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Determining drivers of eco-efficiency: decomposition method[1]

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Abstract
There has been a lively discussion about measures of social welfare *beyond GDP* induced by *Stiglitz Report* (Stiglitz et al, 2009) which can be viewed as a summation of the earlier efforts to deal with those challenges. Environmental indicators constitute one important dimension to be taken into account in assessing the welfare along with the economic and social indicators. Employing non-parametrical approach, the Data Envelopment Analysis SBM model is extended for environment to measure the so called eco-efficiency. Resulting scores and benchmarks are used to decompose eco-productivity into factors attributable to changes in efficiency, technology, extensive factors of production, and emissions. Results suggest that in European countries in the span 2000 – 2010, an environment-saving rather than input-saving technology change has been taking place.

Keywords: eco-efficiency, data envelopment analysis, beyond GDP, decomposition

JEL codes: C43, C61, O47

1 Introduction

There has been a lively discussion about measures of social welfare *beyond GDP* induced by *Stiglitz Report* (Stiglitz et al, 2009) which can be viewed as a summation of the earlier efforts to deal with those challenges. Environmental indicators constitute one important dimension to be taken into account in assessing the welfare along with the economic and social indicators.

In the practice of economic policy decision making, often the claim for meeting multiple goals occurs. The example be the requirements of the Strategy Europe 2020 which defines benchmarks for social and environmental dimensions while keeping the economy on the growth path. Theoretical support for decision making cannot be based on barely proportional indicators relating to goals which may require conflicting actions.

In this study, we concentrate on environmental aspects of economic growth. The method of evaluating country´s performance – data envelopment analysis (DEA) – is employed, assessing economic (technical) and environmental simultaneously. The DEA method allows one to circumvent certain shortcuts of parametric methods, namely only dealing with single output in a production function and need for prices of inputs and outputs as aggregating weights.

There has been an obvious shift in environment-protecting-oriented technology over the last decade or more. One can be interested in the quality of the shift – is the "greener" technology driven by better use of the inputs or is an environment-saving progress going on? Non-parametrical approach is capable of giving answers to such type of questions.

We proceed as follows. Section 2 provides theoretical definitions of the concept of efficiency. Then measurement method as application of linear programming is described, the SBM model is

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particularly paid attention to and the strategy of incorporating undesirable output into the model is presented. Section 3 describes the data used and the model setup. In Section4, decomposition method of Henderson-Russell (2005) is brought out as a starting point for further extension and use in intertemporal analysis of eco-efficiency change over the span of 2000 and 2010. Section 5 provides results of the actual empirical analysis, gives some comments and Section 6 concludes.

2 Measuring eco-efficiency

2.1 SBM efficiency measure

The above-mentioned considerations need to be operationalized. First, measurement of efficiency should be introduced. There are several approaches leading to the same evaluation in the form of a linear program. To follow one of them, let´s organize data and give some definitions.

Economic subjects under examination be called DMUs (Decision Making Units) to reflect their independent economic behavior. Let´s assume to have n DMUs transforming m inputs into s desirable outputs. Inputs are organized in the matrix **X**, element x_{ij} meaning amount of input i used by DMU j, and the similar way in the output matrix **Y**.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ . & . & \cdots & . \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}, \quad Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ . & . & \cdots & . \\ y_{s1} & y_{s2} & \cdots & y_{sn} \end{bmatrix}$$

To assess technical efficiency, the general formula can be used:

$$efficiency = \frac{outputs}{inputs} \tag{2.1}$$

In classical DEA, every DMU aggregates its inputs and outputs by means of individually set weights so that the ratio 2.2.1 is maximized. In order to avoid unboundedness of maximization problem, the constraint is imposed so that normalized efficiency cannot exceed unit which also holds in case of using the weights of DMU under consideration (denoted DMU_0) for any other of *n–1* DMUs. Formally:

$$\max \quad h_0(\boldsymbol{\mu}, \mathbf{v}) = \frac{\sum_{r=1}^{s} y_{r0}\mu_r}{\sum_{i=1}^{m} x_{i0}v_i} \tag{2.2}$$

$$\text{s.t.} \quad \frac{\sum_{r=1}^{s} y_{rj}\mu_r}{\sum_{i=1}^{m} x_{ij}v_i} \le 1 \qquad (j = 1, 2, ..., n) \tag{2.3}$$

$$u_r \ge 0 \qquad (r = 1, 2, ..., s)$$

$$v_i \ge 0 \qquad (i = 1, 2, ..., m)$$

The fractional program can be transformed into the linear one called CCR model (proposed by Charnes et al, 1978) which was first to evaluate performance in a non-parametric way.

