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PARAMETRIC ESTIMATION OF ENVIRONMENTAL EFFICIENCIES AND SHADOW PRICES OF ENVIRONMENTAL POLLUTANTS: CROSS-COUNTRY APPROACH '

This paper has a main purpose of estimation of environmental efficiencies of economies and shadow prices of environmental pollutants for post-communist countries and comparison of them to the respective indicators of other countries. The obtained values of efficiencies can be used as sustainability indicators in determining the international development priorities. Shadow prices estimates can be used as reference values in setting rates of environmental taxation and international environmental trade rates. We approach the problem by using a Shephard-type directional distance function estimated by Translog specification for calculating efficiencies and its duality to the revenue function for estimating the respective shadow prices. Our findings point on inefficient allocation of pollution among the countries as well as provide estimates of economically justified reference values for environmental taxation and international environmental trade rates.

Introduction

This paper has a main purpose of estimation of environmental efficiencies of economies and shadow prices of environmental pollutants for post-communist countries and comparison of them to the respective indicators of other countries. These issues are closely connected to the hypothesis of North-South conflict.

The hypothesis of North-South conflict is the theory that the developed countries (mainly located in the Northern hemisphere, therefore called 'North'), owing to the fact that their basic needs are mostly satisfied, have a higher awareness regarding the use of natural resources. They are characterized by high marginal rates of substitution of environmental degradation for economic development and high environmental efficiencies of economies. At the same time, developing countries (called 'South', since they are mostly located in the Southern hemisphere) tend to satisfy their needs in economic development through an intensive exploitation of environmental and natural resources. These countries have low marginal rates of substitution of environmental degradation for economic development and low environmental efficiencies of economies [1].

Taking into consideration the fact that the transition countries greatly differ from both North and South economically and politically [2], the position of CITs within the context of the North-South conflict is not that obvious. Moreover, taking into consideration an insignificant number of empirical studies in the field of sustainable development in CITs, there are no reasons to regard these countries as either North or South. In addition to this, because of their heterogenic economic and environmental structure, different regions of many CITs may have features of different groups.

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Identification of the role of the countries in the context of the North-South conflict is an important component of development of sustainable policy of national and regional economic development in line with Rio Declaration of 1992 and especially with Principles 3 and 6. These principles urge to develop the policies, which would equitably meet the environmental needs of all people of the Earth with a special attention paid to the least developed and the most environmentally vulnerable countries and regions.

Thus, the 'South' countries must pay attention to the environmental efficiency of their economies and sustainability of the national development. Their 'North' neighbors should consider transboundary effects of environmental degradation and in line with Principles 12 and 17 of the Declaration (about cooperation in sustainable development issues) promote environmental efficiency and sustainability of the 'South' countries. In addition, national policy should pay special attention to those regions that demonstrate the relative instability of development through promotion of regional economic development programs that would improve efficiencies of those regional economies.

Practical value of such a work is its ability to analyze economic aspects of sustainable development and through this analysis evaluate the optimal parameters of environmental legislation, *e. g.* environmental taxes. Calculation of the shadow prices of some pollutants *(e. g.,* greenhouse gases) will enable countries to use economic rationale in making decision on the emission trading according to the international agreements *(e. g.,* Kyoto Protocol).

Moreover, determination of sustainability of development and environmental efficiencies of economies will provide a background for the further studies in the field of environmental economics of the CITs. Due to identification of the roles of the transitional countries and their regions in the North-South conflict, the respective models and approaches used in studies of the countries of either North or South may be justified.

Literature review

Although the earliest works on estimation of shadow prices of undesirable outputs (called bads as an antonym to goods) were published in the beginning of 1980s [3, 4], such studies are not numerous, nevertheless provide theoretically well thought-out models suitable for such estimations.

The majority of these works estimate shadow prices using the output distance function proposed by Shephard [5] as a complete characterization of the wide spectrum of technologies, which is dual towards the income function.

Aforementioned works of Pittman estimate shadow prices of pollutants of pulp and paper industry and give realistic figures pointing on inefficient distribution of resources in the industry. A decade later Fare *et al.* [6] reviewed the results of Pittman and emphasized that the earlier studies were unable to determine the shadow prices of the individual plants. For this reason, the authors use their previous theoretical work [7] regarding the use of nonparametric approach towards the efficiency analysis of the industries producing undesirable outputs in order to estimate shadow prices of individual pulp and paper plants of Michigan and Wisconsin.

The estimation of the shadow prices is based on the assumption of full efficiency, *i. e.* the estimation takes place on the production possibility frontier. This approach provides plausible results and that leads to the acceptance of it as a fundamental approach in the further works on the estimation of the shadow prices of pollutants.

Other works differ from the Fare's works mainly by the choice of the directional vector of the output distance function. Particularly, Fare *et al.* use the hyperbolic [7] and radial [6] efficiency rules; Boyd *et al.* [8] use horizontal and vertical efficiency rules; Chambers *et al.* [9] and Chung *et al* [10] make use of the general directional efficiency rule. Unfortunately, since the studies considered different object, it is hard to compare the results of these studies. However, it is possible to argue that in theory the choice of different directional vectors may give different absolute values of the shadow prices of the individual objects as well as alters their relative efficiency (*i. e.* the objects having the same efficiency according to one efficiency rule may have different efficiencies according to the other efficiency rule).

A recent study of the power plants in South Korea of Lee *et al.* [11] despite minor inaccuracies in its theoretical development [12] is notable among all other studies in the field. This paper proposes to estimate the shadow prices of pollution taking into account environmental inefficiency of production processes and pay attention to the theoretical validation of the efficiency rule. The study explicitly incorporates the weak efficiency assumption over the whole range of frontier in the output domain. The work itself bases its efficiency rule on the annual environmental protection plans of the plants.

