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Long-term trends in economic and environmental efficiency of EU agriculture: A DEA-Malmquist approach

Dirk Beyer[1], *Jana Hinke*[2]*

[1]*Department of Business Studies, Harz University of Applied Sciences, Wernigerode, Germany*
[2]*Department of Trade and Finance, Faculty of Economics and Management, Czech University of Life Sciences Prague, Prague, Czech Republic*

**Corresponding author: hinke@pef.czu.cz*

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Electronic supplementary material (ESM)

Supplementary Figure S1
Supplementary Figure S2
Supplementary Table S1

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SUPPLEMENTARY 1. DEA AND MALMQUIST METHODOLOGY

DEA measures the efficiency of a decision-making unit (DMU) by solving a linear programming problem (LP) as shown in Equation (1) (Coelli and Rao 2005):

$$TE_i^{-1} = d\left(y_i, x_i\right)^{-1} = \max_{\phi,\lambda} \phi \qquad (1)$$

$$s.t.\ Y\lambda - \phi y_i \geq 0$$
$$x_i - X\lambda \geq 0$$
$$\lambda \geq 0$$

where: $1/\phi$ – a technical efficiency score (TE) based on a distance function d (Farrell 1957), where a TE value of 1 indicates full efficiency; X and Y – input and output matrices across all compared DMUs, x_i and y_i – the respective vectors of the i^{th} DMU; λ – the multiplier vector that generates linear combinations of observed inputs and output bundles.

This LP model must be solved for each DMU in the sample. Figure S1 illustrates the principle of DEA in a simplified form considering constant returns to scale (CRS).

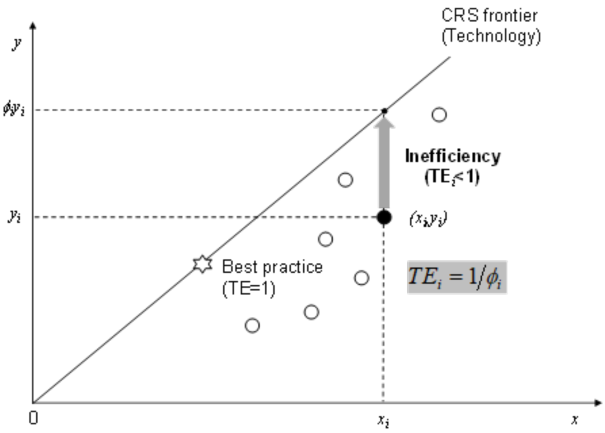

Figure S1. Principle of an output-oriented DEA
Source: Own elaboration

The Malmquist index (MI) extends DEA to analyse temporal changes in efficiency by comparing distance functions d across two periods t and $t + 1$ (Malmquist 1953; Caves et al. 1982; Färe et al. 1992, 1994). It measures the change in total factor productivity (TFP), where $MI > 1$ indicates improvement, while $MI < 1$ indicates a decline. The index is computed as the geometric mean of two TFP measures based on the technologies of both periods (Coelli et al. 2005), as described in Equation (2).

$$MI\left(y^t, x^t, y^{t+1}, x^{t+1}\right) = \sqrt{\frac{d^t\left(y^{t+1}, x^{t+1}\right)}{d^t\left(y^t, x^t\right)} \times \frac{d^{t+1}\left(y^{t+1}, x^{t+1}\right)}{d^{t+1}\left(y^t, x^t\right)}} \qquad (2)$$

Equation (2) can be rearranged to show that the change in TFP can be separated into two components. The first component is a catch-up effect, which reflects the change in technical efficiency (TE) between periods t and t +1. The second component is a frontier shift, which captures technological progress as a geometric mean term, as shown in Equation (3).

$$MI\left(y^t, x^t, y^{t+1}, x^{t+1}\right) = \underbrace{\frac{d^{t+1}\left(y^{t+1}, x^{t+1}\right)}{d^t\left(y^t, x^t\right)}}_{catch-up} \times \underbrace{\sqrt{\frac{d^t\left(y^{t+1}, x^{t+1}\right)}{d^{t+1}\left(y^{t+1}, x^{t+1}\right)} \times \frac{d^t\left(y^t, x^t\right)}{d^{t+1}\left(y^t, x^t\right)}}}_{\text{frontier shift}} \qquad (3)$$

Figure S2 provides a simplified illustration of the fundamental principles of a Malmquist index with output orientation, under the assumption of constant returns to scale (CRS).