The basic model had been improved and modified many ways. The slack-based model (SBM) by Tone is one of the powerful developments to capture all sources of inefficiency. The objective function has two important properties:

- unit invariance
- monotonicity.

A function $\rho = \dfrac{1-\frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{i0}}{1+\frac{1}{s}\sum_{r=1}^{s} s_r^+ / y_{r0}}$ meet the requirements of the both, moreover, it can be shown that $0 < \rho \le 1$ (Cooper et al, 2007, p.100).
Evaluation of efficiency takes the form of a fractional program:

$$\min_{\boldsymbol{\lambda},\mathbf{s}^+,\mathbf{s}^-} \quad \rho = \frac{1-\frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{i0}}{1+\frac{1}{s}\sum_{r=1}^{s} s_r^+ / y_{r0}} \tag{2.4}$$

$$\begin{aligned} \text{s.t.} \quad & \mathbf{x_0} = X\boldsymbol{\lambda} + \mathbf{s}^- \\ & \mathbf{y_0} = Y\boldsymbol{\lambda} - \mathbf{s}^+ \\ & \boldsymbol{\lambda} \ge 0,\ \mathbf{s}^- \ge 0,\ \mathbf{s}^+ \ge 0. \end{aligned}$$

Using substitution $t = \dfrac{1}{1+\frac{1}{s}\sum_{r=1}^{s} s_r^+ / y_{r0}}$ one can obtain a linear program :

(SBMt)

$$\min_{t,\boldsymbol{\lambda},\mathbf{s}^+,\mathbf{s}^-} \quad \tau = t - \frac{1}{m}\sum_{i=1}^{m} t s_i^- / x_{i0} \tag{2.5}$$

$$\begin{aligned} \text{s.t.} \quad & \mathbf{x_0} = X\boldsymbol{\lambda} + \mathbf{s}^- \\ & \mathbf{y_0} = Y\boldsymbol{\lambda} - \mathbf{s}^+ \\ & \boldsymbol{\lambda} \ge 0,\ \mathbf{s}^- \ge 0,\ \mathbf{s}^+ \ge 0,\ t > 0 \end{aligned}$$

.

Substituting $t\mathbf{s}^- = \mathbf{S}^-$, $t\mathbf{s}^+ = \mathbf{S}^+$ a $t\boldsymbol{\lambda} = \boldsymbol{\Lambda}$, *SBMt* is converted into

(SBMt)

$$\min \quad \tau = t - \frac{1}{m}\sum_{i=1}^{m} S_i^- / x_{i0} \tag{2.6}$$

$$\begin{aligned} \text{s.t.} \quad & t\mathbf{x_0} = X\boldsymbol{\Lambda} + \mathbf{S}^- \\ & t\mathbf{y_0} = Y\boldsymbol{\Lambda} - \mathbf{S}^+ \\ & \boldsymbol{\Lambda} \ge 0,\ \mathbf{S}^- \ge 0,\ \mathbf{S}^+ \ge 0,\ t > 0. \end{aligned}$$

The dual linear program associated with *SBMt* is

$$\max_{\xi,\mathbf{v},\mathbf{u}} \quad \xi \tag{2.7}$$

$$\begin{aligned} \text{s.t.} \quad & \xi + \mathbf{v}\mathbf{x_0} - \mathbf{u}\mathbf{y_0} = 1 \\ & -\mathbf{v}X + \mathbf{u}Y \leq \mathbf{0} \\ & \mathbf{v} \geq \frac{1}{m}[1/\mathbf{x_0}] \\ & \mathbf{u} \geq \frac{\xi}{s}[1/\mathbf{y_0}] \end{aligned}$$

The first constraint enables to write the objective function as $\max \mathbf{v}\mathbf{x_0} - \mathbf{u}\mathbf{y_0}$ with the last constraint for **u**

$$\mathbf{u} \geq \frac{1 - \mathbf{v}\mathbf{x_0} + \mathbf{u}\mathbf{y_0}}{s}[1/\mathbf{y_0}].$$

