods is suggested to avoid these problems. The Malmquist (output-orientated) total factor productivity change index between period s (the base period) and period t is given by the Malmquist total factor productivity index and is defined by the geometric mean of two indices, in the spirit of Caves, Christensen and Diewert (1982).

3. Data and Information

This research work collected data exclusively from the AGROSTAT system of the Statistics Division of the Food and Agricultural Organisation in Rome. All necessary data and information were downloaded from the Web site of the Food and Agriculture Organisation 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 variables are crops and livestock. Aggregating detailed output data on agricultural commodities derives these two variables. The base year is 1989-91.

The study considers only five input variables. The first input variable collected is land, which includes permanent crops as well as the area under permanent pasture. The second one is tractors, 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, 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 labour input used in agricultural production, and the extent of overstatement depends upon the level of development of the country. The fourth variable refers to fertiliser, which is expressed by the sum of Nitrogen, Potassium and Phosphate contained in the commercial fertilisers consumed. The livestock variable used in this research is the sheep-equivalent of four categories of animals used in constructing this variable. The categories considered are: cattle, pigs, sheep and goats. Numbers of these animals are converted into sheep equivalents using conversion factors: 8.0 for cattle, and 1.0 for sheep, goats and pigs (Rao et al, 1998).

4. Results

The results of this research work are presented in this section. This paper provides a table of peers for all countries in five different periods, to understand the behaviour of global agricultural productivity in the European Union countries, and four Eastern European countries that have applied for European Union membership, over the period 1980-98. This study also presents information on the means of the measures of technical efficiency change, technical change and Total Factor Productivity change for each country over the 19-year sample period, and the mean changes between each pair of adjacent years over the 18 countries. In addition, it also provides means for certain groups of countries, and plots the total factor productivity trends of some selected groupings of countries.

Table 1 identifies all those countries that define the frontier technology for the years 1980, 1985, 1991, 1995 and 1998 in the vicinity of their observed output and in-

Tab. 1 *Peers for each of the European countries*

Num	Country	1980		1985		1991		1994		1998	
		Peers	Count	Peers	Count	Peers	Count	Peers	Count	Peers	Count
1	Austria	9 16 10	0	9 10	0	9 2 16 10 0	0	9 10 16	0	9 10 15	0
2	Bel-Lux	2	3	2	2	2	3	2	3	2	2
3	Denmark	10 5 2	0	3	1	3	3	3	1	3	2
4	Finland	16 10	0	16 10	0	10 16	0	10 16	0	16 10	0
5	France	5	2	5	1	5	1	5	2	5	2
6	Germany	16 10	0	10 9 3	0	16 3 10 9	0	9 3 10 5	0	10 9 16 5 3	0
7	Greece	7	2	7	0	7	0	7	1	7	1
8	Ireland	2 10	0	2 10	0	2 10	0	10 2	0	2 10	0
9	Italy	9	4	9	5	9	4	9	6	9	5
10	Netherlands	10	10	10	8	10	8	10	8	10	7
11	Portugal	10 7 9	0	12 9 10	0	16 9 10	0	10 26 9	0	7 18 9 10	0
12	Spain	12	0	12	1	16 5 9	0	10 5 9 2	0	12	0
13	Sweden	9 16 10	0	10 9 16	0	16 3 10	0	10 16 9	0	3 16 9 10	0
14	UK	5 2 10 16	0	5 2 16	0	3 2 16	0	2 15 5	0	2 5 16	0
15	Bulgaria	10 18 16 7	0	16 18 10	0	15	1	15	1	15	2
16	Hungary	16	7	16	5	16	9	16	5	16	5
17	Poland	16 9 10	0	10 9 16	0	16 10	0	10 16 9	0	15 9 16 10	0
18	Romania	18	1	18	1	16 10 15	0	18	0	18	1

Source: Model results
Note: The count is the number of times that country acts as a peer for another country

