What are the achievements of the European Union Member States towards Energy-Sustainable Agriculture: A Contribution to the Structural Efficiency Approach

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Motivation

- Agricultural productivity (=efficiency in single-period analysis) gains allow for lower prices/higher income.
- The eco-efficiency is important form the sustainability perspective.
- The non-parametric frontier technique, Data Envelopment Analysis (DEA), can be applied to measure the eco-efficiency (via adjustments in the axioms imposed on the technology).
- The DEA suffers from the curse of dimensionality.
- This issue becomes especially cumbersome in the presence of undesirables (additional variable).
- We rank the EU Member States in terms of the eco-efficiency by using the contribution to the structural efficiency index.

Methodological Preliminaries

- The super-efficiency DEA and the like techniques have been proposed to improve the discriminatory power
- These approaches assume that the production technology is altered for each *efficient* DMU under consideration and not for *inefficient* DMUs. The proximity to the frontier is ignored in the former case.
- Zhu et al. (2019, 2020) proposed the contribution to the structural efficiency index that applies the extended (yet varying) technology for all the DMUs
- We use the weak disposability technology and the contribution index to rank the EU Member States agricultural sector with regards to the eco-efficiency

Methods

- Inputs *x*
- Desirable outputs *y*
- Undesirable outputs *b*
- Environmental Production Technology

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

- Weak disposability DEA technology

$$T = \left\{ (x, y, b) \in \Re^{I+J+L} : \begin{array}{l} \sum_{k=1}^{K} \lambda_k x_{ki} \le x_i, \sum_{k=1}^{K} \lambda_k y_{kj} \ge y_j, \sum_{k=1}^{K} \lambda_k b_{kl} = b_l, \lambda_k \ge 0, \\ i = 1, 2, ..., I,\ j = 1, 2, ..., J, k = 1, 2, ..., K, l = 1, 2, ..., L \end{array} \right\} \qquad (g_j, g_l) = (y_{k'j}, b_{k'l})$$

Methods

- The generalized directional distance function (DDF), Cheng and Zervopoulos (2014):

$$\rho_{k'} = \min \frac{1}{1+\frac{1}{J+L}\left(\sum_{j=1}^{J}\beta g_j / y_{k'j} + \sum_{l=1}^{L}\beta g_l / b_{k'l}\right)}$$

$$s.t. \sum_{k=1}^{K}\lambda_k x_{ik} \le x_{k'i}, i=1,2,...,I,$$

$$\sum_{k=1}^{K}\lambda_k y_{jk} \ge y_{k'j} + \beta g_j, j=1,2,...,J,$$

$$\sum_{k=1}^{K}\lambda_k b_{lk} = b_{k'l} - \beta g_l, l=1,2,...,L$$

$$\lambda_k \ge 0, k=1,2,...,K,$$

$$(g_j, g_l) = (y_{k'j}, b_{k'l})$$

- Super-efficiency DEA

$$\rho_{k'}^{S} = \min \frac{1}{1+\frac{1}{J+L}\left(\sum_{j=1}^{J}\beta g_j / y_{k'j} + \sum_{l=1}^{L}\beta g_l / b_{k'l}\right)}$$

$$s.t. \sum_{\substack{k=1 \\ k\neq k'}}^{K}\lambda_k x_{ik} \le x_{k'i}, i=1,2,...,I,$$

$$\sum_{\substack{k=1 \\ k\neq k'}}^{K}\lambda_k y_{jk} \ge y_{k'j} + \beta g_j, j=1,2,...,J,$$

$$\sum_{\substack{k=1 \\ k\neq k'}}^{K}\lambda_k b_{lk} = b_{k'l} - \beta g_l, l=1,2,...,L$$