Although such a method of choosing the directional vector is not fully relevant (especially in transitional countries, where these plans are either difficult to access or do not exist at all), a consideration of environmental inefficiency of economies in estimation of the shadow prices of bads is an important modification of the model of Fare *et al.* [6].

This modification enables aggregation of the shadow price and environmental efficiency of economy into a single indicator suitable to statistical comparison across countries and regions.

The use of shadow prices and environmental efficiency of production as a sustainability indicator is justified by De Koeijer *et al.* [13] in their sustainability analysis of the Dutch sugar-beet industry. The main advantage of the use of these values to measure sustainability is a simultaneous analysis of biophysical and socioeconomic components of sustainability. Unlike purely biophysical *(e. g.,* [14]) or purely socioeconomic aggregated measures [15], shadow prices of environmental degradation and environmental efficiency of production measure its efficiency in the context of both environmental and economic parameters.

Since none of the previous researches on the shadow prices and environmental efficiency estimation analyzed the aggregated environmental and economic indicators of different countries and regions, this research takes a new step of incorporating an experience accumulated in the field of environmental microeconomics in the field of environmental macroeconomics and the economics of the public sector.

This paper will attempt to estimate the respective sustainability indicators using a general directional vector (the choice will be justified in the methodology section). The estimation will be carried using a conventional parametric estimation through *Translog* specification of the distance function similar to [10] with a consideration of environmental inefficiency of economies in line with [11].

Shadow prices obtained in the analysis will provide estimates of the economically justified prices representing the internal valuation of environmental degradation (by each pollutant) by each country in the sample. Comparison of these with the existing legal requirements enables estimation of efficiency of the existing national and regional legislations, particularly environmental taxes. Based on these estimates we will be able to make conclusions on the need of any corrections in the existing legislation.

Methodology of **research**

Basic concepts

Before we discuss mathematical model used in the work and practical aspects of the data collection and processing, let us introduce basic definitions and assumptions.

The sample is formed by analyzing *K* countries or regions (which will be called decision making units (DMUs) below for the sake of generalization), which produce *L* good (or desirable) output $\mathbf{g} = (g_1\, g_2\, \dots\, g_L)^T \in \Re_+^L$ and *M bad* (or undesirable) outputs $\mathbf{b} = (b_1\, b_2\, \dots\, b_M)^T \in \Re_+^M$ using a vector of *N* inputs $\mathbf{x} = (x_1\, x_2\, \dots\, x_N)^T \in \Re_+^N$. *L* good and *M* bad outputs form a general vector of outputs by fusion of g and b vectors $y = (g_1 \dots g_L\, b_1 \dots b_M)^T \in \in \Re_+^{L\ M}$. Shadow prices of the outputs are expressed as vectors $\mathbf{p}^g = (p_1^g\, p_2^g \dots p_L^g) \in \Re_+^L$ for desirable outputs and $\mathbf{p}^b = (p_1^b\, p_2^b \dots p_M^b) \in \Re_+^L$ with p_i^g and p_j^b denoting shadow prices of /th desirable andy'th undesirable outputs respectively.

Let us introduce definitions of the basic co ncepts used in the work. These definitions correspond to those of neoclassical production theory (e. *g.,* [16]).

Dl. Technology set is defined as

$$T = \{(\mathbf{x}, \mathbf{y}) \in \Re_+^N \times \Re_+^{M\ L} : \mathbf{x} \in \Re_+^N \text{ can produce } y \in \Re_+^{L\ M}\}.$$

D2. Production possibility set is defined as

$$P(\mathbf{x}) = \{y \in \Re_+^{L+M} : (\mathbf{x}, \mathbf{y}) \in T\}.$$

We agree to denote the production possibilities frontier, *i. e.* the combination of outputs produced by the most efficient use of inputs, as $\partial P(\mathbf{x})$. In the presence of undesirable outputs, we may represent the production possibility frontier as

$$\partial P(\mathbf{x}) = \{\mathbf{y} = (\mathbf{g}\ \mathbf{b}) \in \Re_+^{L+M} : \forall\lambda > 1 : \mathbf{y} \in P(\mathbf{x});$$
$$\mathbf{y}' = (\lambda\mathbf{g}\ \mathbf{b}/\lambda) \notin T\}.$$

D3. We define output-based directional distance function (ODDF) through the function

$$\vec{D}_0 : \Re_+^N \times \Re_+^L \times \Re_+^M \times \Re_+^{L+M} \to \Re_+ \cup \{\infty\}:$$

$$\vec{D}_0(\mathbf{x}, \mathbf{g}, \mathbf{b}; \mathbf{d}) = \sup_\tau \{\tau \geq 0 : ((\mathbf{g}\ \ \mathbf{b}) + \tau\mathbf{d}) \in P(\mathbf{x})\},$$

where $\mathbf{d} = (\alpha_1 \dots \alpha_L, \beta_1 \dots \beta_M)^T$ - directional vector that determines the direction set by ODDF

ODDF will project any point in the T in a point on the $\partial P(x)$. This point will be 'a full efficiency point' for a given DMU $(\mathbf{g}_0^*, \mathbf{b}_0^*) = (\mathbf{g}_0, \mathbf{b}_0) + \vec{D}_0(\mathbf{x}, \mathbf{g}_0, \mathbf{b}_0; \mathbf{d}_0) \cdot \mathbf{d}_0$. All points on $\partial P(x)$ are characterized by $\vec{D}_0(\cdot) = 0$.