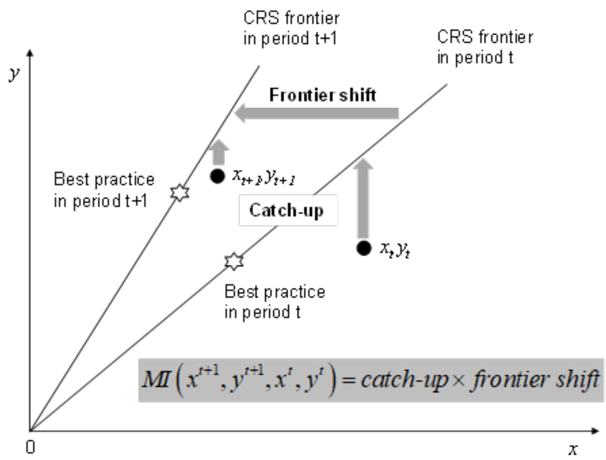

Figure S2. The principle of Malmquist Index
Source: Own elaboration

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The calculation of the distance functions is achieved by solving four DEA-like linear programmes presented in Equation (4) (Coelli and Rao 2005):

$$
\begin{aligned}
& d^{t+1}\left(y_i^{t+1}, x_i^{t+1}\right)^{-1} = \max_{\phi,\lambda} \phi \\
& s.t.\ Y^{t+1}\lambda - \phi y_i^{t+1} \geq 0 \\
& \quad x_i^{t+1} - X^{t+1}\lambda \geq 0 \\
& \quad \lambda \geq 0 \\
& d^{t}\left(y_i^{t}, x_i^{t}\right)^{-1} = \max_{\phi,\lambda} \phi \\
& s.t.\ Y^{t}\lambda - \phi y_i^{t} \geq 0 \\
& \quad x_i^{t} - X^{t}\lambda \geq 0 \\
& \quad \lambda \geq 0 \\
& d^{t+1}\left(y_i^{t}, x_i^{t}\right)^{-1} = \max_{\phi,\lambda} \phi \\
& s.t.\ Y^{t+1}\lambda - \phi y_i^{t} \geq 0 \\
& \quad x_i^{t} - X^{t+1}\lambda \geq 0 \\
& \quad \lambda \geq 0 \\
& d^{t}\left(y_i^{t+1}, x_i^{t+1}\right)^{-1} = \max_{\phi,\lambda} \phi \\
& s.t.\ Y^{t}\lambda - \phi y_i^{t+1} \geq 0 \\
& \quad x_i^{t+1} - X^{t}\lambda \geq 0 \\
& \quad \lambda \geq 0
\end{aligned}
\tag{4}
$$

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Table S1. Sub-measures of efficiency