Tab. 2 *Efficiency and productivity changes for the European countries*

Country	effch	techch	tfpch
France	1.000	1.036	1.036
Bel-Lux	1.000	1.035	1.035
Denmark	1.006	1.028	1.034
Romania	1.000	1.033	1.033
Austria	1.006	1.025	1.031
Germany	1.006	1.025	1.031
Bulgaria	1.006	1.023	1.029
Finland	0.999	1.026	1.024
Ireland	0.998	1.026	1.023
Poland	1.013	1.011	1.023
Netherlands	1.000	1.021	1.021
Hungary	1.000	1.019	1.019
UK	0.985	1.031	1.016
Sweden	0.995	1.018	1.012
Italy	1.000	1.011	1.011
Greece	1.000	1.007	1.007
Spain	1.000	1.007	1.007
Portugal	0.989	1.009	0.999
Geomean	1.000	1.022	1.022

Source: Model results
Note: effch - technical efficiency change
techch - technical change
tpfch - total factor productivity change
Geomean - geometric mean

put mixes. These dates are important for examining the effects of certain decisions and measures on the agriculture of those European countries. The year 1980 represents the period before the accession of Greece to the European Union; the year 1985 the period before the entry of Portugal and Spain into the European Union; the year 1991 the last year of the old Common Agricultural Policy; the year 1995 the period before the accession of Finland, Sweden and Austria to the European Union; and, the year 1998 the period before Agenda 2000.

This table shows that there are 4 countries, France, Bel-Lux and Italy that are on the frontier technology in the period of study. For France, Bel-Lux and Italy are technical efficient, and Common Agricultural Policies have had a positive impact on their agriculture. The United Kingdom does not appear as a peer for any country from these periods of study. In contrast, the Netherlands appears as a peer for 10 countries in 1980 and 7 countries in 1998. Although Bulgaria and Hungary do not belong to the European Union now, the results show that these countries are technical efficient during the period of study, and appear as peers for 2 countries in 1998.

Table 2 shows the mean technical efficiency change, technical change and total factor productivity change for the 18 countries over the period 1980 to 1998. Countries in this table are presented in a descending order of the magnitude of the total factor productivity changes.

Table 3 shows a 2.2 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.

Table 4 provides a measure of technical efficiency change, technical change and total factor productivity change for five regions. The North European region consists of Denmark, Finland and Sweden; the Central European region Austria, Bel-Lux, France, Germany and the Netherlands; the Western European region Ireland and United Kingdom; the South European region Portugal, Spain, Italy and Greece; and the Eastern European region

Tab. 3 *Annual mean efficiency and productivity changes*

Year	effch	techch	tfpch
1981	0.986	0.995	0.981
1982	0.979	1.182	1.157
1983	1.039	0.876	0.910
1984	1.059	1.015	1.075
1985	0.962	1.025	0.986
1986	0.980	1.015	0.995
1987	1.024	1.015	1.039
1988	0.983	1.011	0.994
1989	1.014	1.040	1.055
1990	1.005	1.035	1.040
1991	0.979	1.097	1.073
1992	0.963	1.027	0.989
1993	1.053	0.951	1.002
1994	0.978	1.046	1.023
1995	0.988	1.061	1.048
1996	1.022	0.983	1.004
1997	1.005	1.042	1.047
1998	0.989	1.008	0.997
Geomean	1.000	1.022	1.022

Source: Model results
Note: effch - technical efficiency change
techch - technical change
tpfch - total factor productivity change
Geomean - geometric mean

Tab. 4 *Efficiency and productivity changes for each region*

Regions	effch	techch	tfpch
North	1.002	1.021	1.023
Central	1.002	1.022	1.024
Western	0.995	1.029	1.024
South	0.998	1.010	1.008
Eastern	1.005	1.021	1.026
Geomean	1.000	1.022	1.022

Source: Model results
Note: effch - technical efficiency change
techch - technical change
tpfch - total factor productivity change
Geomean - geometric mean

