THE TRENDS OF TECHNICAL, ENVIRONMENTAL AND RESOURCE EFFICIENCY ACROSS AGRICULTURAL SECTORS OF EUROPEAN COUNTRIES

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This paper aims to analyse economic, environmental and resource use efficiency in the European Union agriculture. Specifically, we focus on selected countries specific with rather similar output mix. Different frontier models are defined to analyse the underlying trends in efficiency across the European countries. The data come from the World Input-Output Database and cover the period of 1995–2009. Frontier models assume weak disposability and consider such variables as labour, capital, energy, land, materials, water, gross value added, and carbon emission. Slovenia, Belgium, France, Austria and Poland appeared to be the most technically efficient countries. Bulgaria, the Netherlands, and Romania also gained considerable competitiveness in terms of eco-efficiency and resource use efficiency thus appearing among most efficient countries under frontier models with undesirable outputs. Latvia, Czech Republic, Estonia, and Hungary emerged as the least efficient countries in terms of agricultural production under all specifications of the frontier models.

Keywords: data envelopment analysis, eco-efficiency, resource efficiency, technical efficiency, weak disposability.

JEL codes: C44, Q15.

1. Introduction

Efficiency and productivity are the key elements of competitiveness of a firm, sector or economy. Indeed, these indicators reflect the effort taken by decision makers in order to increase performance of an entity of interest. Therefore, it is important to track the development in efficiency and productivity to fathom the possible challenges for businesses and related stakeholders. Application of an appropriate methodology might eventually lead to identification of possible ways of improvement. Therefore, public support is allotted to agricultural producers. Finally, a common market prevails across the European Union (EU) Member States. These factors imply that there is a need for research into efficiency of agricultural sectors within and across the European countries.
As regards the measures of efficiency, the main strand for multi-dimensional analysis rests on frontier techniques (Gorton, 2004), which allow for estimation of the underlying production frontier along with relative efficiency. Specifically, frontier techniques can be grouped into parametric and non-parametric ones. The non-parametric framework rests on M. J. Farrell (1957), who introduced technique known as Data Envelopment Analysis (DEA), see R. Färe et al. (2013) for a more recent survey. Indeed, efficiency measures can also be used to construct indices for measurement of changes in the total factor productivity (TFP).

There have been studies that attempted to compare agricultural sectors across different countries in terms of TFP change. T. J. Coelli and D. S. Rao (2005) analysed the performance of agricultural sectors across various countries. L. Błażejczyk-Majka et al. (2012) focused on European countries. A. Nin-Pratt and B. Yu (2010) employed Malmquist TFP index with shadow price restrictions for an international comparison. V. N. Hoang (2011) analysed TFP changes along with considerations of environmental pressures rendered by agriculture.

Measurement of efficiency is based upon the choice of input and output variables, which define the technology. Usually, such inputs as land, labour, capital as well as such outputs as production quantity are considered in the analysis. Such a setting yields estimates of technical efficiency. However, it has been pointed out that such indicators as output quantity or value added do not encompass all the dimensions of welfare (cf., e.g., Stiglitz, 2010). Therefore, one can distinguish among different types of efficiency and corresponding settings of inputs and outputs. First, technical efficiency is the most common type of efficiency analysed in the literature. It basically focuses on transformation of marketable inputs into marketable outputs. Second, eco-efficiency relates ecological pressures to economic activities (Korhonen, 2004; Lábaj, 2014). Ecological pressures are represented by greenhouse gas (GHG) emission, nutrient balance (Piot-Lepetit, 2007; Hoang, 2011) or any other quantified externalities of interest. Therefore, additional dimensions of sustainability are taken into consideration. Third, resource efficiency focuses on material flows of resources (Hoang, 2014). Indeed, energy (exergy or emergy can also be used) flows represent environmental pressures induced by the production process. However, such natural resources as water can also directly enter the model. Therefore, several models need to be considered in order to arrive at a comprehensive ranking.

In frontier-based analysis, inclusion of such undesirable outputs as GHG emission requires certain assumptions regarding their disposability. R. Färe et al. (1989) proposed modelling processes with undesirable outputs under the assumption of weak disposability. Accordingly, various DEA-based models have been proposed to include environmental pressures as undesirable outputs in the production process (Mahlberg, 2011; Sahoo, 2011). In this paper, we follow the latter approach and assume weak disposability of carbon emission.