$$\lambda_k \ge 0, k=1,2,...,K, \lambda_{k'} = 0.$$

Contribution to Structural Efficiency

- Let there be set T^D comprising *K* DMUs.
- DMUs can be aggregated into arbitrary observations $\xi(A)$, where $A \subseteq T^D$
- An aggregate DMU is defined as $\xi(A) = \left(\sum_{k \in A} x_k, \sum_{k \in A} y_k, \sum_{k \in A} b_k \right) \in \Re^{I+J+L}$
- The resulting aggregate DMUs form an extended technology
- For each *k'*, $T^E = \{ \xi(A) \mid A \subseteq T^D \}$ $T^E_{k'} = \{ \xi(A) \mid A \subseteq T^D \setminus k' \}$
- The marginal contribution to structural efficiency is obtained as $I^C_{k'} = \frac{1}{2^{K-1}-1} \sum_{\substack{A \subseteq T^D \setminus \{k'\} \\ A \neq \varnothing}} \frac{\rho(A \cup k')}{\rho(A)}$

>1 indicates that DMU k' improves structural efficiency

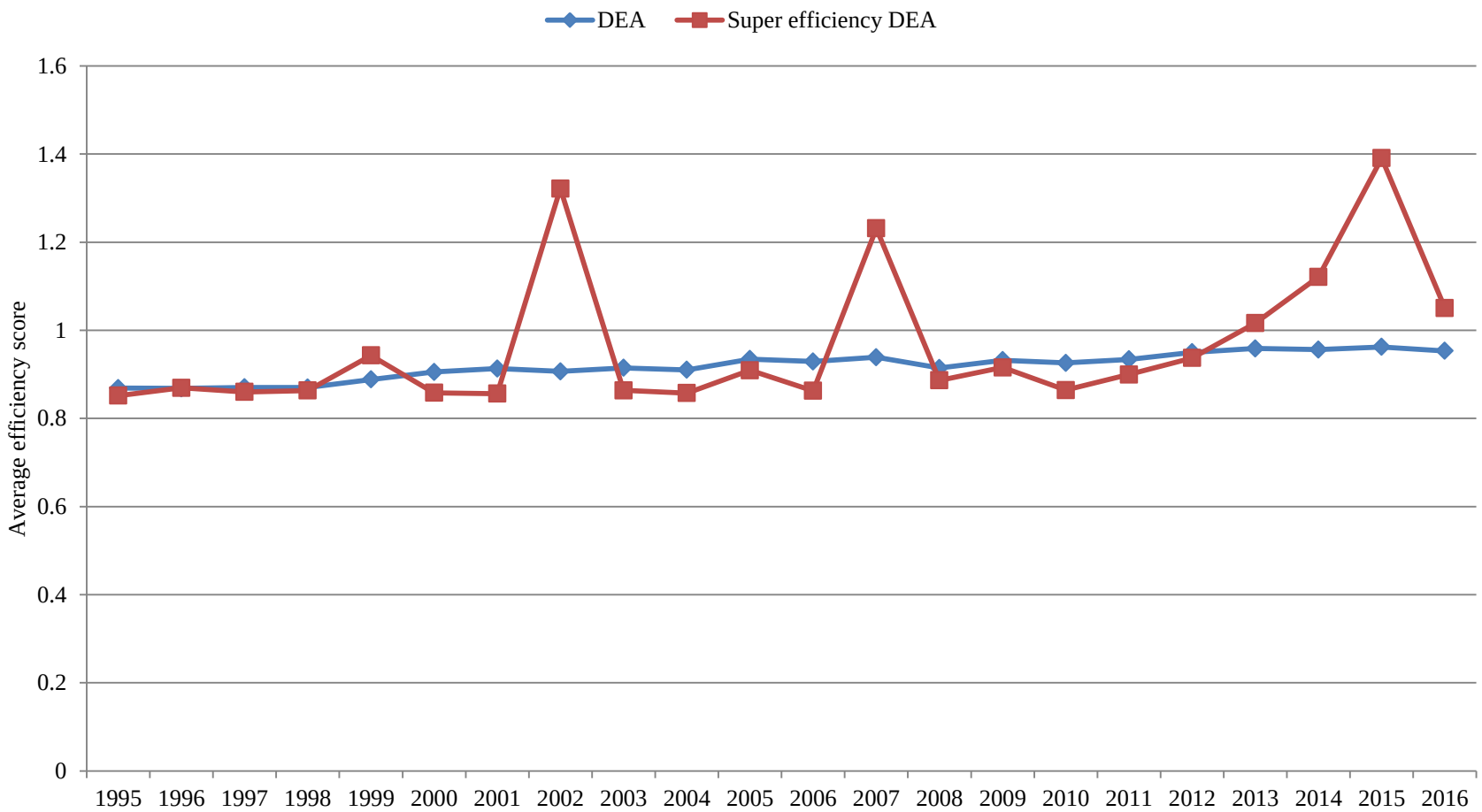
Data

- The desirable output is the total agricultural output (PPS based on the constant prices of 2010).
- The undesirable output is the energy-related GHG emission (in tonnes CO2 equivalent).
- The inputs include:
  - Agricultural land area (hectares),
  - Labour input (Annual Work Units equal to 2036 working hours),
  - Fixed capital consumption (PPS),
  - Final energy consumption (metric tonnes oil equivalent).
- The data come from the Eurostat database (Eurostat, 2020), primarily from the energy balance and agricultural statistics.

Efficiency scores for the EU Member States' agricultural sectors (CRS DEA), 1995-2016

Country	1995	2000	2005	2010	2016	Average	Trend
Austria	0.89	0.89	0.90	0.95	0.95	0.91	0.005
Belgium	0.81	1.00	1.00	1.00	1.00	0.97	0.007
