MULTIDIMENSIONAL APPROACH TO MEASURING ECO-EFFICIENCY IN GENERALIZED IO MODELS

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Measuring Eco-efficiency

- ‘Eco-efficiency’ notion:
  - ❑ understood as a management philosophy that aims at minimizing ecological damage /costs/ while maximizing the efficiency of a firm's production processes (by minimizing costs or maximizing profits),
  - ❑ recently a topic of considerable interest for both researchers and politicians (Merli et al., 2018; Cheng et al., 2018; Pham et al., 2019, among others).
- Performance assessment in the presence of undesirable outputs, such as pollutant emissions, is usually modelled within the framework of data envelopment analysis (DEA).

THREE PROBLEMS WITH DEA

- DEA approach must only be used when the decision maker has no doubts about the technical relations between undesirable outputs and certain inputs and outputs (Dyckhoff and Allen, 2001),
- DEA-based approach to measuring eco-efficiency does not allow supply- and demand-driven production processes that take place in economic systems to be analysed separately and in detail.
- A purely mathematical approach to measuring efficiency may not be able to fully satisfactorily take into account many economic mechanisms like interindustry linkages, production technologies, competitive advantages, international trade relations and the structure of GVCs (Tarancón et al., 2008; Gurgul and Lach, 2018).

Main goals of the study

- **GOAL 1:** Proposal of a new approach to measuring eco-efficiency in generalized input-output (gIO) models with multiple policy goal variables.
- **GOAL 2:** Formulation of sector-specific policy recommendations based on the outcomes of the new approach (case study: Poland).

THE NEW APPROACH VS DEA

- The new approach builds upon a theory of intersectoral linkages and thus it looks at economic processes from a perspective other than that of DEA-based models.
- Therefore, the new approach seems to be a supplementary proposal to the mainstream approach.
- In an illustrative empirical example we focus on two particular **composite** policy target variables.

GOAL 1

KEY SECTOR MEASURES

- Following the review of literature on key sector analysis of Temurshoev (2016) in this study two general types of measures of inter-industry linkages will be studied in the frame-work of extended IO models.

- These measures are related to two general concepts of measuring interindustry linka-ges:
  - Traditional measures of backward and for-ward linkages,
  - Size-adjusted interindustry linkages.

KEY SECTOR MEASURES - NOTATION REMARKS

Key sector analysis in the framework of extended input-output model

$\boldsymbol{\pi}_t = [\pi_{i,t}, i = 1, \dots, n]$ - policy goal variable

$\mathbf{f}_t = [f_i^t, i = 1, \dots, n]$ - final demand

$\mathbf{L}_t = (\mathbf{I} - \mathbf{A}_t)^{-1} = [l_{ij}^t, i, j = 1, \dots, n]$ - Leontief inverse

$\mathbf{v}_t = [v_i^t, i = 1, \dots, n]$ - sectoral value added

$\mathbf{G}_t = (\mathbf{I} - \mathbf{E}_t)^{-1} = [g_{ij}^t, i, j = 1, \dots, n]$ - Ghosh inverse

SIZE-ADJUSTING THE LINKAGES - IS IT NECESSARY?

- In empirical applications, the heterogeneity of industries in terms of their size should also be explicitly taken into account, which is not always the case in the existing key sector studies.
- Temurshoev (2016) signalizes that if the effect of sector size is not corrected for one would very often and not surprisingly get an expectable outcome that big (small) industries have a big (small) impact on the whole economy, which will further disregard the greater cost of stimulating a large industry.
- For this purpose, the input-output linkages used in this study are size-adjusted by the relevant size or direct impact of the sectors.

KEY SECTOR MEASURES IN GIO MODELS

Traditional linkages

$$\bar{B}_{i,t}(\boldsymbol{\pi}_t) = \sum_{k=1}^{n} \pi_{k,t} l_{ki}^{t}$$

$$\bar{F}_{i,t}(\boldsymbol{\pi}_t) = \sum_{k=1}^{n} g_{ik}^{t} \pi_{k,t}$$

Size-adjusted traditional linkages

$$B_{i,t}(\boldsymbol{\pi}_t) = \frac{\bar{B}_{i,t}(\boldsymbol{\pi}_t)}{\pi_{i,t}}$$

$$F_{i,t}(\boldsymbol{\pi}_t) = \frac{\bar{F}_{i,t}(\boldsymbol{\pi}_t)}{\pi_{i,t}}$$