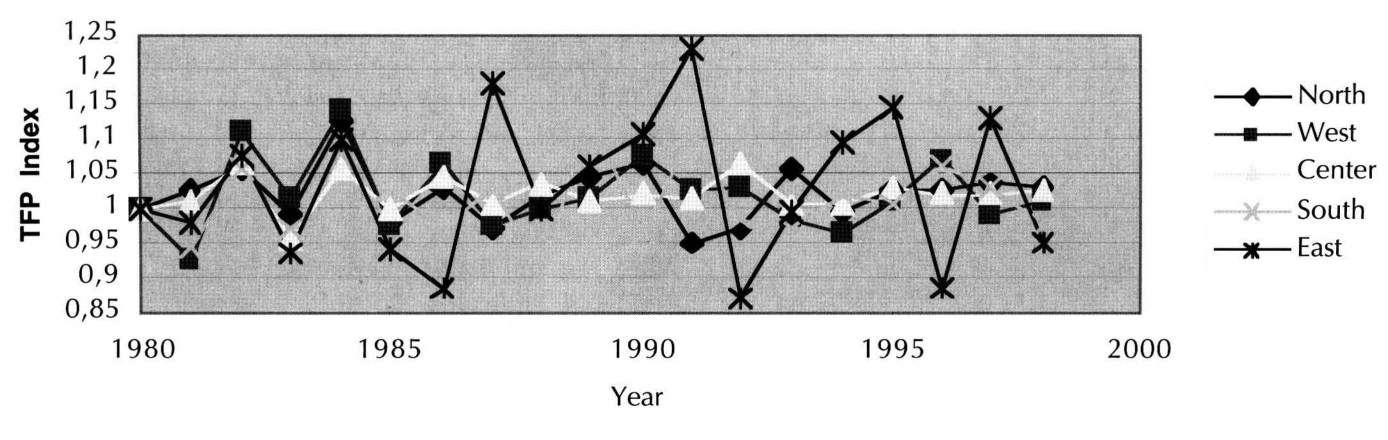

Figure 1 *Cumulative total factor productivity indices*

Bulgaria, Hungary, Poland and Romania.

The Eastern European region has the highest total factor productivity growth of 2.6 percent, followed by the Central and Western European regions. The Eastern European region growth is explained mainly by the technical change growth of 2.1 percent. The South European region, the Mediterranean, has the lowest growth rate of 0.8 percent in total factor productivity. The South and Western European regions are the two regions with negative growth in technical efficiency change. A surprising result is that, over the period 1980-1998, these results show no evidence of regional technological regression. 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.

Figure 1 shows cumulative total factor productivity indices over the period 1980-1998 for five different European regions. The North European region (consisting of Denmark, Finland and Sweden) has the highest cumulative growth by 1998, followed by the Central and the Western European region. The South and the Eastern European regions remain as the bottom regions in 1998. The Eastern European region (consisting of Bulgaria, Poland, Hungary and Romania) exhibits the greatest variation in total factor productivity growth over the period 1980-1998.

Tab. 5 *European countries classified by technical efficiency*

Efficient Level in 1980	effch	techch	tpfch
TE=1	1.000	1.021	1.021
1<TE<0.75	0.999	1.023	1.021
TE<0.75	1.003	1.021	1.023
Geomean	1.000	1.022	1.022

Source: Model results
Note: effch - technical efficiency change
techch - technical change
tpfch - total factor productivity change
Geomean - geometric mean

Table 5 shows the average annual changes for groups of European countries classified by their technical efficiency scores in 1980. The first group had 8 countries on the production frontier in 1980, and posted a 2.1 percent growth in total factor productivity due to 2.1 percent in technical change.

The second group, consisting of 7 countries that had an efficiency score between 0.75 and 1, posted a 2.1 percent growth in total factor productivity mainly driven by 2.3 percent technical change. The last group of 3 countries, with a technical efficiency score less than 0.75, posted a 2.3 percent growth in total factor productivity due to 0.3 percent in technical efficiency and 2.1 percent growth in technical change. These results are interesting since they confirm technological progress, in contrast to some conclusions of the earlier studies for the period 1961 to 1985. Another interesting feature is that there does not exist the predominance of technical efficiency change as a source of total factor productivity, in contrast to Rao and Coelli's findings (1998).

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. This study includes fifteen European Union countries and four East European countries that have already applied for European Union membership. The study makes use of data collected from the Food and Agriculture Organisation of the United Nations and covers the period 1980-1998.

An approach based on Data Envelopment Analysis is used to provide information on the peers of the (inefficient) i-th country and to derive the Malmquist productivity indices. This approach is chosen due to the non-availability of reliable input price data, and it does not assume all countries are fully efficient; it does not need to assume a behavioural objective function such as cost minimisation or revenue maximisation, and it permits total factor productivity growth to be decomposed into technical efficiency change and technical change.

Model results indicate which countries are on the frontier technology, and examine the growth in agricultural productivity in European Union countries and four East European countries, namely Bulgaria, Poland, Hungary and Romania over the period 1980 to 1998. France, Bel-Lux and Italy are on the frontier technology in the period of study. Although Bulgaria and Hungary do not belong to the European Union, these countries are on the frontier technology, too.