Bulgaria	1.00	1.00	1.00	1.00	1.00	1.00	0.000
Czechia	0.93	0.94	1.00	0.96	0.94	0.97	0.001
Denmark	1.00	1.00	1.00	1.00	1.00	1.00	0.000
Estonia	0.85	1.00	0.96	0.87	0.73	0.90	-0.003
Finland	0.69	0.67	0.70	0.71	0.68	0.69	0.002
France	1.00	1.00	1.00	1.00	0.93	1.00	-0.001
Hungary	0.86	0.88	0.96	0.84	0.97	0.89	0.003
Latvia	0.62	0.64	0.64	0.70	1.00	0.72	0.018
Lithuania	0.73	1.00	1.00	1.00	1.00	0.96	0.009
Netherlands	1.00	1.00	1.00	1.00	1.00	1.00	0.000
Poland	0.68	0.66	1.00	1.00	1.00	0.84	0.022
Romania	1.00	1.00	1.00	1.00	1.00	1.00	0.000
Slovakia	1.00	1.00	1.00	1.00	1.00	1.00	0.000
Slovenia	1.00	1.00	1.00	1.00	1.00	1.00	0.000
Sweden	0.71	0.72	0.73	0.72	1.00	0.77	0.013
Average	0.87	0.91	0.93	0.93	0.95	0.92	0.004
# of efficient	7	10	11	10	11	5	

Average efficiency scores rendered by the DEA and super-efficiency DEA



Efficiency scores for the EU Member States' agricultural sectors (CRS super-efficiency), 1995-2016

Country	1995	2000	2005	2010	2016	Average	Trend
Austria	0.89	0.89	0.90	0.95	0.95	0.91	0.005
Belgium	0.81					0.93	
Bulgaria					1.80	1.80	
Czechia	0.93	0.94	1.01	0.96	0.94	0.98	0.001
Denmark				1.02	1.14	1.05	
Estonia	0.85	1.01	0.96	0.87	0.73	0.88	
Finland	0.69	0.67	0.70	0.71	0.68	0.69	0.002
France					0.93	1.08	
Hungary	0.86	0.88	0.96	0.84	0.97	0.89	0.003
Latvia	0.62	0.64	0.64	0.70	1.01	0.71	
Lithuania	0.73	1.13	1.21	1.01	1.03	1.02	0.012
Netherlands							
Poland	0.68	0.66				0.68	
Romania	1.13					2.56	
Slovakia	1.33	1.05	1.08		1.36	1.23	
Slovenia							
Sweden	0.71	0.72	0.73	0.72		0.72	
Average	0.85	0.86	0.91	0.86	1.05	0.97	0.011
# of infeasible	5	7	8	8	6	2	
# of super-efficient	2	3	3	2	5	6	

