Measuring Eco-efficiency of Agricultural Activity in European Countries: A Malmquist Index Approach

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Abstract

This paper develops an environmental performance index by applying the benefit of the doubt weighting and the Malmquist index concepts using Kuosmanen and Kortelainen's approaches. The main difference between these approaches and other methods is that environmental performance is based on the definition of the eco-efficiency as the ratio of economic value added to the environmental damage index.

The overall environmental performance index is also decomposed into two components representing changes due to technological progress (or regress) and due to changes in relative eco-efficiency.

The dynamic environmental performance analysis is applied to 15 European agricultures from 1990 to 2004. Model results show that technical progress mostly explain overall environmental performance growth, while relative eco-efficiency changes have been minor for most European agricultures for the sample period.

Key Words: Benefit of the doubt weighting, Data Envelopment Analysis, Eco-efficiency, Environmental performance analysis, Malmquist Index, Agricultural Activity

JEL classification: Q57, C43, C61

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1 - Introduction

Eco-efficiency concept has received much attention and changed in ecological economics literature during the last decade. A considerable number of measures for environmental efficiency has been suggested (Tyteca, 1996). Most of these measures are only simply indicators, such as “economic output per unit of waste” ratios, which consider eco-efficiency from a very limited perspective. This research work considers that the eco-efficiency aggregates various environmental pressures related to the emissions of harmful substances and depletion of natural resources into a single environmental damage index like Kortelainen (2006). A static framework was developed by Kuosmanen and Kortelainen (2005) for measuring eco-efficiency, using the so-called benefit of the doubt weighting principle scheme based on Data Envelopment Analysis (Koopmans, 1952; Farrel, 1957; Charnes et al., 1978). This approach uses a non-parametric linear programming model for evaluating performance of comparable production units.

The Kuosmanen and Kortelainen’s approach is a static framework and does not account for technical change or explain changes in environmental performance over time. Korteleinen (2006) developed a framework for the measurement of eco-efficiency over time using the Malmquist index that allows dynamic eco-efficiency analysis. This approach analyzes the sources of changes in environmental performance over time and decomposes the environmental performance into two components that represents the changes due to progress (or regress) and due to changes in relative eco-efficiency.

The main purpose of this research work is to apply Kortelainen’s approach for measuring eco-efficiency at aggregate level in agriculture of 15 European countries from 1990 to 2004. The purpose of the application is to examine how changes of environmental performance and its components have been changing during the sample period and identify major factors in each European agriculture's performance growth.

This paper is organized into five sections. Following this introduction, an analytical framework is presented. Next, data and their sources are described. The last two sections present model results and some concluding remarks.

2 – Analytical Framework

The present framework is based on the definition of eco-efficiency as a ratio of economic value added to environmental damage or pressure index. So, it is important to explain in more detail what is meant by the numerator and the denominator of eco-efficiency ratio. The components of the denominator use the notion of "environmental pressure" which refers to an environmental theme or category that is influenced by multiple pollutants contributing to the same environmental problem. An environmental pressure category is global warming potential that is affected by carbon-dioxide (CO_2), methane (CH_4) and other green house gases. The amounts of different green house gases are translate into a single environmental pressure category measured in carbon dioxide equivalents (Houghton et al., 1996). Besides green house gases, conversion factors allow to aggregate other emissions into broader environmental pressure themes such as acidification potential theme and eutrophication theme. A more detailed discussion about environmental pressures and aggregation possibilities of individual pollutants was presented by Kuosmanen and Kortelainen (2005). The numerator of the eco-efficiency ratio, economic value added, is another important concept. Gross domestic product (GDP) can be used as a measure for economic value added, because it does not include intermediate outputs. Economic value added is the sum of firm's profit and its labor and capital costs. This concept can include either explicitly or implicitly the effects of emissions that have a direct effect on economic activity, i.e, environmental externalities are fully internalized as a social cost in value added. If environmental pressure themes do not have a direct effect on economic activity, they are not fully or partially internalized. So, it seems reasonable to account for physical environmental measures separately from value added, as is done in eco-efficiency analysis.