This paper aims to analyse economic, environmental and resource use efficiency in the EU agriculture. Specifically, we focus on countries specific with rather similar output mix. The following tasks are set: i) to describe the frontier methodology under the assumption of weak disposability, ii) to define frontier models for estimation of measures of efficiency, iii) to analyse the underlying trends in efficiency.
across the EU Member States. The data come from the World Input-Output Database (Timmer, 2012) and cover the period of 1995–2009.

The paper proceeds as follows: Section 2 presents the preliminaries for frontier models under the assumption of weak disposability. Section 3 presents the data used along with frontier models for analysis of technical, environmental, and resource efficiency. Section 4 presents results of the research.

2. Preliminaries

Frontier models represent a productive technology in terms of inputs and outputs. Indeed, the measures of efficiency rendered by these models can be interpreted as ratios of the weighted outputs to the weighted inputs. The weights are, indeed, shadow prices of inputs and outputs.

Assume the underlying technology is represented by a vector of inputs, 
$$x = (x_1, x_2, \ldots, x_m) \in \mathbb{R}^m$$
and a vector of good (desirable) outputs, 
$$y = (y_1, y_2, \ldots, y_n) \in \mathbb{R}^n$$
and a vector of bad (undesirable) outputs, 
$$b = (b_1, b_2, \ldots, b_p) \in \mathbb{R}^p$$. Then, the technology is defined as the following relation (Färe et al., 2005):

$$T = \{(x, y, b) : x \text{ can produce } (y, b)\}. \quad (1)$$

Furthermore, the underlying technology can be represented by an output correspondence set:

$$P(x) = \{(y, b) : (x, y, b) \in T\}. \quad (2)$$

In the presence of undesirable (bad) outputs, the production technology is assumed to feature weak disposability of bad outputs (Shephard, 1970), strong disposability of good outputs, and null-jointness (Shephard, 1974). Weak disposability implies that good and bad outputs can be scaled down mutually, i.e. \((y, b) \in P(x)\) and \(0 \leq \theta \leq 1\) render \((\theta y, \theta b) \in P(x)\). As regards strong disposability, for \((y, b) \in P(x)\) and \(y' \leq y\) we have \((y', b) \in P(x)\). Finally, null-jointness imposes restriction on good outputs in the absence of bad ones: if \((y, b) \in P(x)\) and \(b = 0\), then \(y = 0\).

Directional output distance function (Chung, 1997) is applied to measure the efficiency of production plan:

$$D(x, y, b; g_y, g_b) = \max \left\{ \beta : (x, y + \beta g_y, b + \beta g_b) \in T \right\}, \quad (3)$$

where \(g_y \in \mathbb{R}^n\) and \(g_b \in \mathbb{R}^p\) are directional vectors defining the direction of movement towards the production frontier and \(d = (g_y, g_b)\). In case the elements of the latter vectors are positive (resp. negative), one seeks for increase (resp. decrease) in respective output when moving towards the frontier. Therefore, various programs are possible.
for this kind of efficiency measures. For instance, one can pick \( d_y = (y, b) \) to increase both desirable and undesirable inputs or \( d_y = (y, -b) \) to increase desirable outputs while maintaining a decrease in undesirable ones. In both cases, \( \beta \in [0, +\infty) \) will be a proportional change in output vectors, where \( \beta = 0 \) indicates full efficiency.

The underlying technology can be approximated via DEA. Specifically, the observations are enveloped assuming no specific functional form of the production frontier in the spirit of minimal extrapolation. The following linear programming problem yields the estimate of directional distance function for observation \((x_0, y_{0g}, b_0)\) under the assumption of constant returns to scale (cf. Färe, 2006):

\[
D(x_0, y_0, b_0; g_y, g_b) = \max_{\lambda_1, \beta} \beta
\]

\[
\sum_{k=1}^{K} \lambda_k x_{ik} \leq x_{0i}, i = 1, 2, ..., m,
\]

\[
\sum_{k=1}^{K} \lambda_k y_{jk} \leq y_{0j} + \beta g_y, j = 1, 2, ..., n,
\]

\[
\sum_{k=1}^{K} \lambda_k b_{lk} \leq b_{0l} + \beta g_b, l = 1, 2, ..., p,
\]

\[
\lambda_k \geq 0, k = 1, 2, ..., K,
\]

where \( k = 1, 2, ..., K \) is the index of decision making units, \( \lambda_k \) are the intensity variables, \( g_y \) and \( g_b \) are directional vectors. Figure 1 below depicts an output correspondence set in two-dimensional case.