After solving *SBMt* formulated by 2.6 or 2.7, one can go back to $\mathbf{s}^{0+}$, $\mathbf{s}^{0-}$, $\boldsymbol{\lambda}^0$ as optimal solutions of *SBM* and determine ρ^0 for DMU_0. Efficient DMUs will have values of ρ equal unit. Inefficient ones will have $\rho < 1$ due to positive slack variables $\mathbf{s}^{0+}$, $\mathbf{s}^{0-}$ which express deviation from the frontier or "potential". Projections to the frontier are thus given by

$$\begin{aligned} \hat{\mathbf{x}}_\mathbf{0} &\Leftarrow \mathbf{x_0} - \mathbf{s}^{-0} \\ \hat{\mathbf{y}}_\mathbf{0} &\Leftarrow \mathbf{y_0} + \mathbf{s}^{+0} \end{aligned} \quad (2.8)$$

Indexes of variables $\lambda_j > 0$ constitute the reference set R_0 (efficiency frontier), every frontier point $(\mathbf{x}_\mathbf{0}^*, \mathbf{y}_\mathbf{0}^*)$ being positive linear combination of the other elements of the reference set:

$$\hat{\mathbf{x}}_\mathbf{0} = \sum_{j \in R_0} \mathbf{x}_j \boldsymbol{\lambda}_j, \; \hat{\mathbf{y}}_\mathbf{0} = \sum_{j \in R_0} \mathbf{y}_j \boldsymbol{\lambda}_j$$

It obvious from the construction of ρ that it takes into account all the sources of inefficiency and therefore $\rho_{\text{SBM}} \leq h_{\text{CCR}}$. *SBM* efficient DMUs are also CCR efficient but not the other way round. It is possible to give model input or output orientation in order to reflect preferences and feasibility of the policy. Input orientation is carried out by omitting output *slacks* in (2.2.4):

$$\begin{aligned} \min \quad & \rho = 1 - \frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{i0} \\ \text{s.t.} \quad & \mathbf{x_0} = X\boldsymbol{\lambda} + \mathbf{s}^- \\ & \mathbf{y_0} = Y\boldsymbol{\lambda} - \mathbf{s}^+ \\ & \boldsymbol{\lambda} \geq 0, \; \mathbf{s}^- \geq 0, \; \mathbf{s}^+ \geq 0. \end{aligned}$$

Output orientation (*SBM-O*) is achieved in a similar way by omitting input *slacks*:

$$\begin{aligned} \min \quad & \rho = \frac{1}{1 + \frac{1}{s}\sum_{r=1}^{s} s_r^+ / y_{r0}} \\ \text{s.t.} \quad & \mathbf{x_0} = X\boldsymbol{\lambda} + \mathbf{s}^- \\ & \mathbf{y_0} = Y\boldsymbol{\lambda} - \mathbf{s}^+ \\ & \boldsymbol{\lambda} \geq 0, \; \mathbf{s}^- \geq 0, \; \mathbf{s}^+ \geq 0. \end{aligned} \quad (2.9)$$

2.2 Modelling undesirable outputs

Once the measure of efficiency has been defined, one can proceed to evaluating eco-efficiency. Individual European countries will be considered as 29 DMUs. As the concept encompasses two dimensions, it´s natural to divide the problem of evaluation into two separate parts – economic and "ecological" performance, the former being evaluated using the classical approach described above. In order to assess ecological efficiency, an SBM model can be employed with GDP acting as output and emissions as inputs which is in line with the work of Korhonen and Luptáčik (2004) where such specification is justified along with the assumption of *strong disposability* of outputs. Thus, model denoted *tech* gives values of technical efficiency evaluating use of capital and labor for producing output while model *eco* provides information on the efficient (i.e. as little as possible) "use" of emissions. This is a "pure ecological efficiency" approach of Kuosmanen and Kortelainen (2005). Each model gives values describing the two dimensions. To obtain the overall indicator, the two values have to be combined in a composite model. Such model is constructed by taking *tech* and *eco* scores as outputs for the composite output oriented model, inputs being equal unit. The resulting *eco_tech* score can be considered a measure of eco-efficiency.