D4. Efficiency rule *(ER)* is defined through the function, which corresponds a point $\mathbf{y} = (\mathbf{g}\ \mathbf{b}) \in \in P(\mathbf{x})$ to a point $(\mathbf{g}^*\ \mathbf{b}^*)$ on $\partial P(\mathbf{x})$ in such a way: $\sigma_i^g(\tau) \cdot g_i = g_i^*, \sigma_j^b(\tau) \cdot b_j = b_j^*\ \forall\, i \in 1 \dots L,\ j \in 1 \dots M.$

Parameters σ_i^g and σ_j^b are inefficiency factors for *i*th good and *j*th bad output respectively. *L* good output inefficiency factors $\sigma_1^{\mathbf{g}} \dots \sigma_L^{\mathbf{g}}$ form an *(Lx1)* column vector $\sigma^{\mathbf{g}}$ of good output inefficiency factors; similarly, *M* bad output inefficiency factors $\sigma_1^b \dots \sigma_M^b$ form an *(Mx1)* column vector $\sigma^{\mathbf{b}}$ of bad output inefficiency factors. Within a framework of the current work, we accept them as

$$\sigma_i^g = \left(1 - \vec{D}_0(\cdot)\frac{\alpha_i}{g_i^*}\right)^{-1} \text{ and } \sigma_j^b = \left(1 - \vec{D}_0(\cdot)\frac{\beta_j}{b_j^*}\right)^{-1} \quad (1)$$

(see Appendix 1 for proof).

D5. Efficiency path (EP) mathematically can be expressed as

$$EP(\mathbf{g}^*, \mathbf{b}^*) = \{(\mathbf{g}\ \mathbf{b}) \in P(\mathbf{x}): \mathbf{g}^* = \sigma^g \bullet \mathbf{g}, \mathbf{b}^* = \sigma^b \bullet \mathbf{b}\},$$

where by · we denote pair-wise vector product.

In other words, EP is a set of points, which are brought to the common point $(\mathbf{g}^*, \mathbf{b}^*)$ on $\partial P(\mathbf{x})$ by the ER used. For graphical interpretation in one bad-one good output case, see Figure 1.

D6. Iso-efficiency path (IEP) around $(\mathbf{g}^0, \mathbf{b}^0)$

$$\text{IEP}(\mathbf{g}^0, \mathbf{b}^0; \mathbf{d}) = \{(\mathbf{g}\ \mathbf{b}) \in P(\mathbf{x}):$$
$$\vec{D}_0\ (\mathbf{x}, \sigma^{g0} \bullet g, \sigma^{b0} \bullet \mathbf{b}, \mathbf{d}) = 0\},$$

where σ^{g0} and σ^{b0} are defined by the chosen ER and the observed values of $(\mathbf{g}^0, \mathbf{b}^0)$. All points of IEP have the same level of inefficiency.

Let us make the basic assumptions used in this work[1].

A1. We assume that in the production of good and bad outputs we cannot keep the strong free disposability of outputs assumption (see Fare and Primont, 1995), since at any fixed level of inputs and good output a decrease in bad output production is possible only until a certain nonnegative limit. Therefore, we still rely on the assumption of the $\partial P(x)$ concavity but allow a positive slope of it. The slope is gradually diminishing as bad output production increases.

A2. We assume that producing a positive amount of good output requires producing non-zero amount of bad output, *i. e.*

$$\mathbf{g} > 0 \Rightarrow \mathbf{b} > 0 \text{ or identically } \mathbf{b} = 0 \Rightarrow \mathbf{g} = 0.$$

However, the opposite is not necessary true, i. *e.* production of non-zero bad output is not necessarily accompanied by the production of non-zero good output. Intuitively it may be understood as existing of a threshold (it *may* be equal to zero, but it also may be non-zero) in bad outputs, after which a DMU can produce some good inputs *(e. g.,* some industries need to emit pollution before starting production plainly to heat the machinery up).

A3. We assume good output to be freely disposable, *i. e.*

$$(\mathbf{g}\ \mathbf{b}) \in P(\mathbf{x}) \Rightarrow \forall \mathbf{g}' \le \mathbf{g} : (\mathbf{g}'\ \mathbf{b}) \in P(\mathbf{x}).$$

However, in regard to bad output we assume that

$$(\mathbf{g}\ \mathbf{b}) \in P(\mathbf{x}) \Rightarrow \forall \mathbf{b} \le \mathbf{b}' : (\mathbf{g}\ \mathbf{b}') \in P(\mathbf{x}).$$

A4. All DMUs may have different environmental efficiencies, but have an access to the same technologies. Difference in the *level* of access is a reason of the inefficiencies.

A5. All DMUs produce a single good output (GNP) but a number of bad outputs.

A6. Prices for good outputs equal to their shadow prices, *i. e.* we assume competition on the goods (but not bads) market. This assumption allows us to determine absolute shadow prices of bads, since theoretical expression allows to estimate them only relatively to the shadow prices of goods (otherwise, we need other assumptions).

A7. All observations are technologically feasible.

A8. We assume that all outputs (bad and good) are produced jointly. By this, we are able to extend the methodology of Lee *et al.* [11], who implicitly imposed the non-joint production structure (which may result an estimation bias).