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Fig. 1. Weak disposability technology as represented by the output correspondence set and directional efficiency measures for observation \( E \)

Output correspondence set under weak disposability is represented by \( 0ABCDD' \) in Figure 1. Without the assumption of weak disposability, the set would be expanded to \( 0'C'DDD' \). The estimates of directional distance function (cf. Eq. 3 and Eq. 4) for point \( E \) can be defined as those projecting it onto the frontier in the direction of \((y_E + \beta y_E, b_E - \beta b_E)\), i.e. by reducing the bad output and increasing the good
one simultaneously. Denoting the estimates of $\beta$ associated with points $E'$ and $E''$ as $\beta_{E'}$ and $\beta_{E''}$, respectively, we see that $\beta_{E'} \leq \beta_{E''}$, which means that the assumption of free disposability is associated with higher inefficiency.

Note that Eq. 4 assumes constant returns to scale. Indeed, such a setting is usually employed for aggregate data analysis. As we focus on international comparisons based on aggregate data, we stick to this assumption. However, H. Leleu (2013) discussed the imposition of variable returns to scale under weak disposability.

### 3. Data used

The research relies on the data from the World Input-Output Database (Timmer, 2012). The data cover years 1995–2009. Specifically, the research focuses on the data series for the Agriculture, Hunting, Forestry and Fishing sector (NACE 1.1 sectors A-B). In order to facilitate the international comparisons, the gross value added (GVA) and real fixed capital stock are deflated by respective price indices available in the World Input-Output Database (base year 1995) thus constructing the implicit quantity indices. Furthermore, purchasing power parities of 1995 based on the EU-28 Gross Domestic Product are used. Therefore, the monetary terms used in this study are expressed in purchasing power standards (PPS) of 1995, which are devoid of price and exchange rate differences, otherwise existing among the analysed states. Note that the World Input-Output Database presents material extraction rather than direct material consumption.

To model the production process, we also include total hours worked by employees, emission relevant energy use (in terajoules), CO$_2$ emissions (in tonnes), land use (in hectares), materials use (in tonnes), and water use (in cubic meters).

As the analysis focuses on the three types of efficiency, namely technical efficiency, eco-efficiency, and resource efficiency, the three DEA models are defined (Table 1). Model I includes no undesirable outputs and therefore collapses to simple output-oriented DEA model. Models II and III include undesirable output and thus seek to minimise the carbon emission and maximise value added simultaneously.

| Table 1. Specifications of the DEA models |
|------------------------------------------|
| Model                  | Inputs                             | Good outputs | Bad outputs  |
| I – Technical efficiency  | Labour, capital, energy            | GVA          |             |
| II – Eco-efficiency      | Labour, capital, energy            | GVA          | Carbon emission |
| III – Resource efficiency| Labour, capital, energy, land, materials, water | GVA          | Carbon emission |

Therefore, technical efficiency is estimated in terms of marketable input consumption and generation of value added, whereas eco-efficiency accounts for carbon emission. Finally, the use of natural resources (which are often unmarketable) is considered when estimating resource efficiency. Accordingly, the latter measure can be considered as the most holistic one. We use output orientation in each model; however, different directional vectors can be employed to address different aspects of sustainability.
4. Results

The data were pooled and analysed in a cross-sectional way. The obtained efficiency scores can be interpreted as an increase in good outputs (along with the same decrease in bad outputs for Models II and III) measured in percentage of the initial output level. Note that we keep adding additional variables when moving from Model I to Model III. Therefore, inefficiency can only decrease for a given country due to inclusion of new variables, yet changes in ranking are not that certain.