3 Data and modelling

For empirical analysis, two standard technical inputs – capital stock (K) measured in mil. EUR and labour (L) in thousands of workers were used. Units of measurement can be arbitrarily chosen since as has been shown in Section 2 SBM models have unit invariance property. The same applies to technical output GDP (Y) measured in mil. EUR. Emissions come in thousands of ton of greenhouse equivalent acting as undesirable output associated with the production. All data come from European databases AMECO and Eurostat. For intertemporal analysis, data from 29 DMUs (European countries) of 2000 and 2010 have been used. Thus n=29, in linear programs formulated in the previous section. 29 optimizations of the SBM-O-C type given by (2.9) must be computed to obtain efficiency scores of DMUs as well as the potential improvement of desirable output given by projections onto the efficiency frontier for every model specification. Statistical properties of the data used are in Table 1.

Table 1 Statistics on Input/Output Data

2000

	K1	L1	E1	Y1
Max	6012960,0	39382,0	1038999,0	1840730,7
Min	14466,3	156,4	3845,0	7049,8
Avg	1050117,6	8079,9	191296,3	352374,6
SD	1454945,8	9769,7	245822,9	487381,2

2010

	K2	L2	E2	Y2
Max	6466000,0	40603,0	936544,0	2028463,7
Min	21078,6	167,2	4542,0	8750,3
Avg	1288951,0	8494,5	178059,9	409727,7
SD	1705341,9	10264,7	222615,3	540928,3

Correlation

	K1	L1	E1	Y1
K1	1	0,973	0,975	0,992
L1	0,973	1	0,989	0,973
E1	0,975	0,989	1	0,971
Y1	0,992	0,973	0,971	1

Correlation

	K2	L2	E2	Y2
K2	1	0,979	0,964	0,994
L2	0,979	1	0,989	0,985
E2	0,964	0,989	1	0,973
Y2	0,994	0,985	0,973	1

Source: author´s calculation

As could be expected, the data show quite a big variance due to variability in size of individual economies.

4 Decomposition: identifying drivers of eco-efficiency change

Identification of drivers of the eco-efficiency change can be approached by intertemporal analysis. One of the possible attempts could be through Malmquist productivity index and decomposition of the TFP as it was carried out in Mahlberg et al (2011) for example. Another approach makes use of the decomposition method used in productivity studies. We refer to the work of Henderson and Russell (2005) as HR whose analysis constitutes a starting point for further extension. The key purpose of the method is to separately describe three "movements" of the DMU with respect to efficiency boundary over time:

(1) technology change – *frontier-shift* movement

(2) *catch-up* – movement towards or away from the frontier

(3) capital accumulation – movement along the frontier.

Relative magnitude of these effects can help interpret the nature of the technology change – whteher there is an input-saving technological improvement exploiting better use of technical inputs to increase eco-efficiency or environment- saving technology which enables to produce more output while reducing pollution.
Setting out in a HR manner, we first define a productivity indicator subject to decomposition. To reflect two-dimensional assessment of economic activity, we define y as an output-emissions ratio, i.e. output per unit of emissions Y/E. this can be also interpreted as the reciprocal of pollutants-intensity of production (output). Thus higher values of y represent greener production. Focusing on the intertemporal change between starting period 1 and the period 2 and indexing variables with respective numbers, the ratio of the interest becomes $\frac{y_2}{y_1} = \frac{Y_2/E_2}{Y_1/E_1}$.
Taking into account efficiency scores, actual values can be expressed by means of the benchmarks (potentials) indicated by the bar:

$$\frac{y_2}{y_1} = \frac{e_2}{e_1} \cdot \frac{\bar{y}_2(K_2, L_2, E_2)}{\bar{y}_1(K_1, L_1, E_1)} = \frac{\bar{Y}_2(K_2, L_2, E_2)\,/\,E_2}{\bar{Y}_1(K_1, L_1, E_1)\,/\,E_1}$$

The following step consists in multiplying numerator and denominator by the terms