After presenting concepts and variables used in this research work, it is presented how eco-efficiency can be measured in a cross-sectional setting using the so-called benefit of the doubt weighting scheme based on Data Envelopment Analysis (Farrell, 1975; Charnes, Cooper and Rhodes, 1978). This approach uses DEA-based weighting method but do not include physical inputs and outputs (Cherchye, 2001; Cherchye et al. 2004; Cherchye and Kousmanen, 2006; Cherchye at al., 2006).

The eco-efficiency measure can be defined formally as a ratio of economic value-added to the environmental index (Schmidheiny and Zorraquin,1996):

$$EP_k = \frac{V_k}{D(Z_k)} \qquad (1)$$

where V_k represents the economic value added and Z_k is a vector of environmental pressure themes generated by the unit k. D is the unknown damage function that aggregates M environmental pressure themes into a single environmental damage score.

EP_k, environmental performance measure, is an absolute measure in the sense that it does not reveal any baseline to which to compare the given eco-efficiency value. This measure is not very informative. It is necessary to compare production unit's eco-efficiency value with the values of other comparable units that face same kinds of environmental challenges. This can be done if it is introduced the relative eco-efficiency measure as the ratio of environmental measure (1) to the maximum observed environmental performance in the sample, defined as follows:

$$EE_k = \frac{EP_k}{\max\limits_{n \in \{1,..,N\}} EP_k} \qquad (2)$$

The relative eco-efficiency scores are calculated using some weighting method for constructing environmental damage score $D(Z_k)$. An approach is to take a weighted average (or sum) of the various environmental pressure themes, that is,

$D(z) = w_1z_1+\ldots+w_mz_m$

Where w_i represents the weight accorded to environment pressure i. The damage index D must be a weighted sum of z in order to satisfy desirable properties of units' invariance, weakly increasing, and continuous (Elbert and Welch, 2004). The question is how the weights (w_i) should be chosen or determined. Hence, an approach is used to determine those weights.

The empirical eco-efficiency measure can be calculated by formulating the primal problem:

$$\begin{aligned}
&\max EE_k = \frac{V_k}{w_1 Z_{n1} + \cdots + w_M Z_{nM}} \\
&\text{s.t.} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (3) \\
&\frac{V_n}{w_1 Z_{n1} + \cdots + w_M Z_{nM}} \le 1 \qquad \forall n = 1,...,N \quad \text{(normalization constraint)} \\
&w_m \ge 0 \qquad\qquad\qquad\qquad \forall m = 1,...,M \ \ \text{(non - negativity constarint)}
\end{aligned}$$

This mathematical programming model involves a non-linear objective function and non-linear constrains, which makes it computationally hard. This problem can be linearized by taking the inverse of the eco-efficiency ratio and solving the reciprocal problem:

$$\min \ \left(EE_k\right)^{-1} = \frac{1}{V_k}\left(w_1 Z_{k1} + \ldots + w_M Z_{kM}\right)$$

$$\text{s.t.} \qquad (4)$$

$$\frac{1}{V_n}\left(w_1 Z_{n1} + \ldots + w_M Z_{nM}\right) \geq 1 \qquad \forall n = 1,\ldots,N \ \text{(normalization constraint)}$$

$$w_m \geq 0 \qquad \forall m = 1,\ldots,M \ \text{(non - negativity constraint)}$$

This problem is linear in terms of the unknown parameters w_m and can be solved by standard linear programming algorithms. The relative eco-efficiency measure is obtained by taking the inverse of the optimal solution. For the purpose of dynamic eco-efficiency analysis, it is important to refer that the presented benefit of the doubt weighting approach is equivalent (i. e. dual problem) to the Shephard's (1953, 1970) distance function approach employed in the literature of productivity analysis. This research work uses the benefit of doubt weighting to calculate the relative eco-efficiency measures (4) instead of the input distance function, because the former has a straight and intuitive connection to eco-efficiency ratio (1). However, the framework presented is static and it cannot explain observed changes in environmental performance over time. A dynamic co-efficiency approach must be developed to permit the analysis of technical progress and can explain sources of environmental performance changes.