Tables 2–4 below present the main findings regarding technical efficiency, eco-efficiency, and resource efficiency. Average inefficiency scores over the period of 1995–2009 are reported and ranked. Standard deviation (SD) and coefficient of variation (CV) is presented for each country. To gain insights into the trend of relative efficiency, ranks at the endpoints of the research periods are also reported.

Table 2. Technical efficiency across the selected European countries, 1995–2009

| Country     | Average | SD  | CV   | Rank | Rank 1995 | Rank 2009 |
|-------------|---------|-----|------|------|-----------|-----------|
|             | $\beta$ | SD  | CV   | Rank |           |           |
| Austria     | 0.14    | 0.08| 0.54 | 4    | 1         | 7         |
| Belgium     | 0.12    | 0.14| 1.13 | 2    | 3         | 10        |
| Bulgaria    | 0.18    | 0.18| 0.97 | 6    | 9         | 8         |
| CzechR.     | 1.26    | 0.21| 0.16 | 16   | 16        | 18        |
| Germany     | 0.86    | 0.24| 0.28 | 14   | 15        | 16        |
| Denmark     | 0.66    | 0.13| 0.20 | 12   | 12        | 12        |
| Estonia     | 1.31    | 0.45| 0.34 | 17   | 14        | 17        |
| Finland     | 0.61    | 0.10| 0.16 | 11   | 10        | 13        |
| France      | 0.12    | 0.05| 0.43 | 3    | 5         | 3         |
| Hungary     | 1.45    | 0.85| 0.59 | 18   | 18        | 9         |
| Lithuania   | 0.71    | 0.21| 0.29 | 13   | 11        | 15        |
| Latvia      | 1.08    | 0.48| 0.44 | 15   | 17        | 14        |
| Netherlands | 0.28    | 0.07| 0.25 | 9    | 6         | 6         |
| Poland      | 0.14    | 0.09| 0.63 | 5    | 4         | 5         |
| Romania     | 0.21    | 0.18| 0.82 | 7    | 7         | 10        |
| Slovakia    | 0.47    | 0.34| 0.72 | 10   | 13        | 1         |
| Slovenia    | 0.06    | 0.07| 1.17 | 1    | 1         | 1         |
| Sweden      | 0.22    | 0.11| 0.51 | 8    | 8         | 4         |

Slovenia, Belgium, France, Austria and Poland appeared to be the most technically efficient countries considering the average inefficiency scores for 1995–2009 (cf. Table 2). Indeed, these countries should have expanded their outputs by 6–14% relative to the initial output levels. Whereas Slovenia, France, and Poland showed insignificant changes in ranking throughout the said period, Austria and Belgium were specific with rather steep changes in ranks. Indeed, these countries showed decreases in the overall ranking. Latvia, Czech Republic, Estonia, and Hungary emerged as the least efficient countries in terms of agricultural production. Specifically, the output expansions of 108–145% were needed for the latter countries. Out of the worst performing countries, only Hungary managed to as-
cend in the ranking throughout 1995–2009. Indeed, such countries as Latvia and Estonia are restricted in the sense of efficiency gains due to geo-climatic conditions.

Table 3. Eco-efficiency across the selected European countries, 1995–2009

| Country   | Average β Rank | SD    | CV    | Rank 1995 | Rank 2009 |
|-----------|----------------|-------|-------|-----------|-----------|
| Austria   | 0.08           | 2     | 0.05  | 0.60      | 1         | 5         |
| Belgium   | 0.08           | 3     | 0.09  | 1.08      | 4         | 10        |
| Bulgaria  | 0.12           | 5     | 0.15  | 1.28      | 10        | 6         |
| Czech R.  | 0.88           | 18    | 0.06  | 0.07      | 16        | 18        |
| Germany   | 0.67           | 16    | 0.14  | 0.21      | 18        | 15        |
| Denmark   | 0.48           | 12    | 0.09  | 0.18      | 14        | 11        |
| Estonia   | 0.66           | 15    | 0.23  | 0.35      | 12        | 17        |
| Finland   | 0.46           | 11    | 0.07  | 0.14      | 13        | 13        |
| France    | 0.09           | 4     | 0.06  | 0.67      | 6         | 1         |
| Hungary   | 0.73           | 17    | 0.24  | 0.33      | 17        | 12        |
| Lithuania | 0.58           | 13    | 0.16  | 0.28      | 11        | 16        |
| Latvia    | 0.64           | 14    | 0.10  | 0.16      | 15        | 14        |
| Netherlands | 0.21         | 10    | 0.06  | 0.27      | 7         | 7         |
| Poland    | 0.13           | 6     | 0.10  | 0.77      | 1         | 7         |
| Romania   | 0.16           | 7     | 0.15  | 0.90      | 8         | 9         |
| Slovakia  | 0.20           | 9     | 0.13  | 0.65      | 5         | 1         |
| Slovenia  | 0.05           | 1     | 0.06  | 1.22      | 1         | 1         |
| Sweden    | 0.19           | 8     | 0.12  | 0.65      | 9         | 1         |