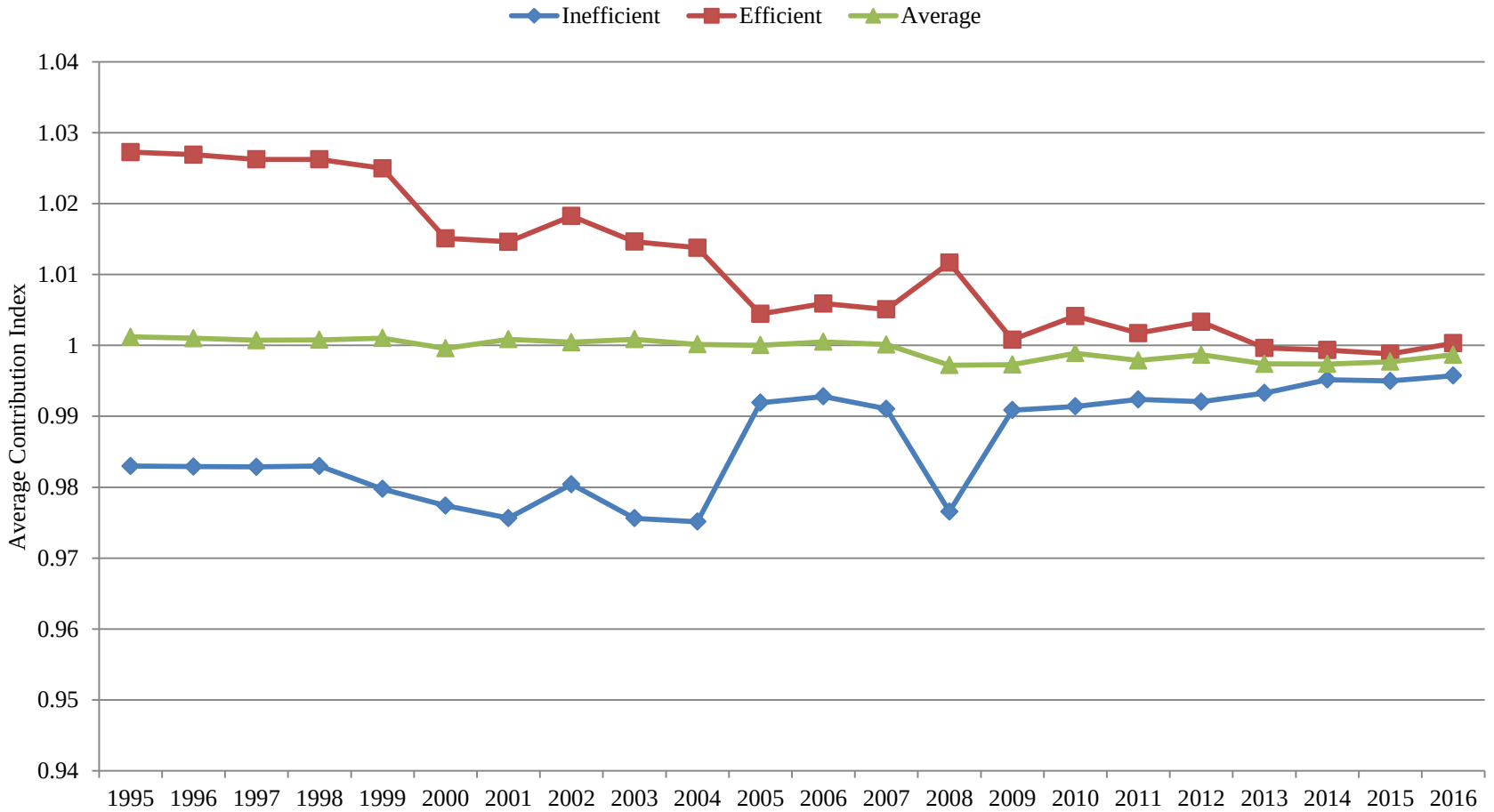
The average levels of efficiency according to the average contribution towards structural efficiency