Brief review of the theoretical model

Based on the similar assumptions Fare *et al.* [6] estimate absolute shadow price of a bad output in terms of the Shephard's output distance function defined through the function $D_0 : \Re_+^N \times \Re_+^{L+M} \to \Re_+ \cup \{\infty\} : D_0(\mathbf{x}, \mathbf{y}) = \inf_\theta \{\theta : (\mathbf{y}/\theta) \in P(\mathbf{x})\}$ [5]. In terms of our model these shadow prices can be estimated as

$$\frac{\tilde{p}^b}{p^g} = \frac{\partial D_0(\cdot)/\partial b}{\partial D_0(\cdot)/\partial g}, \quad (2)$$

where $\tilde{p}^b$ - is a shadow price of a bad output, estimated on $\partial P(x)$, *i. e.* assuming full efficiency.

Modification of the Fare's model made by Lee *et al.* [11] makes a correction for inefficiency and leads to the following result

$$p^b = p^g \frac{\partial \vec{D}_0(\cdot)/\partial b}{\partial \vec{D}_0(\cdot)/\partial g} \cdot \frac{\sigma^b}{\sigma^g}. \quad (3)$$

Graphical interpretation is given on Fig. 1.

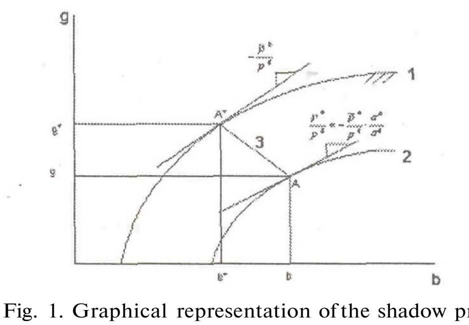

Fig. 1. Graphical representation of the shadow prices of bad outputs at the point of full efficiency *(A*)* and at the observed point *(A):* 1 - *dP(x), 1* - IEP, 3 - EP

[1] All these assumptions have been reviewed regarding the possibility to apply them for the countries in transition. The authors found no reasons for these assumptions not to hold true in these countries, since they are based on the general nature of pollution and do not depend on whether the economy is market or transitional. We would like to thank Turatbek Aydyraliev for the comment regarding the reliability of the assumptions in the transitional countries made on the 14th EERC workshop.

As it follows from the IEP definition, all points on this surface are characterized by the same value of the σ^g and σ^b vectors. Since σ^g and σ^b are uniquely defined by τ, points *A* and *B* belong to different IEP if and only if $\tau_A \neq \tau_B$. At this, IEP_A represents higher efficiency than IEP_B if $0 \le \tau_A < \tau_B$. Hence, we may compare environmental efficiencies of DMUs based on the values of $\vec{D}_0(\cdot)$ only.

For estimating ODDF we are using a general directional vectors: $\mathbf{d} = (g_1 \dots g_L - b_1 \dots - b_M)^T$, a vector, which requires the DMU to increase its good output while simultaneously decreasing its bad output. The slope of the vector is set proportionally to the current level of output. This vector allows seeking for the maximum possible increase in economic wealth *and* the maximum possible decrease in environmental loss at the same time.

In line with A5, we consider the case of $L = 1$.

ODDF estimation

Estimation of the P(x) set, the inefficiency factors and the shadow prices can be realized by using various techniques. The traditional studies in the field take an approach of Aigner and Chu [17] of specifying a parametric form for the technology and select the parameters that provide the most precise envelope of the observed data through using the linear programming.

Parametric Translog ODDF estimation

Chung [18]' proposed to parameterize ODDF by the *Translog* function for $\mathbf{d} = (g_1 \dots g_L - b_1 \dots - b_M)^T$. Skipping the discussion of the original model, we go straight to the specification made in terms of our model.

Parametric estimation of inefficiencies

This specification is flexible and linear. In addition, it does not impose strong disposability of outputs. Simplification of the original model to the specific case under review *(i. e.* $L = 1$) provides with the following *Translog* specification of ODDF:

$$\begin{aligned}
&\ln\left[1+\vec{D}_0(\mathbf{x},\mathbf{g},\mathbf{b},\mathbf{d})\right] = \\
&\alpha_0 + \alpha_1 \ln g + \sum_m \beta_m \ln b_m + \sum_n \gamma_n \ln x_n \\
&+\frac{1}{2}\alpha_{11}(\ln g)(\ln g) + \frac{1}{2}\sum_m\sum_{m'}\beta_{mm'}(\ln b_m)(\ln b_{m'}) \qquad (4)\\
&+\frac{1}{2}\sum_n\sum_{n'}\gamma_{nn'}(\ln x_n)(\ln x_{n'}) + \frac{1}{2}\sum_n \delta_n(\ln g)(\ln x_n)\\
&+\frac{1}{2}\sum_m\sum_n \varepsilon_{mn}(\ln b_m)(\ln x_n) + \frac{1}{2}\sum_m \zeta_m(\ln g)(\ln b_m).
\end{aligned}$$

The reason for having $\ln\left[1+\vec{D}_0(\cdot)\right]$ instead of $\ln\left[\vec{D}_0(\cdot)\right]$ is that domain of the logarithmic function is positive numbers, while $\vec{D}_0(\cdot)$ can take a zero value on $\partial P(\mathbf{x})$. Therefore, we have to make an artificial restriction of the domain of the function to the positive numbers only.