$\bar{y}_2(K_1, L_1, E_1)$ and $\bar{y}_2(K_1, L_1, E_2)$ which would represent potential eco-productivities achievable with the level of emissions of periods 1 and 2, both given factors of production K and L of period 1 and the technology of period 2. After rearanging one obtains

$$\frac{y_2}{y_1} = \frac{e_2}{e_1} \cdot \frac{\bar{y}_2(K_2, L_2, E_2)}{\bar{y}_1(K_1, L_1, E_1)} = \frac{e_2}{e_1} \cdot \frac{\bar{y}_2(K_2, L_2, E_2)}{\bar{y}_1(K_1, L_1, E_1)} \cdot \frac{\bar{y}_2(K_1, L_1, E_1)}{\bar{y}_2(K_1, L_1, E_1)} \cdot \frac{\bar{y}_2(K_1, L_1, E_2)}{\bar{y}_2(K_1, L_1, E_2)}$$

$$= \frac{e_2}{e_1} \cdot \frac{\bar{Y}_2(K_2, L_2, E_2)/E_2}{\bar{Y}_1(K_1, L_1, E_1)/E_1} \cdot \frac{\bar{Y}_2(K_1, L_1, E_1)}{\bar{Y}_2(K_1, L_1, E_1)} \cdot \frac{\bar{Y}_2(K_1, L_1, E_2)}{\bar{Y}_2(K_1, L_1, E_2)}$$

$$= \frac{e_2}{e_1} \cdot \frac{\bar{Y}_2(K_1, L_1, E_1)}{\bar{Y}_1(K_1, L_1, E_1)} \cdot \frac{\bar{Y}_2(K_2, L_2, E_2)}{\bar{Y}_2(K_1, L_1, E_2)} \cdot \frac{\bar{Y}_2(K_1, L_1, E_2)/E_2}{\bar{Y}_2(K_1, L_1, E_1)/E_1}.$$

The resulting expression consists of the four factors that we denote the following way. Superscript is used for benchmark technology. Factor *TECH* compares technologies by relating potential outputs achievable by the same set of inputs and emissions (of period 1 in this case).

$$\frac{y_2}{y_1} = ECOEFF\,.TECH^1\,.\,KACC_2^2\,.\,EMIS_2^1\left[E_2/E_1\right] \qquad (2.10)$$

$$\frac{Y_2}{Y_1} = ECOEFF\,.TECH^1\,.\,KACC_2^2\,.\,EMIS_2^1 \qquad (2.11)$$

Superscript is used to indicate at which period´s level have been the other variables kept fixed, e.g. $KACC_2^2 = \dfrac{\bar{Y}_2(K_2,L_2,E_2)}{\bar{Y}_2(K_1,L_1,E_2)}$ reflects change in eco-productivity whch would be induced by the change in the extensive factors of production while keeping emissions at the level of period 2 under the technology of period 2.

There are four variations of possible decomposition of $\dfrac{e_2}{e_1}\cdot\dfrac{\bar{y}_2(K_2,L_2,E_2)}{\bar{y}_1(K_1,L_1,E_1)}$ which differ in combinations of indices:

$$[1]\ \frac{Y_2}{Y_1} = \frac{e_2}{e_1}\cdot\frac{\bar{Y}_2(K_1,L_1,E_1)}{\bar{Y}_1(K_1,L_1,E_1)}\cdot\frac{\bar{Y}_2(K_2,L_2,E_1)}{\bar{Y}_2(K_1,L_1,E_1)}\cdot\frac{\bar{Y}_2(K_2,L_2,E_2)}{\bar{Y}_2(K_2,L_2,E_1)} = ECOEFF.\,TECH^1.\,KACC_2^1.\,EMIS_2^2$$

$$[2]\ \frac{Y_2}{Y_1} = \frac{e_2}{e_1}\cdot\frac{\bar{Y}_2(K_1,L_1,E_1)}{\bar{Y}_1(K_1,L_1,E_1)}\cdot\frac{\bar{Y}_2(K_2,L_2,E_2)}{\bar{Y}_2(K_1,L_1,E_2)}\cdot\frac{\bar{Y}_2(K_1,L_1,E_2)}{\bar{Y}_2(K_1,L_1,E_1)} = ECOEFF.\,TECH^1.\,KACC_2^2.\,EMIS_2^1$$