Inefficiency scores in Table 3 represent a simultaneous expansion of good output (i.e., GVA) and contraction of bad one (i.e., carbon emission). Indeed, this setting implies a different direction of movement along with different technology. As one can note, Slovenia, Belgium, France, Austria and Poland remained as the most efficient countries with Bulgaria intercepting among them. It can be assumed that rather low emission intensity induced increase in eco-efficiency for Bulgaria as opposed to technical efficiency, where carbon emission was neglected. Bulgaria and France showed an increase in their ranking during 1995–2009, whereas Austria and Belgium went down several ranks. Germany joined the ranks of least efficient countries in terms of eco-efficiency. However, an increase of three ranks was observed during 1995–2009 for the latter country.

Table 4 reports the inefficiency scores representing increase of good output and decrease of bad one needed to reach the production frontier, which is now defined with respect to natural resources (viz., land, water, and materials). In this setting, the Netherlands turned out to be the most efficient country possibly due to intensive horticulture farming prevailing there. Romania also gained considerable competitiveness in terms of resource use efficiency and appeared as the third efficient country under Model III. However, the rank for the latter country was not stable and show decrease from the sixth place down to eleventh.
Table 4. Resource efficiency across the selected European countries, 1995–2009

| Country     | Average | SD  | CV   | Rank 1995 | Rank 2009 |
|-------------|---------|-----|------|-----------|-----------|
| Austria     | 0.06    | 6   | 0.04 | 69        | 1         | 8         |
| Belgium     | 0.05    | 5   | 0.06 | 11.2      | 1         | 12        |
| Bulgaria    | 0.05    | 4   | 0.09 | 1.85      | 9         | 1         |
| Czech R.    | 0.52    | 14  | 0.25 | 0.48      | 12        | 17        |
| Germany     | 0.58    | 16  | 0.13 | 0.22      | 18        | 14        |
| Denmark     | 0.29    | 11  | 0.08 | 0.28      | 13        | 10        |
| Estonia     | 0.66    | 18  | 0.23 | 0.35      | 15        | 18        |
| Finland     | 0.32    | 12  | 0.06 | 0.20      | 11        | 13        |
| France      | 0.08    | 7   | 0.05 | 0.63      | 8         | 1         |
| Hungary     | 0.43    | 13  | 0.26 | 0.61      | 17        | 7         |
| Lithuania   | 0.53    | 15  | 0.15 | 0.29      | 13        | 16        |
| Latvia      | 0.64    | 17  | 0.10 | 0.16      | 16        | 15        |
| Netherlands | 0.02    | 1   | 0.03 | 1.22      | 1         | 1         |
| Poland      | 0.09    | 8   | 0.08 | 0.89      | 1         | 8         |
| Romania     | 0.05    | 3   | 0.05 | 1.05      | 6         | 11        |
| Slovakia    | 0.20    | 10  | 0.13 | 0.67      | 7         | 1         |
| Slovenia    | 0.03    | 2   | 0.04 | 1.37      | 1         | 1         |
| Sweden      | 0.17    | 9   | 0.12 | 0.70      | 10        | 1         |

At the other end of spectrum, Czech Republic, Lithuania, Germany, Latvia, and Estonia were the least efficient countries with respect to resource use. Indeed, Germany showed a positive trend in change in ranking during 1995–2009, while the opposite holds for Czech Republic. Estonia and Lithuania were specific with descent in ranking as they dropped by three ranks. Therefore, increasing resource use efficiency is particularly important for these regions in order to maintain competitiveness in the common market of the EU.