The dynamic approach is developed from total productivity measurement literature and the Malmquist index introduced by Caves et a.(1982) and popularized as an empirical index by Färe et al. (1994a, 1994b). The Malmquist index has some desirable properties which are highly useful in empirical work. This index can be used in situations where either prices do not exist or where existing prices have little economic meaning and it can be decomposed into economically relevant sources of productivity changes. Färe et al. (1994a, 199b) showed that Malmquist index can be expressed as the product of an efficiency change index and a technical change index, which measure the extent to which changes are due to changes in efficiency and technology, respectively. However, the most important difference is that this approach is based on the definition of eco-efficiency and do not consider traditional inputs and outputs, but value added and environmental pressures used to calculate the relative eco-efficiency measure of production of unit k observed in period s ($EE_k(Z^s,V^s,t)$), measured relative to the frontier of period t by the following model:

$$\min \ \left[EE_k\left(Z^s, V^s, t\right)\right]^{-1} = \frac{1}{V_k(s)}\left(w_1 Z_{k1}(s) + \ldots + w_M Z_{kM}(s)\right)$$

$$\text{s.t.} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (5)$$

$$\frac{1}{V_n(t)}\left(w_1 Z_{n1}(t) + \ldots + w_M Z_{nM}(t)\right) \geq 1 \qquad \forall n = 1,\ldots,N \ \ \text{(normalization constraint)}$$

$$w_m \geq 0 \qquad \forall m = 1,\ldots,M \ \ \text{(non - negativity constraint)}$$

where symbols in brackets (i. e. after Z_{km} and V_k) refer to the period of observation. To measure the change of environmental performance in unit k from period t-1 to t, it is considered the frontier of period t as the benchmark and quantifies environmental performance change by ratio of relative eco-efficiency scores based on adjacent observations. The frontier of period t-1 can also be used as a benchmark to calculate the environmental change measure, but there is no reason to prefer period t or t-1 as a benchmark. Using Fisher's approach (1922) and taking the geometric mean of the two measures, the environmental performance index (EPI) is calculated as follows:

$$EPI_k(t-1, t) = \left(\frac{EE_k(Z^t, V^t, t-1}{EE_k(Z^{t-1}, V^{t-1}, t-1} \text{ x } \frac{EE_k(Z^t, V^t, t}{EE_k(Z^{t-1}, V^{t-1}, t}\right)^{1/2}, \ \ t = 2,\ldots,7 \qquad (6)$$

The environmental performance index (EPI) is similar to the input-oriented Malmquist productivity index, but in this context it measures environmental performance and not traditional or environmental performance sensitive productivity. If this index has values greater than one, it will indicate improvement of environmental performance in time;

otherwise it will indicate deterioration in environmental performance from period t-1 to t.

The environmental performance index (6) shows whether the production unit has progressed or not, but does not indicate any source of environmental performance change. The overall environmental performance change can be decomposed into two components representing changes due to technological progress (or regress) and due to changes in relative eco-efficiency. Following Nishimizu and Page (1982), Färe et a. (1994a) and Korlelainnen (2006), this decomposition is presented by the following expression:

$$EPI_k(t-1,t) = \frac{EE_k(Z^t,V^t,t)}{EE_k(Z^{t-1},V^{t-1},t-1)} \text{ x } \left(\frac{EE_k(Z^t,V^t,t-1}{EE_k(Z^{t-1},V^{t-1},t} \text{ x } \frac{EE_k(Z^t,V^t,t-1}{EE_k(Z^t,V^t,t}\right)^{1/2} \qquad (7)$$

$$= ECOEFF_k(t-1,t) \text{ x } TECH_k^{t,t-1}$$

This index is the same environmental performance index (6), but now written as a product of two mutually exclusive an exhaustive components, catching up and technical change. According to this decomposition, environmental performance growth may result from reduced relative inefficiency or improvement of the production technology or both. Technical change and relative eco-efficiency change components may move in opposite directions, it is possible that there is simultaneous improvement in overall environmental performance and deterioration in relative performance ($EPI_k(t-1,t)>1$ when $ECOEFF(t-1,t)<1$ or vice-versa).