USING LINKAGES TO MEASURE ECO-EFFICIENCY

- We suggest to measure eco-efficiency in gIO models in a way similar to the general DEA-based approach, i.e. to define the eco-efficiency indicator as a ratio of the desired output effect to the size of undesired output.
- Since we distinguish between backward and forward linkages in an economy, one should define separately the respective measures of the 'backward eco-efficiency' and 'forward eco-efficiency'.
- We propose the following formulas to define the linkage-based measures of the eco-efficiency of sector i at time point t:

BACKWARD (FORWARD) ECO-EFFICIENCY

$$ECOEFF_{i,t}^{BACK} = \frac{\|BACK_{i,t}(\boldsymbol{\pi}_t^{D})\|}{\|BACK_{i,t}(\boldsymbol{\pi}_t^{UD})\|} \quad (1)$$

$$ECOEFF_{i,t}^{FORW} = \frac{\|FORW_{i,t}(\boldsymbol{\pi}_t^{D})\|}{\|FORW_{i,t}(\boldsymbol{\pi}_t^{UD})\|} \quad (2)$$

where:

- $ECOEFF_{i,t}^{BACK}$ ($ECOEFF_{i,t}^{FORW}$) - the backward (forward) eco-efficiency measure,
- $BACK_{i,t}(\cdot)$ ($FORW_{i,t}(\cdot)$) - the chosen type (i.e. traditional or sector-size-adjusted) of backward (forward) linkage measure, i.e. $BACK_{i,t}(\cdot) = B_{i,t}(\cdot)$ or $BACK_{i,t}(\cdot) = \bar{B}_{i,t}(\cdot)$ ($FORW_{i,t}(\cdot) = F_{i,t}(\cdot)$ or $FORW_{i,t}(\cdot) = \bar{F}_{i,t}(\cdot)$),
- $\boldsymbol{\pi}_t^{D} = [\pi_{i,t}^{D}, i = 1, \dots, n]$ ($\boldsymbol{\pi}_t^{UD} = [\pi_{i,t}^{UD}, i = 1, \dots, n]$) - the desired (undesired) output **composite** policy goal variable,
- $\|\mathbf{x}\| = (\|x_i\|)_{i=1,\dots,n} = \left(\frac{n x_i}{\sum_{s=1}^{n} x_s}\right)_{i=1,\dots,n}$, where $\mathbf{x} = (x_i)_{i=1,\dots,n}$.

Sectoral Classification 1/2

Table 1. Measuring eco-efficiency in extended demand-driven IO models (backward linkages).

Sector type	Desired output (backward linkage $\mathbf{e}_t = \hat{\boldsymbol{\pi}}_t^{D} \mathbf{L}_t \mathbf{f}_t$)	Undesired output (backward linkage $\mathbf{e}_t = \hat{\boldsymbol{\pi}}_t^{UD} \mathbf{L}_t \mathbf{f}_t$)
Eco-effective (EFF)	**Above economy-wide average**	**Below economy-wide average**
Bi-Key sector (KEY)	Above economy-wide average	Above economy-wide average
Bi-Weak sector (W)	Below economy-wide average	Below economy-wide average
Eco-ineffective (INEFF)	Below economy-wide average	Above economy-wide average

Note: Linkages are given relative to their relevant economy-wide average values.

Sectoral Classification 2/2

Table 1. cont. Measuring eco-efficiency in extended supply-driven IO models (forward linkages).

Sector type	**Desired output (forward linkage $\mathbf{e}_t' = \mathbf{v}_t \mathbf{G}_t \widehat{\boldsymbol{\pi}}_t^D$)**	**Undesired output (forward linkage $\mathbf{e}_t' = \mathbf{v}_t \mathbf{G}_t \widehat{\boldsymbol{\pi}}_t^{UD}$)**
Eco-effective (EFF)	**Above economy-wide average**	**Below economy-wide average**
Bi-Key sector (KEY)	Above economy-wide average	Above economy-wide average
Bi-Weak sector (W)	Below economy-wide average	Below economy-wide average
Eco-ineffective (INEFF)	Below economy-wide average	Above economy-wide average

Note: Linkages are given relative to their relevant economy-wide average values.

GOAL 2

SECTOR-SPECIFIC POLICY IMPLICATIONS

- In order to translate the sectoral classification given in Table 1 into a set of practical policy recommendations one must know what policies should be taken in order to influence the desired and undesired output linkages of particular sectors within an economy. In general, for each type of linkage measures two general answers may be given to this question.