Country	Avg. GVA (mill EUR)		Avg. labour (Mh)		Avg. capital (mill EUR)		Avg. land (Kha)		Avg. GHG (Kt)		Avg. acid. gases (Kt)	
	09–14	**15–20**	**09–14**	**15–20**	**09–14**	**15–20**	**09–14**	**15–20**	**09–14**	**15–20**	**09–14**	**15–20**
Belgium	2 601.0	2 658.1	142.3	150.5	8 730.1	9 879.1	1 471.3	1 485.8	11 831.3	12 112.3	146.7	139.5
Czechia	3 455.0	4 085.9	320.2	311.9	11 788.4	13 720.2	3 439.8	3 505.5	8 922.0	9 564.6	134.3	148.7
Denmark	2 472.2	2 409.8	108.1	100.4	29 801.8	27 212.9	2 679.8	2 785.7	13 983.8	13 818.9	168.2	164.9
Germany	22 404.5	20 243.5	1 202.0	1 057.9	155 507.7	150 306.0	16 521.5	16 058.5	67 690.3	67 219.1	1 238.4	1 180.4
Estonia	514.4	504.4	49.2	44.2	2 000.1	2 582.5	997.0	1 062.2	1 716.2	1 674.6	24.2	22.0
Ireland	1 865.0	2 763.5	267.0	265.1	10 052.5	10 551.8	4 412.1	4 468.6	20 436.0	22 404.0	243.0	265.9
Greece	6 722.9	6 908.7	1 214.9	1 144.8	16 355.4	15 107.3	3 035.8	2 964.6	10 484.9	9 056.4	142.0	128.0
Spain	26 915.7	30 442.8	1 477.8	1 474.7	48 401.2	55 784.3	21 225.9	19 797.8	44 762.1	46 705.0	996.9	1 035.3
France	30 993.9	31 032.3	1 716.9	1 567.0	116 684.2	107 145.5	25 740.2	25 298.6	85 804.9	82 982.2	1 287.6	1 223.3
Italy	33 076.6	33 188.7	2 410.2	2 419.2	173 576.8	151 915.8	11 954.7	11 581.9	42 031.3	42 040.4	750.2	716.4
Latvia	773.1	876.4	140.7	136.4	8 591.4	7 838.7	1 649.4	1 675.5	2 478.6	2 779.5	30.6	32.3
Lithuania	1 128.1	1 243.9	223.6	198.7	4 584.8	6 070.8	2 706.5	2 967.8	4 588.8	4 953.5	76.2	79.9
Luxembourg	119.5	117.4	5.7	5.4	2 116.0	2 457.3	129.8	126.5	710.5	754.3	11.9	12.2
Hungary	3 938.3	4 531.5	538.1	499.1	21 080.4	20 425.1	5 165.5	5 195.6	7 933.8	9 460.2	142.6	156.9
Netherlands	11 645.3	13 167.0	385.6	396.1	49 349.3	53 148.0	1 857.4	1 761.3	29 520.7	29 318.9	267.2	258.5
Austria	3 809.5	4 062.4	469.0	401.8	45 310.1	46 297.1	2 824.8	2 382.6	8 121.8	8 188.3	126.7	129.9
Poland	11 405.4	10 552.1	3 866.4	3 331.0	19 248.0	19 242.9	13 578.6	14 857.1	53 250.5	53 422.2	734.7	713.6
Romania	6 876.9	8 088.5	4 194.3	2 985.9	18 981.9	26 714.8	10 532.8	9 891.5	19 942.2	20 881.2	300.1	296.8
Slovenia	725.4	851.6	154.1	146.9	2 973.6	3 009.9	449.2	446.4	1 999.1	2 066.5	36.8	36.4
Slovakia	1 468.4	1 830.7	138.9	133.5	10 268.4	11 557.9	2 112.5	1 869.5	2 237.3	2 248.9	41.7	43.3
Finland	4 361.3	5 007.8	222.7	190.9	20 136.7	19 460.9	2 163.2	2 076.4	8 157.4	8 020.7	72.4	63.9
Sweden	4 953.2	5 832.4	252.8	254.1	41 863.2	44 643.4	2 830.7	2 907.9	9 097.2	8 725.6	106.3	104.9
Sum	182 225.6	190 399.3	19 500.7	17 215.5	817 401.8	805 072.0	137 478.3	135 167.5	455 700.8	458 397.4	7 078.5	6 952.8

GHG – green house gases; GVA – gross value added

Source: Source: Own elaboration