$$[3]\ \frac{Y_2}{Y_1} = \frac{e_2}{e_1}\cdot\frac{\bar{Y}_2(K_2,L_2,E_2)}{\bar{Y}_1(K_2,L_2,E_2)}\cdot\frac{\bar{Y}_1(K_2,L_2,E_2)}{\bar{Y}_1(K_1,L_1,E_2)}\cdot\frac{\bar{Y}_1(K_1,L_1,E_2)}{\bar{Y}_1(K_1,L_1,E_1)} = ECOEFF.\,TECH^2.\,KACC_1^2.\,EMIS_1^1$$

$$[4]\ \frac{Y_2}{Y_1} = \frac{e_2}{e_1}\cdot\frac{\bar{Y}_2(K_2,L_2,E_2)}{\bar{Y}_1(K_2,L_2,E_2)}\cdot\frac{\bar{Y}_1(K_2,L_2,E_1)}{\bar{Y}_1(K_1,L_1,E_1)}\cdot\frac{\bar{Y}_1(K_2,L_2,E_2)}{\bar{Y}_1(K_2,L_2,E_1)} = ECOEFF.\,TECH^2.\,KACC_1^1.\,EMIS_1^2$$

Multiplying the four out and taking geometrical means one obtains the expresiion $\dfrac{Y_2}{Y_1} = ECOEFF\,.\,TECH\,.\,KACC.EMIS$, where

$$TECH = \left[TECH^1\cdot TECH^2\right]^{1/2}$$

$$KACC = \left[KACC_1^1\cdot KACC_2^1\cdot KACC_1^2\cdot KACC_2^2\right]^{1/4}$$

$$EMIS = \left[EMIS_1^1\cdot EMIS_2^1\cdot EMIS_1^2\cdot EMIS_2^2\right]^{1/4}$$

Factors *TECH*, *KACC* a *EMIS* may be thought of as the expression of the partial effect of the technology, capital accumulation or reduction of emissions to overal eco-productivity change. The term *ECOEFF* stays constant through the four alterations and for each DMU it represents eco-efficiency change, i.e. ratio of the scores resulting from models for periods 2 and 1 being identical with the *catch-up* effect.

5 Results

The computation was carried out using DEA Solver by Saitech. Each of 6 models involved 29 optimizations and determining output projections. These were used to form decomposition terms described in Section 4. Potentials from the respective models are given in Table A1 in Annex. Table A2 in Annex displays terms TECH, KACC, and EMIS with the indexation as it appears in (2.10) – (2.11)

Table 2 Decomposition of eco-productivity

	y2/y1	e2/e1	TECH	KACC	EMIS
Belgium	1,269	1,0000	1,150	0,966	1,143
Bulgaria	1,527	1,2101	1,179	0,992	1,079
Czech Republic	1,462	1,2164	1,174	0,944	1,084
Denmark	1,185	1,0000	1,137	0,922	1,131
Germany	1,223	1,0000	1,102	0,976	1,137
Estonia	1,194	0,8733	1,191	1,211	0,948
Ireland	1,448	1,0000	1,273	0,958	1,187
Greece	1,314	1,0715	1,140	0,968	1,112
Spain	1,310	0,9728	1,147	1,032	1,137
France	1,207	1,0000	1,117	0,973	1,111
Italy	1,141	0,9652	1,062	0,993	1,120
Cyprus	1,232	1,1323	1,207	0,930	0,969
Latvia	1,209	0,9206	1,164	1,155	0,976
Lithuania	1,426	1,1002	1,151	1,084	1,038
Hungary	1,388	1,0047	1,151	1,008	1,191
Malta	1,015	1,0000	1,184	0,959	0,894
Netherlands	1,161	0,9869	1,159	0,959	1,058
Austria	1,107	0,9971	1,143	0,973	0,998
Poland	1,406	1,1984	1,188	0,978	1,009
Portugal	1,248	0,9026	1,150	0,997	1,206
Romania	1,738	1,2683	1,173	0,968	1,208
Slovenia	1,258	1,0120	1,158	1,031	1,041
Slovakia	1,713	1,2855	1,148	1,019	1,139
Finland	1,102	1,0618	1,173	0,920	0,962
Sweden	1,289	1,0000	1,238	0,948	1,098
United Kingdom	1,352	1,0000	1,191	0,957	1,186
Island	1,050	1,0000	1,240	0,948	0,893
Norway	1,148	1,0000	1,158	0,964	1,029
Switzerland	1,135	1,0000	1,187	0,958	0,998
priemer	*1,285*	*1,041*	*1,167*	*0,989*	*1,072*
SD	*0,176*	*0,105*	*0,041*	*0,065*	*0,091*