- To illustrate the two respective policies let us focus on the case of increasing the traditional desired output backward linkage for a particular sector i_0.

Strategy 1: Modifying the policy goal variable $\boldsymbol{\pi}_t^D$

$$\left\|BACK_{i_0,t}(\boldsymbol{\pi}_t^D)\right\| = \left\|\sum_{k=1}^{n} \pi_{k,t}^D l_{ki_0}^t\right\|$$

$$\left\|BACK_{i_0,t}(\boldsymbol{\pi}_t^{UD})\right\| = \left\|\sum_{k=1}^{n} \pi_{k,t}^{UD} l_{ki_0}^t\right\|$$

⇓

- Intuitively, the simplest policy for increasing $\left\|\sum_{k=1}^{n} \pi_{k,t}^D l_{ki_0}^t\right\|$ is to increase $\pi_{i_0,t}^D$ (for proof see the analysis of properties of on-diagonal elements in a Leontief inverse given in Miller and Blair (2009)).

- Using the same logic one may easily show that the simplest policy for lowering $\left\|BACK_{i_0,t}(\boldsymbol{\pi}_t^{UD})\right\|$ is to lower $\pi_{i_0,t}^{UD}$.

OPTIMIZATION PROBLEM NO 1

Goal: Given the data on elements of Leontief inverse, find the shift vector $\Delta_t^D = \left(s_{i,t}^D\right)_{i=1,\dots,n}$, where $i = 1, \dots, n$ and t stands for a fixed time point, which maximize the objective function:

$$\left\|\sum_{k=1}^{n}\left(\pi_{k,t}^D + s_{k,t}^D\right) l_{k i_0}^t\right\|,$$

for desired output policy target goal variable $\boldsymbol{\pi}_t^D$, assuming that $-l_{i,t}^{D-} \leq s_{i,t}^D \leq l_{i,t}^{D+}$ for some vectors of the upper $(0 \leq l_{i,t}^{D+})$ and lower $(0 \leq l_{i,t}^{D-})$ bounds and the following constraints hold true:

$$\left|\sum_{i=1}^{n} s_{i,t}^D\right| \leq M_t^D \sum_{i=1}^{n} \max\left(l_{i,t}^{D-}, l_{i,t}^{D+}\right),$$

where $0 \leq M_t^D \leq 1$.

STRATEGY 2: MODIFYING THE LEONTIEF INVERSE

To shed some light on an alternative approach to formulating policies aimed at modifying the linkages, let $\mathbf{L}_t^{\mathbf{M}}$ stand for a modified Leontief inverse obtained for input matrix $\mathbf{A}_t$ modified by adding elements of a shift matrix $\Delta\mathbf{A}_t$, i.e.:

$$\mathbf{L}_t^{\mathbf{M}} = [\mathbf{I} - \mathbf{A}_t - \Delta\mathbf{A}_t]^{-1},$$

or, equivalently:

$$\Delta\mathbf{A}_t = \mathbf{I} - \mathbf{A}_t - \left(\mathbf{L}_t^{\mathbf{M}}\right)^{-1}.$$

- One can simply find the modification in a given input matrix (i.e., $\Delta\mathbf{A}_t$) which corresponds to a set of known changes in the corresponding Leontief matrix ($\mathbf{L}_t^{\mathbf{M}}$).
- Thus, the only remaining issue is to find the modification of Leontief inverse ($\mathbf{L}_t^{\mathbf{M}}$) which will maximize (minimize) desired (undesired) output linka-ges given some policy goal variables.

Optimization problem no 2

Goal: Given the data on desired output policy goal variable $\boldsymbol{\pi}_t^D$, find shift matrices $\Delta_t^D = \left(s_{ij,t}^D\right)_{i,j=1,\ldots,n}$ (where $i,j = 1,\ldots,n$, and t stands for a fixed time point), which maximize the objective function:

$$\left\|\sum_{k=1}^{n} \pi_{k,t}^D \left(l_{ki_0}^t + s_{ki_0,t}^D\right)\right\|,$$

assuming that $-p_{ij,t}^{D-} \leq s_{ij,t}^D \leq p_{ij,t}^{D+}$, for some matrices of the upper ($0 \leq p_{ij,t}^{D+}$) and lower ($0 \leq p_{ij,t}^{D-}$) bounds, and the following constraints hold true:

- $\left|\sum_{i,j=1}^{n} s_{ij,t}^D\right| \leq M_t^D \sum_{i,j=1}^{n} max\left(p_{ij,t}^{D-}, p_{ij,t}^{D+}\right)$,
- $P_t \leq \dfrac{\left\|\sum_{k=1}^{n} \pi_{k,t}^{UD}\left(l_{ki_0}^t + s_{ki_0,t}^D\right)\right\|}{\left\|\sum_{k=1}^{n} \pi_k^{UD,t}\left(l_{ki_0}^t\right)\right\|} \leq U_t$,

where $0 \leq M_t^D \leq 1$ and $0 \leq P_t \leq U_t$.