Chung [18] then estimates the parameters of (4) by minimizing the sum of the deviations of the observations from the efficient level, *i. e.* $\partial P(\mathbf{x})$. Mathematically, the optimization problem is

$$\begin{aligned}
&\min \sum_k \left[\ln\left(1+\vec{D}_0(\cdot)\right) - \ln\left(1+\vec{D}_0(\cdot)\big|_{\partial P(x)}\right)\right]\\
&\equiv \min \sum_k \left[\ln\left(1+\vec{D}_0(\cdot)\right) - \ln(1+0)\right] \equiv \qquad (5)\\
&\equiv \min \sum_k \left[\ln\left(1+\vec{D}_0(\cdot)\right)\right].
\end{aligned}$$

Then (4) can be modeled by using (5) as an objective function as

$$\min \sum_k \left[\ln\left(1+\vec{D}_0(\mathbf{x}^k,\mathbf{g}^k,\mathbf{b}^k,\mathbf{d})\right)\right] \qquad (6)$$

s. t.

$$\begin{aligned}
&\text{(i)} \quad \ln\left(1+\vec{D}_0(\mathbf{x}^k,\mathbf{g}^k,\mathbf{b}^k,\mathbf{d})\right) \ge 0 \quad k = 1\dots K\\
&\text{(ii)} \quad \frac{\partial\left\{\ln\left(1+\vec{D}_0(\cdot)\right)\right\}}{\partial(\ln g)} \le 0\\
&\qquad \frac{\partial\left\{\ln\left(1+\vec{D}_0(\cdot)\right)\right\}}{\partial(\ln b_m)} \ge 0 \quad m = 1\dots M\\
&\text{(iii)} \quad \alpha_1 - \sum_m \beta_m = -1\\
&\qquad \alpha_{11} - \sum_m \zeta_m = 0 \quad m, m' = 1\dots M\\
&\qquad \zeta_m - \sum_{m'} \beta_{mm'} = 0 \quad n = 1\dots N\\
&\qquad \delta_n - \sum_m \varepsilon_{mn} = 0\\
&\text{(iv)} \quad \beta_{mm'} = \beta_{m'm}; \quad \gamma_{nn'} = \gamma_{n'n}.
\end{aligned}$$

Constraint (i) corresponds to A7 requiring that all observations are technologically feasible, (ii) guarantees nonnegative prices for good outputs and nonpositive prices for bad outputs, (iii) imposes functional properties of the ODDF as an approximation of the hyperbolic efficiency measure. Finally, (iv) imposes symmetry on Hessian matrix according to the Young's theorem.

Hence, we need to minimize a single objective function subject to a total of $K(M + 2) + 0.5(M(M+1) + N(N+1)) + 2$ constraints [2]. The optimization results $3 + 2M + 2N + M^2 + MN + N^2$ parameters of (4). Plugging into (4) the parameters and the observations for a given DMU will result

Similar approach was used by Hailu and Veeman [19] to estimate input distance function (IDF) and by Fare *et al.* [6] to estimate ODF.

[2] K constraints under (i), $K*(M+1)$ under (ii), $2 + M+$ Wunder (iii) and $0.5*(M(M-1) + N(N-1))$ under (iv).

an efficiency value for that DMU in $\ln\left[1+\vec{D}_0(\cdot)\right]$ terms. A transformation of it as

$$\vec{D}_0\left(\mathbf{x}^k, \mathbf{g}^k, \mathbf{b}^k, \mathbf{d}\right)=\exp\left\{\ln\left[1+\vec{D}_0\left(\mathbf{x}^k, \mathbf{g}^k, \mathbf{b}^k, \mathbf{d}\right)\right]\right\}-1 \quad (7)$$

will supply a value of the ODDF estimate for a given DMU.

Parametric estimation of shadow prices

D3 allows to calculate a 'full efficiency point' $(\mathbf{g}^*, \mathbf{b}^*)$, while (1) allows to calculate $M+\backslash$ inefficiency factors. The shadow prices then are estimated in line with (8), which is a modification of (3) with a joint production of the bad outputs taken into consideration

$$p_j^b = p^g \frac{\partial\vec{D}_0(\cdot)/\partial b_j}{\partial\vec{D}_0(\cdot)/\partial g}\cdot\frac{\sigma_j^b}{\sigma^g}. \quad (8)$$

At this,

$$\frac{\partial\vec{D}_0(\cdot)}{\partial b_j}=\frac{\partial\vec{D}_0(\cdot)}{\partial\ln\left[1+\vec{D}_0(\cdot)\right]}\cdot\frac{\partial\ln\left[1+\vec{D}_0(\cdot)\right]}{\partial\left(\ln b_j\right)}\cdot\frac{\partial\left(\ln b_j\right)}{\partial b_j}$$

and

$$\frac{\partial\vec{D}_0(\cdot)}{\partial g}=\frac{\vec{D}_0(\cdot)}{\partial\ln\left[1+\vec{D}_0(\cdot)\right]}\times\frac{\partial\ln\left[1+\vec{D}_0(\cdot)\right]}{\partial(\ln g)}\times\frac{\partial(\ln g)}{\partial g}.$$

Hence (8) can be rewritten as,

$$\hat{p}_j^{\,b}=p^g\frac{\dfrac{\partial\vec{D}_0(\cdot)}{\partial\ln\left[1+\vec{D}_0(\cdot)\right]}\cdot\dfrac{\partial\ln\left[1+\vec{D}_0(\cdot)\right]}{\partial\left(\ln b_j\right)}\cdot\dfrac{\partial\left(\ln b_j\right)}{\partial b_j}}{\dfrac{\partial\vec{D}_0(\cdot)}{\partial\ln\left[1+\vec{D}_0(\cdot)\right]}\cdot\dfrac{\partial\ln\left[1+\vec{D}_0(\cdot)\right]}{\partial(\ln g)}\cdot\dfrac{\partial(\ln g)}{\partial g}}\cdot\frac{\sigma_j^b}{\sigma^g}$$

$$= p^g\frac{\partial\ln\left[1+\vec{D}_0(\cdot)\right]/\partial\left(\ln b_j\right)}{\partial\ln\left[1+\vec{D}_0(\cdot)\right]/\partial(\ln g)}\cdot\frac{\sigma_j^b}{\sigma^g}\cdot\frac{g}{b_j}. \quad (9)$$