These results show an annual growth in total factor productivity of 2.2 percent, where a major contributing factor is technical change. Negative growth in efficiency change is observed in a couple of years.

France posts the most spectacular performance, with an average annual growth of 3.6 percent in total factor productivity over the study period. Bel-Lux and Denmark have a similar performance. Portugal posts a total factor productivity growth decline.

Turning to the performance of the five European regions defined in this research work, the Eastern European region (consisting of Romania, Bulgaria, Poland and Hungary) is the major performer, with an annual total factor productivity growth of 2.6 percent. The South European region, (consisting of Mediterranean countries such as Portugal, Spain, Italy and Greece) seems to be the weakest performer, with only 0.8 percent growth in total factor productivity.

The analysis of the question of catch-up and convergence shows that there were countries well below the production frontier in 1980, with a 2.3 percent growth in total factor productivity. This is in contrast to a 2.1 percent growth for the countries that were on the production frontier in 1980. These results indicate that technical efficiency is not a source of total factor growth productivity. Another interesting result is that there is not a degree of catch-up due to improved technical efficiency along with growth in technical change in the European Union Countries and the four Eastern European countries.

This research work has data limitations and further work in this area will be necessary. Future work will also include extending the study period to cover 1960-1979, to include other inputs and to examine the robustness of the results to shifts in the base period for the calculations of output aggregates.

References

Bureau, C., R. Färe and Grosskopf. "A Comparison of Three Nonparametric Measures of Productivity Growth in European and United States Agriculture" *Journal of Agricultural Economics*, 46(September 1995):309-326.

Caves, D. W., L. R. Christensen and W. E. Diewert, (1982). "The Economic Theory of Index Numbers and the Measurement of Input, Output and Productivity" *Econometrica* 50(November 1982):1393-1414.

Charnes, A., W.W. Coopers and E. Rhodes. "Measuring Efficiency of Decision Making Units" *Journal of Operational Research Society* 2(1978):429-444.

Coelli, Tim D.S. Prasada and George E. Battese. *An Introduction to Efficiency and Productivity Analysis.* Kluwer Academic Publishers, Boston, 1998.

Färe, R., S. Grosskopf, M. Morris and Zhang, (1994). "Productivity Growth, Technical Progress and Efficiency Changes in Industrialized Countries" *American Economic Review* 84(March 1994):66-83.

Fried, Harold O., C. A. Knox Lovell, Shelton S. Schmidt, editors. *The Measurement of Productive Efficiency - Techniques and Applications.* Oxford University Press, 1993.

Hayami, Y., and V. Ruttan (1970), "*Agricultural Productivity Differences among Countries*" American Economic Review 40(September 1970): 895-911.

Hayami, Y., and V. Ruttan. *Agricultural Development: An International Perspective.* Johns Hopkins Press, Baltimore, 1971.

Kawagoe, T.and Y. Hayami. "*The Production Structure of World Agriculture: An Intercountry Cross-Section Analysis*". Developing Economies 21(1983):189-206.

Kawagoe, T.and Y. Hayami (1983), "*An Intercountry Comparison of Agricultural Production Efficiency*". American Journal of Agricultural Economics 67(February 1985): 87-92.

Kawagoe, T.and Y. Hayami. "*An Intercountry Comparison of Agricultural Production Function and Productivity Differences among Countries*". Journal of Development Economics 19(1983): 113-132.

Lau, L. and P. Yotopoulos. "*The Meta-Production Function Approach to Technological Change in World Agriculture*". Journal of Development Economics 31(1981):241-269.

Maniadakis, N. and Thanassoulis, E. "*A Cost Malmquist Productivity Index*". European Journal of Operational Research(2000). Special issue on DEA and its Worldwide Applications (W. Cooper, L. Seiford, S. Zanakis, co-editors).

Rao D.S.P. and Coelli T. J. "*Catch-up and Convergence in Global Productivity 1980-1995*". Center for Efficiency and Productivity Analysis, Working Paper N° 4/98, Department of Econometrics, University of New England, Armidale, Australia, 1998.

Rao, D. S. Prasada. "*Intercountry Comparisons of Agricultural Output and Productivity*". FAO, Rome, 1993.