Source: author´s calculation

In the first column, DMUs under evaluation are listed. The second column shows change of eco-productivity, all European countries got „greener“ over time. The most pronounced improvement can be viewed in Romania and Slovakia, Iceland appears to undergo virtually no change. The other four factors help explain drivers of observed change in eco-productivity. *Catch-up* effect *ECOEFF* in the third column expresses individual effort of a country. Unit value implies that the DMU constitutes efficiency frontier in both periods. There are 11 countries with *ECOEFF* = 1, the most clear-cut improvement can be observed in case of the new EU member states (Bulgaria, Czech Republic, Slovakia, Romania). Countries Technology change *TECH* – *frontier-shift* effect in the fourth column stands for how technology change contributed to individual country´s performance. This effect is clearly positive for all countries making up the average of 1,167. *KACC* shows the effect of the change in extensive factors of production, i.e. substitution between capital and labour representing the movement along the frontier as well as the change induced by the mere reduction of emissions ceteris paribus. Extensive factors´contribution appears to be of no importance, it seems to have a tangible effect in developing European countries with rather high levels of capital investment (Slovenia, Slovakia, Estonia, Latvia acompanied by Spain). The effect of reduction of pollutants is at large variance in the sample with the average above the unit.

6 Conclusion

Concept of eco-efficiency has gained much attention and has been widely implemented in managerial and economic policy decision-making. In intertemporal setting, non-parametric approach to measuring eco-efficiency enables to decompose eco-productivity into factors attributable to changes in efficiency, technology, extensive factors of production, and emissions. Results suggest that in European countries in the span 2000 – 2010, an environment-saving rather than input-saving technology change has been taking place contributing to raising the quality of life.

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ANNEX

Table A1 Potential outputs for DMUs from SBM model

	Y2_K2_L2_E2	Y2_K2_L2_E1	Y2_K1_L1_E2	Y2_K1_L1_E1	Y1_K2_L2_E2	Y1_K2_L2_E1	Y1_K1_L1_E2	Y1_K1_L1_E1
Belgium	283267	246391	283267	283267	246391	246391	246391	246391
Bulgaria	92570	86663	97770	97770	86663	86663	86663	75096
Czech Republic	293890	257102	309374	309093	257102	257102	257102	256224
Denmark	142158	133759	161704	162605	133759	133759	133759	133759
Germany	2028391	1840665	2028391	2028391	1840665	1840665	1840665	1840665
Estonia	25919	23361	20332	20332	23361	23361	23361	15907
Ireland	124583	100253	124583	124583	100253	100253	100253	95590
Greece	286730	249481	284705	283899	249481	248796	249481	251114
Spain	1024057	917325	964786	959387	917325	909068	917325	813861
France	1487970	1332584	1487970	1487970	1332584	1332584	1332584	1332584
Italy	1369541	1274741	1338863	1338863	1274741	1274741	1274741	1274741
Cyprus	16907	14803	18489	18489	14803	14803	14803	14498
Latvia	32129	28631	26219	25066	28631	26396	28631	20745
Lithuania	48180	44529	43975	42396	44529	41523	44529	34597
Hungary	175656	159887	173498	175020	159887	162026	159887	145184
Malta	7624	6440	7624	7624	6440	6440	6440	6440
Netherlands	504084	432217	506968	501311	432217	429203	432217	435043
Austria	248664	216744	245827	242627	216744	211298	216744	213058
Poland	518351	445851	514992	514992	445851	445851	445851	423940
Portugal	187676	169425	186436	188888	169425	173092	169425	158174
Romania	238235	213465	247801	248030	213465	213465	213465	201250
Slovenia	50939	45701	48485	47562	45701	44228	45701	39514
Slovakia	107774	101018	107711	107210	101018	99394	101018	86799
Finland	139373	125850	159625	154842	125850	125850	125850	124682
Sweden	266801	215572	266801	266801	215572	215572	215572	215572
United Kingdom	1587738	1333024	1587738	1587738	1333024	1333024	1333024	1333024
Island	8743	7050	8743	8743	7050	7050	7050	7050
Norway	163330	141051	163330	163330	141051	141051	141051	141051
Switzerland	240940	203022	240940	240940	203022	203022	203022	203022