Some simple algebra allows to derive from (4) that

$$\frac{\partial\ln\left[1+\vec{D}_0(\cdot)\right]}{\partial\left(\ln b_j\right)}=\beta_j+\sum_m\beta_{mj}(\ln b_m)+ +\frac{1}{2}\sum_n\varepsilon_{jn}(\ln x_n)+\frac{1}{2}\zeta_j(\ln g) \quad (10)$$

and

$$\frac{\partial\ln\left[1+\vec{D}_0(\cdot)\right]}{\partial(\ln g)}=\alpha_1+\alpha_{11}(\ln g)+ +\frac{1}{2}\sum_n\delta_n(\ln x_n)+\frac{1}{2}\sum_m\zeta_m(\ln b_m). \quad (И)$$

Corollary, based on A6, (9), (10) and (11), shadow price of y'th bad output for $ku\backslash$ DMU can be numerically estimated as

$$\hat{p}_j^{\,b^k}=\frac{\beta_j+\sum_m\beta_{mj}(\ln b_m^k)+\frac{1}{2}\sum_n\varepsilon_{jn}(\ln x_n^k)+\frac{1}{2}\zeta_j(\ln g^k)}{\alpha_1+\alpha_{11}\left(\ln g^k\right)+\frac{1}{2}\sum_n\delta_n(\ln x_n^k)+\frac{1}{2}\sum_m\zeta_m(\ln b_m^k)}\times \times\frac{\sigma_j^{b^k}}{\sigma^{g^k}}\cdot\frac{g^k}{b_j^k}. \quad (12)$$

Empirical analysis

The empirical study will take a static approach on the global level, which will consider countries as separate DMUs. It will analyze 67 countries including 27 CITs. The rest of countries contain typical North and South representatives for the purpose of comparing CITs with those. The list of countries as well as their theoretical affiliation in the context of the North-South conflict is represented in Table 1.

Table 1. **Countries analyzed in the global study**

CITs	North	South
Albania	Australia	Angola
Armenia	Austria	Bangladesh
Azerbaijan	Belgium	Burkina Faso
Belarus	Canada	Burundi
Bosnia and Herzegovina	Denmark	Chad
Bulgaria	Finland	Congo (Dem. Rep.)
Croatia	France	Eritrea
Czech Republic	Germany	Ethiopia
Estonia	Ireland	Kenya
Georgia	Italy	Madagascar
Hungary	Japan	Malawi
Kazakhstan	The Netherlands	Mali
Kyrgyz Republic	New Zealand	Mozambique
Latvia	Norway	Nepal
Lithuania	Sweden	Niger
Macedonia	Switzerland	Nigeria
Moldova	United Kingdom	Rwanda
Poland	The United States	Sierra Leone
Romania		Tanzania
Russian Federation		Uganda
Serbia-Montenegro		Yemen
Slovak Republic		Zambia
Slovenia		
Tajikistan		
Turkmenistan		
Ukraine		
Uzbekistan		

The list of inputs and outputs for each of the DMUs is represented in Table 2.

Table 2. **Inputs and outputs analyzed in the study**

Good Output	Bad Outputs	Inputs
GNP	CO_2 emissions SO_2 emissions NO_x emissions	Labor Arable land Total primary energy supply (TPES) Fixed capital consumption

The data was taken from UN [20] and WRI **[21].**

The analysis of the data will yield values of environmental inefficiencies of the respective economies and the shadow prices of the respective pollutants for these countries. Cluster analysis executed on the values of environmental inefficiencies may enable to group countries according to their North-South affiliation and identify the role of CITs in the North-South conflict. Shadow prices of pollutants will indicate the internal value of environmental degradation for a given society and, hence, enable to identify economically justified rates of environmental taxation in each given country.

Data description

General statistics on the data is provided in Table 3.

Table 3. **Descriptive statistics on the data**

Variable	Units of measurement	Mean	Median	Max	Min	St. Dev.	Obs.
GNP	Bln. US$	342.190	9.750	7783.092	0.762	1152.879	67
CO_2	Th. metr. tons	81.033	13.800	861.200	0.100	155.878	67
SO_2	Th. metr. tons	1016.909	145.400	18142.200	5.300	2576.921	67
NO_X	Th. metr. tons	791.008	195.000	18051.200	13.000	2337.162	67
Labor	Millions	12.900	4.779	136.494	0.802	22.137	67
Arable land	Millions sq.km	105.322	29.470	1750.000	2.310	273.687	67
TPES	Th. metr. tons of oil equiv.	100.888	17.449	2134.960	1.036	299.437	57
Fixed capital	Bil. US$	48.236	1.322	832.8	0.0345	149.870	60

As a result of exclusion of the DMUs with missed observations, the following countries were rejected from the sample: Armenia, Bosnia-Herzegovina, Burkina Faso, Burundi, Chad, Ethiopia, Georgia, Macedonia, Madagascar, Malawi, Mali, Moldova, Niger, Rwanda, Serbia-Montenegro, Sierra Leone, Uganda, resulting a final sample of 50 DMUs.

Estimation results

Running MATLAB code specially designed for the estimation of the ODDF in the *Translog* form resulted the values of the estimation parameters as provided in Table 4.