Contribution	Inefficiency		Average
	Inefficient	Efficient	
$I_{k'}^{C} \leq 1$	0.80	1	0.87
$I_{k'}^{C} > 1$	0.94	1	0.99
Average	0.81	1	0.92

Distribution of the observations (agricultural sectors of the EU Member States) across efficiency levels and contribution to the aggregate efficiency

Contribution	Inefficiency		Total
	Inefficient	Efficient	
Absolute frequencies			
$I_{k'}^{C} \leq 1$	144	75	219
$I_{k'}^{C} > 1$	16	139	155
Total	160	214	374
Relative frequencies			
$I_{k'}^{C} \leq 1$	90%	35%	59%
$I_{k'}^{C} > 1$	10%	65%	41%
Total	100%	100%	100%

The average index of contribution to structural efficiency for efficient and inefficient observations



The average efficiency and contribution to the structural efficiency for the EU Member States

Country	Average $I_{k'}^{C}$	Average DEA	# of eff.	# of infeas.	# of positive contrib.	Final Ranking
Romania	1.023149	1	22	12	22	1
Netherlands	1.02307	1	22	22	18	2
Bulgaria	1.011594	1	22	21	22	3
Slovakia	1.001755	1	22	6	18	4
Slovenia	1.000281	1	22	22	12	5
Denmark	0.997418	0.99808	20	12	3	6
France	1.070929	0.997029	21	18	21	7
Czechia	0.998272	0.970281	7	0	5	8
Belgium	1.007048	0.969351	18	16	19	9
Lithuania	0.995932	0.956892	16	0	4	10
Austria	0.997139	0.914025	0	0	3	11
Estonia	0.996926	0.898644	5	4	0	12
Hungary	0.999253	0.886912	0	0	8	13
Poland	0.914115	0.841534	11	11	0	14
Sweden	0.981677	0.77143	4	4	0	15
Latvia	0.99011	0.722572	2	1	0	16
Finland	0.982399	0.687002	0	12	0	17

Conclusions

- The empirical results indicate an overall increase in the environmental performance of the EU Members States over 1995-2016. The agricultural performance of Bulgaria, Denmark, France, the Netherlands, Romania, Slovakia and Slovenia, as measured by the conventional DEA, approached the frontier. Therefore, these countries could not be ranked based on the conventional DEA model. The application of supper-efficiency DEA still did not allow for a complete ranking. Such countries as the Netherlands and Slovenia could not be attributed with super-efficiency scores due to infeasibilities. This indicates that such countries show particular input-output mixes which are not directly comparable to those for the other countries.
- Application of the contribution index rendered the complete ranking of the countries. Romania, the Netherlands, Bulgaria, Slovakia and Slovenia were ranked as the best-performing countries (in that order) based on the contribution to the structural efficiency. Notably, France and Belgium showed positive contribution to the structural efficiency even though they were not classified as efficient countries. Therefore, cooperation with these countries would allow other countries to exploit their agricultural resources in a more productive and sustainable manner.
- The results indicate that both the new and old EU Member States appeared as best-performing ones. However, among the five countries that are fully efficient according to the conventional DEA model, there are four countries that entered the EU in 2004. Thus, the countries with relatively lower economic development level (including agricultural productivity) can be environmentally efficient due to less intensive agricultural production and energy-related GHG emission..

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