![Fig. 2. Coefficients of variation for technical efficiency (TE), eco-efficiency (EE), and resource efficiency (RE)](image-url)
Given the data in Tables 2–4, it is evident that inefficiencies varied across countries, time periods, and different frontier models. Belgium and Slovenia exhibited the highest values of CV for each type of efficiency. Anyway, these countries differed in the trend of change in ranking. Obviously, the number of countries specific with high variation in efficiency increased for Model III. Figure 2 above, therefore, depicts the trends of the within-year coefficients of variation for each type of efficiency.

The trends in Figure 2 imply that there has been no convergence in resource efficiency (as suggested by increasing coefficient of variation), whereas the other types of efficiency maintained rather stable coefficients of variation. Thus, it is an important task for the EU to encourage the spread of practices and policies aimed at increase in resource efficiency. Indeed, the trends in Figure 2 should be reversed for all the types of efficiency in order to ensure the convergence.

5. Conclusions

1. Slovenia, Belgium, France, Austria, and Poland appeared to be the most technically efficient countries considering the average inefficiency scores for 1995–2009. Bulgaria, the Netherlands, and Romania also gained considerable competitiveness in terms of eco-efficiency and resource use efficiency thus appearing among most efficient countries under frontier models with undesirable outputs.

2. Latvia, Czech Republic, Estonia, and Hungary emerged as the least efficient countries in terms of agricultural production under all specifications of the frontier models. Germany joined the ranks of least efficient countries in terms of eco-efficiency.

3. The results showed substantial variation in efficiencies. The trends in coefficients of variation imply that there has been no convergence in resource efficiency, whereas stable coefficients of variation were pertinent to eco-efficiency along with resource efficiency. Encouraging exchange of the best practice and research directed towards increase in resource efficiency in agriculture, therefore, remains a topical issue for the European Union.

4. Further research might employ different methodologies to identify the sources of inefficiency. For instance, non-radial models would enable to decompose the inefficiency in terms of the model variables. Furthermore, additional environmental pressures might be considered by utilising different data sources.

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Straipsnyje analizuojamos techninio, aplinkosauginio ir išteklių efektyvumo tendencijos Europos valstybių žemės ūkio sektoriuose. Tyrimas apima valstybes, panašias savo gaminamos produkcijos struktūra. Sudaryti ribiniai modeliai, skirti įvertinti efektyvumo dėsningumus Europos valstybėse. Tyrimas remiasi duomenų bazės „WorldInput-OutputDatabase“ duomenimis ir apima 1995–2009 m. laikotarpį. Ribiniai modeliai sudaryti remiantis silpnojo nustatymo prielaida pagal šiuos rodiklius: darbo sąnaudos, kapitalo kiekis, energijos kiekis, gamtinių išteklių sąnaudos, žemės ūkio naudmenų plotas, vandens sąnaudos, bendroji pridėtinė vertė ir anglies duvinio emisija. Tyrimo rezultatai parodė, kad Slovėnija, Belgija, Prancūzija, Austrija ir Lenkija tiriamuoju laikotarpiu buvo techniškai efektyviausios valstybės. Bulgarija, Nyderlandai ir Lenkija taip pat atskleidė turimą konkurencingumą, įvertinus aplinkosauginį ir išteklių efektyvumą. Latvija, Čekija, Estija ir Vengrija pasirodė esančios neefektyviausios valstybės žemės ūkio gamyboje taikant visų tipų ribinius modelius. Visų efektyvumo tipų sklaida padidėjo, todėl yra svarbu skatinti inovacijų plėtrą tarp Europos Sąjungos valstybių. Lietuvoje svarbiausia problema išlieka techninis neefektyvumas, kurį galima sumažinti diegiant modernias gamybos technologijas.

Raktiniai žodžiai: duomenų apgaubties analizė, aplinkosauginis efektyvumas, išteklių efektyvumas, techninis efektyvumas, silpnas nustatymas.

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