Table 4. **Parameters of ODDF Translog estimation**

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
α_0	0.0972	β_{22}	–0.0321	γ_{32}	0.2650	ε_{14}	–0.0109
α_1	0.0144	β_{23}	–0.0501	γ_{33}	–0.8640	ε_{21}	–0.0110
β_1	0.1960	β_{31}	0.0028	γ_{34}	–0.1740	ε_{22}	0.0188
β_2	0.3700	β_{32}	–0.0501	γ_{41}	0.0712	ε_{23}	0.3020
β_3	0.4480	β_{33}	–0.0598	γ_{42}	–0.1500	ε_{24}	0.0636
γ_1	0.5440	γ_{11}	0.1250	γ_{43}	–0.1740	ε_{31}	–0.0683
γ_2	–0.6550	γ_{12}	–0.0390	γ_{44}	0.0927	ε_{32}	0.1300
γ_3	–1.2900	γ_{13}	–0.0361	δ_1	–0.1500	ε_{33}	0.1860
γ_4	0.3200	γ_{14}	0.0712	δ_2	0.1180	ε_{34}	0.1260
α_{11}	–0.3010	γ_{21}	–0.0390	δ_3	0.7750	ζ_1	–0.0680
β_{11}	–0.0267	γ_{22}	–0.1820	δ_4	0.1780	ζ_2	–0.1260
β_{12}	–0.0440	γ_{23}	0.2650	ε_{11}	–0.0712	ζ_3	–0.1070
β_{13}	0.0028	γ_{24}	–0.1500	ε_{12}	–0.0309		
β_{21}	–0.0440	γ_{31}	–0.0361	ε_{13}	0.2860		

Consequently, the estimation of ODDF and shadow prices of pollutants results the values given in Table 5.

***Table* 5.** **Values of ODDF and shadow prices of pollutants in US$/ton of pollutant**

Country	ODDF	CO_2 shadow price	SO_2 shadow price	NO_X shadow price
Albania	0.0000	-17.79	-20277.00	-49477.00
Angola	0.3775	-48.04	0.00	0.00
Australia	0.0000	0.00	0.00	-135770.00
Austria	0.2312	-151.84	-31217.00	-214780.00

The continuation of the Table 5

Country	ODDF	CO_2 shadow price	SO_2 shadow price	NO_X shadow price
Azerbaijan	0.4670	-37.19	^1697.40	-22915.00
Bangladesh	0.0000	0.00	-24908.00	-31620.00
Belarus	0.2242	-55.66	-11969.00	-56606.00
Belgium	0.0000	-152.38	0.00	-91331.00
Bulgaria	0.4408	-10.69	-448.47	-10820.00
Canada	0.3270	-105.48	-11180.00	-62806.00
Congo, DR	0.0000	-1359.50	-27861.00	-101710.00
Croatia	0.0000	-72.34	-10033.00	-70554.00
Czech Rep.	0.4593	-11.48	-1549.70	-35763.00
Denmark	0.2787	-109.39	-25910.00	-178500.00
Eritrea	0.2458	-177.11	-6869.90	0.00
Estonia	0.3886	-29.42	-1599.00	-16335.00
Finland	0.3611	-147.72	-26393.00	-156450.00
France	0.0000	-413.41	-155210.00	-624710.00
Germany	0.1275	-41.83	-22986.00	-354740.00
Hungary	0.0016	-12.98	-1369.00	-65605.00
Ireland	0.0000	-183.77	-21215.00	-175890.00
Italy	0.2110	0.00	0.00	-148060.00
Japan	0.2173	-177.66	-80106.00	-335130.00
Kazakhstan	0.1752	-4.26	-230.20	-21557.00
Kenya	0.0000	-576.00	-74265.00	-27415.00
Kyrgyz Rep.	0.1115	-101.93	-36557.00	-71943.00
Latvia	0.0000	-70.13	-9350.00	-54649.00
Lithuania	0.0000	-202.01	-23185.00	-73062.00
Mozambique	0.2149	-1101.70	-9924.10	-139.35
Nepal	0.0000	-859.81	-25268.00	-9963.90
Netherlands	0.0334	-325.52	-50731.00	-218280.00
New Zealand	0.0740	-350.05	-62971.00	-112920.00
Nigeria	0.0000	-157.90	-18008.00	-29494.00
Norway	0.5599	-24.14	-2003.70	-78611.00
Poland	0.0804	0.00	0.00	-39503.00
Romania	0.1001	-36.32	-4824.00	-46886.00
Russia	0.0000	-107.12	-37488.00	-263550.00
Slovakia	0.4858	-28.33	-2167.30	-18774.00
Slovenia	0.6777	-37.98	-2683.30	-12071.00
Sweden	0.0000	-957.45	-201350.00	-609330.00
Switzerland	0.0000	-741.84	-238650.00	-585430.00
Tajikistan	0.0325	-309.79	-276000.00	-60766.00
Tanzania	0.0141	-1118.30	-17209.00	0.00
Turkmenistan[1]	0.2987	-Inf	-Inf	-Inf
UK	0.0559	-70.28	0.00	-127540.00
Ukraine	0.3164	-126.09	-20310.00	-69290.00
US	0.0000	-87.04	-33532.00	-328330.00
Uzbekistan	0.0000	-104.38	-17604.00	-53092.00
Yemen, Rep.	0.0865	0.00	-907.46	-10270.00
Zambia	0.1609	0.00	0.00	0.00
MEAN	0.1567	–221.31	–33694.21	–119641.60
MEDIAN	0.0835	–101.93	–17209.00	–62806.00
MAX	0.6777	0.00	0.00	0.00
MIN	0.0000	–1359.50	–276000.00	–624710.00
ST. DEV.	0.1821	331.89	59997.95	154583.63

[1] Turkmenistan's values of shadow prices were excluded while calculating the descriptive statistics.