3 – Data and Information

This research work calculates an environmental performance index and its components for a sample of 15 European agricultures from 1990 to 2004 and representing four different environmental pressure themes.

The 15 European agricultures including abbreviations are: Belgium (BEL), Denmark (DEN), Germany (GER), Ireland (IRL), Greece (GRE), Spain (SPA), France (FRA), Italy (ITA), Luxemburg (LUX), Netherlands (NED), Austria (AUT), Portugal (POR), Finland (FIN), Sweden (SWE) and United Kingdom (UK).

The environmental pressure themes related to agriculture and used in this research work are global warming potential (GWP), acidification potential (ACID), eutrophication (EUTRO) and waste (WAS). Global warming potential theme relates to the danger of climate change caused by a concentration of greenhouse gases in atmosphere including carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). The acidification theme relates to the damage caused by the deposition of nitrogen oxides (NO_x), sulphur oxides (SO_2) and ammonia (NH_3) in soil and surface water. The eutrophication theme relates to the problem of the problem of accumulation of nitrogen (N) and phosphorus (P) in soils and subsequently in groundwater and surface water. Acidification and eutrophocation themes are serious threats, because they endanger ecosystems and the quality of drinking water. The accumulation of waste is a serious problem. This theme is restricted to waste consisting of products that have lost their economic use and have a negative impact on environment when they are thrown out.

The present approach focus on environmental pressure themes rather than specific undesirable outputs (Kortelainen, 2006). Undesirable outputs of production include air emissions such as carbon dioxide and methane. These emissions have much more impact on climate change than the amount of carbon dioxide in the atmosphere. Other environmental pressure themes are also important, because they can pollute surface water resources, groundwater and natural environment. This seems to be more appropriate to build eco-efficiency analysis on aggregated measures of environmental themes using conversion factors to aggregate individual pollutants that contribute to the same environmental theme. The used conversion factors are collected from Houghton et al. (1996), Leeuw (2002) and Kortelainen (2006) remembering that they allow to aggregate individual pollutants into environmental pressures indicators, but environmental pressure represent potential not true environmental impacts.

The relationship between "environmental pressure themes" and "pollutants" due to agriculture is shown in table 3.1.

Environmental pressure	**Specific emissions**	**Unit measurement**
Global warming potential	CO_2, CH_4, N_2O	tons of CO_2 equivalents / year
Acidification	NO_x, SO_2, NH_3	tons of acid equivalents / year
Eutrophication	P, N	tons of nutrient-equivalents / year
Waste	Solid waste	tons / year

Table 3.1 – The main environmental pressure themes due to agricultural activity

The analysis of table 3.1 indicates that some adverse environmental effects from agricultural activity are directly measured by a single indicator (waste), while other environmental pressure themes (global warming potential, acidification and eutrophication) are influenced by several emissions, which can be aggregated by using well-defined conversion factors.

The value added measure is measured by agricultural gross domestic product and for environmental pressure data in European agricultures various pollutant emissions are used. Agricultural gross domestic product is collected from European Agricultural

Statistics (base year 1998). Agricultural emission data for each European agriculture are taken from the European Environmental Agency and the Netherlands Statistics.

4 - Results

The eco-efficiency scores are calculated to each year's frontier and presented in Table 4.1, which lists both average eco-efficiency scores and scores in years 1990 and 2004 for each European agriculture.