Source: author´s calculation

Table A2 Decomposition factors

	e2/e1	y2 / y1	TECH1	TECH2	1KACC1	1KACC2	1EMIS1	1EMIS2	2KACC1	2KACC2	2EMIS1	2EMIS2
Belgium	1,000	1,269	1,150	1,150	1,000	1,000	1,103	1,103	0,870	1,000	1,103	1,269
Bulgaria	1,210	1,527	1,302	1,068	1,154	1,000	1,182	1,024	0,886	0,947	1,024	1,094
Czech Republic	1,216	1,462	1,206	1,143	1,003	1,000	1,051	1,048	0,832	0,950	1,049	1,197
Denmark	1,000	1,185	1,216	1,063	1,000	1,000	1,115	1,115	0,823	0,879	1,109	1,185
Germany	1,000	1,223	1,102	1,102	1,000	1,000	1,109	1,109	0,907	1,000	1,109	1,223
Estonia	0,873	1,194	1,278	1,109	1,469	1,000	1,233	0,839	1,149	1,275	0,839	0,931
Ireland	1,000	1,448	1,303	1,243	1,049	1,000	1,165	1,111	0,805	1,000	1,111	1,380
Greece	1,071	1,314	1,131	1,149	0,991	1,000	1,067	1,077	0,879	1,007	1,077	1,234
Spain	0,973	1,310	1,179	1,116	1,117	1,000	1,206	1,080	0,956	1,061	1,076	1,195
France	1,000	1,207	1,117	1,117	1,000	1,000	1,081	1,081	0,896	1,000	1,081	1,207
Italy	0,965	1,141	1,050	1,074	1,000	1,000	1,100	1,100	0,952	1,023	1,100	1,182
Cyprus	1,132	1,232	1,275	1,142	1,021	1,000	0,952	0,933	0,801	0,914	0,933	1,065
Latvia	0,921	1,209	1,208	1,122	1,272	1,000	1,170	0,919	1,142	1,225	0,887	0,951
Lithuania	1,100	1,426	1,225	1,082	1,200	1,000	1,198	0,998	1,050	1,096	0,965	1,007
Hungary	1,005	1,388	1,206	1,099	1,116	1,000	1,257	1,127	0,914	1,012	1,132	1,254
Malta	1,000	1,015	1,184	1,184	1,000	1,000	0,857	0,857	0,845	1,000	0,857	1,015
Netherlands	0,987	1,161	1,152	1,166	0,987	1,000	1,008	1,022	0,862	0,994	1,026	1,184
Austria	0,997	1,107	1,139	1,147	0,992	1,000	0,968	0,976	0,893	1,012	0,964	1,091
Poland	1,198	1,406	1,215	1,163	1,052	1,000	1,009	0,960	0,866	1,007	0,960	1,116
Portugal	0,903	1,248	1,194	1,108	1,094	1,000	1,249	1,141	0,897	1,007	1,151	1,291
Romania	1,268	1,738	1,232	1,116	1,061	1,000	1,228	1,158	0,861	0,961	1,157	1,292
Slovenia	1,012	1,258	1,204	1,115	1,119	1,000	1,115	0,996	0,961	1,051	0,983	1,075
Slovakia	1,285	1,713	1,235	1,067	1,145	1,000	1,249	1,091	0,942	1,001	1,078	1,145
Finland	1,062	1,102	1,242	1,107	1,009	1,000	0,937	0,929	0,813	0,873	0,957	1,028
Sweden	1,000	1,289	1,238	1,238	1,000	1,000	1,041	1,041	0,808	1,000	1,041	1,289
United Kingdom	1,000	1,352	1,191	1,191	1,000	1,000	1,135	1,135	0,840	1,000	1,135	1,352
Island	1,000	1,050	1,240	1,240	1,000	1,000	0,847	0,847	0,806	1,000	0,847	1,050
Norway	1,000	1,148	1,158	1,158	1,000	1,000	0,992	0,992	0,864	1,000	0,992	1,148
Switzerland	1,000	1,135	1,187	1,187	1,000	1,000	0,956	0,956	0,843	1,000	0,956	1,135

Source: author´s calculation