Conclusions

The obtained estimation results clearly demonstrate that with respect to the technical efficiency, both reach and poor countries can be considered as fully technical efficient. At this, transitional countries take positions of the most efficient as well as the least efficient. With regard to Ukraine (which I suppose we are interested in the most). It seems to be far away from its technical potential being more than two times inefficient than the mean value of the indicator. That clearly points on a significant perspectives our country has in moving towards production possibility frontier.

As the value of the present work for the public policy lays mostly in the domain of the shadow prices as estimates for an efficient environmental taxation, we must note that the estimation results point out that CC>2 is 'the least expensive' pollutant, while NO_x being 'the most expensive' one. Such result is not surprising, as any society would value an undesirable output with an indirect harm (in our case a greenhouse gas affecting global climate) less then an undesirable output having a direct influence on the human health (such as NO_x).

The values of the shadow prices obtained from the estimation can be used as the proxy values in setting efficient environmental tax rates. At the moment, (as far as I can judge from my own environmental auditing experience) in Ukraine these rates are far below the estimated values. That provides us with a conclusion that in order to meet the societal valuation of the environment, the government should inevitably raise the rates for air pollutants. At this, rates of environmental taxation in Ukraine will be lower than the average rate among all countries (provided all countries use shadow prices as proxies for their taxation).

In the long-run that might result a migration of polluting industries from, let's say, Russian Federation, having higher shadow prices for NO_x and SO? to Ukraine. Such migration will result a fall of Russian shadow prices and an increase in Ukrainian until they are equal.

Fare *et al.* (1993) indicated that unequal values of shadow prices among DMUs point on the inefficient allocation of resources. For this reason, our final conclusion of this work will plainly state that at present the global economy's economic wealth and pollution is allocated technically inefficiently. One of the ways to change this situation is to set environmental taxes equal to the shadow prices estimates and allow invisible hand of Adam Smith to take all countries towards a common valuation of environmental resources.

Further works in this direction may involve nonparametic estimation of technology using DBA as well as alternative approaches towards parametric estimation *(e. g.,* quadratic specification). In addition, we should consider as much of undesirable outputs as possible, since that would allow to avoid an estimation bias. Further development of the topic may result solution of 'impossibility of shadow prices determination' problem stated by [22]. Consequently, that may provide a by-pass to calculate country-specific demands for undesirable outputs and economically justified values of green GDPs.

APPENDIX 1

Proof of equation (1)

Prove that $\sigma_i^g = \left(1 - \vec{D}_0(\cdot)\frac{\alpha_i}{g_i^*}\right)^{-1}$

□

According to D4

$$\sigma_i^g g_i = g_i^*$$

Hence, $g_i = g_i^* / \sigma_i^g$ (1.1)

'Full efficiency point' definition from D3 is

$$(\mathbf{g}^*, \mathbf{b}^*) = (\mathbf{g}, \mathbf{b}) + \vec{D}_0(\cdot)\cdot\mathbf{d},$$

which implies that

$$g_i^* = g_i + \vec{D}_0(\cdot)\alpha_i \qquad (1.2)$$

Plugging (1.1) into (1.2) provides

$$g_i^* = \frac{g_i^*}{\sigma_i^g} + \vec{D}_0(\cdot)\alpha_i \Rightarrow \frac{g_i^*}{\sigma_i^g} = g_i^* - \vec{D}_0(\cdot)\alpha_i$$

$$\Rightarrow \frac{\sigma_i^g}{g_i^*} = \frac{1}{g_i^* - \vec{D}_0(\cdot)\alpha_i} \Rightarrow \sigma_i^g = \frac{1}{1 - \vec{D}_0(\cdot)\frac{\alpha_i}{g_i^*}} = \left(1 - \vec{D}_0(\cdot)\frac{\alpha_i}{g_i^*}\right)^{-1}$$

■

The expression $\sigma_j^b = \left(1 - \vec{D}_0(\cdot)\frac{\beta_j}{b_j^*}\right)^{-1}$ can be proven using the same pattern.

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ПАРАМЕТРИЧНА ОЦІНКА ЕФЕКТИВНОСТЕЙ ВИКОРИСТАННЯ НАВКОЛИШНЬОГО СЕРЕДОВИЩА ТА ТІНЬОВИХ ЦІН ЗАБРУДНЮВАЧІВ: ГЛОБАЛЬНИЙ АНАЛІЗ

Статтю присвячено оцінці ефективності використання навколишнього середовища національними економіками та тіньових цін забруднювачів довкілля у посткомуністичних країнах і порівнянню цих даних із відповідними показниками інших країн. Отримані результати можуть бути використані як індикатори стабільності економічного поступу при визначенні міжнародних пріоритетів розвитку. Тіньові ціни можуть використовуватись як контрольні при визначенні розміру оплати за використання навколишнього середовища (природоохоронних податків) та рівня цін на міжнародному ринку торгівлі викидами. При обрахунку ефективностей ми використовували цільову дистанційну функцію класу Шепарда, оцінка якої здійснюється за допомогою транслогарифмічної специфікації. Використовуючи дуальність цієї функції до функції виручки, здійснювали оцінку тіньових цін. Результати вказують на неефективний розподіл забруднення між різними країнами, а також дають економічно обгрунтовані контрольні значення рівнів оплати за використання довкілля та цін на міжнародному ринку торгівлі викидами.