Country	1990	2004	Average Eco-efficiency
BEL	0.952	0.810	0.878
DEN	0.862	0.902	0.882
GER	0.903	0.995	0.948
IRL	0.823	0.726	0.773
GRE	0.805	0.657	0.727
SPA	0.913	0.848	0.880
FRA	0.925	0.967	0.946
ITA	0.971	0.882	0.925
LUX	0.783	0.984	0.878
NED	0.991	0.944	0.967
AUT	0.995	0.975	0.985
POR	0.651	0.703	0.677
FIN	0.824	0.735	0.778
SWE	1.000	1.000	1.000
UK	0.843	0.938	0.889
Mean	0.877	0.863	0.870

Table 4.1- Relative Eco-efficiency scores

Source: Model results

Model results show that there were in minimum two European agricultures (1994 and 1995) and maximum four European Agricultures (2000) with the score of one. Sweden is the only agriculture on the efficient frontier each year, Austria, Germany and Sweden were efficient in some years. Portugal was the most inefficient agriculture each year with the average efficiency of 0.677. Other poorly ranked agricultures include Greece, Ireland and Finland. The eco-efficiency of these European agricultures is much lower in 2004 compared to 1990, while for Germany and United Kingdom is reverse.

Country	EPch	Eco-effch	Techch
BEL	1.050	1.000	1.050
DEN	1.053	0.998	1.051
GER	1.056	1.003	1.059
IRL	1.048	1.002	1.050
GRE	1.069	0.989	1.057
SPA	1.082	0.972	1.052
FRA	1.063	1.005	1.068
ITA	1.103	0.964	1.063
LUX	1.060	1.010	1.071
NED	1.110	0.975	1.082
AUT	1.076	1.005	1.081
POR	1.048	0.971	1.018
FIN	1.096	0.963	1.055
SWE	1.063	1.000	1.063
UK	1.051	1.000	1.051
Mean	1.068	0.990	1.058

Table 4.2 – Environmental performance change and its components

Source: Model results (average values)

The average values of European agricultures' environmental performance index and its components are reported in Table 4.2. All European agriculture results show that it is indeed technical change that mostly explains environmental performance growth. Netherlands, Italy and Finland environmental performance has increased the most, whereas Belgium, Ireland and Portugal the growth has been the lowest in the sample period. These results are not surprised because in Portugal the absolute level of greenhouse gases and eutrophification effects have increased most among European agricultures. Environmental performance growth of Netherlands is explained by the reduction of ACID and Eutrophication.

The analysis of eco-efficiency changes shows that there are no great differences between European agricultures. Finland has the lowest value (0.963), while Luxembourg has the highest value (1.010). Model results show that for eight of 15 European agricultures the average eco-efficiency change has been positive (over one), which means that these agricultures have caught up the eco-efficiency benchmarks. However, it is average technical change that contributes most to environmental performance growth, as each European agriculture value deviates from one. This is understandable because technical change describes the change of the frontier, i.e. the best performers of the sample and not the development of the agricultures under the frontier.

5- Conclusions

This research work applies Kuosmanen and Kortelainen’s frameworks for developing a dynamic eco-efficiency analysis for 15 European agricultures. These frameworks uses benefit of doubt weighting and a Malmquist index concept to construct an environmental performance index (EPI) and decomposes this index into technical change and relative eco-efficiency components. This decomposition can be very useful when sources and reasons for changes in environmental performance are analyzed over time.

The main difference between this approach and other methods is that environmental performance is based on the definition of the eco-efficiency as the ratio of economic value added to the environmental damage index as it is presented in ecological economic literature. The environmental damage index is built aggregating emissions of individual pollutants into environmental pressure themes. So, this approach can be seen as integrating the perspectives of ecological economics and the frontier approach of environmental performance analysis into a unified framework. A very important advantage of this framework is that it can include a large number of different emissions simultaneously allowing interesting directions for further research and many applications possibilities such as agricultural activity.

The dynamic environmental performance analysis in this research work is applied to 15 European agricultures from 1990 to 2004. Model results show that technical progress mostly explains overall environmental performance growth, while relative eco-efficiency changes have been minor for most European agricultures for the sample period.

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