MULTIPLE POLICY GOAL VARIABLES

In order to shed some light on the multidimensional case let us focus on the problem of measuring backward eco-efficiency based on traditional linkages. Let:

$$\widehat{\boldsymbol{\pi}}_t^{D,j} = diag\left(\left(\pi_{k,t}^{D,j}\right)_{k=1,\dots,n}\right), \text{ where } j = 1,\dots,J$$

stand for a J-element set of desired output policy goal variables at time point t (e.g. income, employment, etc.). If one divides both sides of the demand-driven Leontief model constructed for the j-th output variable:

$$\mathbf{e}_t^j = \widehat{\boldsymbol{\pi}}_t^{D,j}\mathbf{L}_t\mathbf{f}_t$$

by a scalar equal to the average value of the j-th desired output policy goal variable the following model is obtain-ed:

$$\bar{\mathbf{e}}_t^j = diag\left(\left\|\boldsymbol{\pi}_t^{D,j}\right\|\right)\mathbf{L}_t\mathbf{f}_t, \text{ where } \bar{\mathbf{e}}_t^j = \frac{\mathbf{e}_t^j}{\frac{1}{n}\sum_{k=1}^{n}\pi_{k,t}^{D,j}}.$$

MULTIPLE POLICY GOAL VARIABLES

Nevertheless the physical units of $\mathbf{e}_t^j$:

- the vector $\bar{\mathbf{e}}_t^j$ is expressed in monetary units,
- $\|\boldsymbol{\pi}_t^{D,j}\|$ is a dimensionless quantity.

If we now define the combined desired output policy goal variable as:

$$\boldsymbol{\pi}_t^D = \sum_{j=1}^{J} \omega_j \|\boldsymbol{\pi}_t^{D,j}\|,$$

where $\sum_{j=1}^{J} \omega_j = 1$, and define the combined output as:

$$\mathbf{e}_t^D = \sum_{j=1}^{J} \omega_j \bar{\mathbf{e}}_t^j,$$

we may examine the following generalized demand-driven Leontief IO model:

$$\mathbf{e}_t^D = \hat{\boldsymbol{\pi}}_t^D \mathbf{L}_t \mathbf{f}_t$$

by means of the two-dimensional approach presented previously.

Multiple policy goal variables

Choosing the weights:

- **Expert knowledge:** Since the weight ω_j measures the importance of the j-th desired output policy goal variable $\hat{\boldsymbol{\pi}}_t^{D,j}$ $(j = 1, \ldots, J)$ in the overall desired output policy goal variable $\hat{\boldsymbol{\pi}}_t^{D}$, they might be chosen on an arbitrary basis by the policy decision maker.

- **Purely statistical:** Alternatively one may use less-subjective statistical methods, e.g. the OECD's approach to setting the weights in the multi-criteria rankings of importance proposed by Nicoletti et al. (2000).

GOAL 2: EMPIRICAL RESULTS

ECO-OPTIMAL DISTRIBUTION OF LINKAGES

Table 2. Composite desired and undesired output variables.

Composite undesired output (CUO)	Composite desired output (CDO)
• CO_2 emission • CH_4 emission • N_2O emission • NOX emission • SOX emission • CO emission • NMVOC emission • NH_3 emission	• Gross value added at current basic prices (in millions PLN) • Number of persons engaged (thousands) • Number of employees (thousands) • Total hours worked by persons engaged (millions) • Total hours worked by employees (millions)

Notes: We constructed the generalized demand-driven IO model for the composite undesired output (henceforth denoted as CUO) and the composite desired output variable (henceforth denoted CDO).
Emission levels are given in tons except for emission of CO_2, which is expressed in kilotons.
Source: Own elaboration based on WIOD 2013 Release.

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ECO-OPTIMAL DISTRIBUTION OF LINKAGES

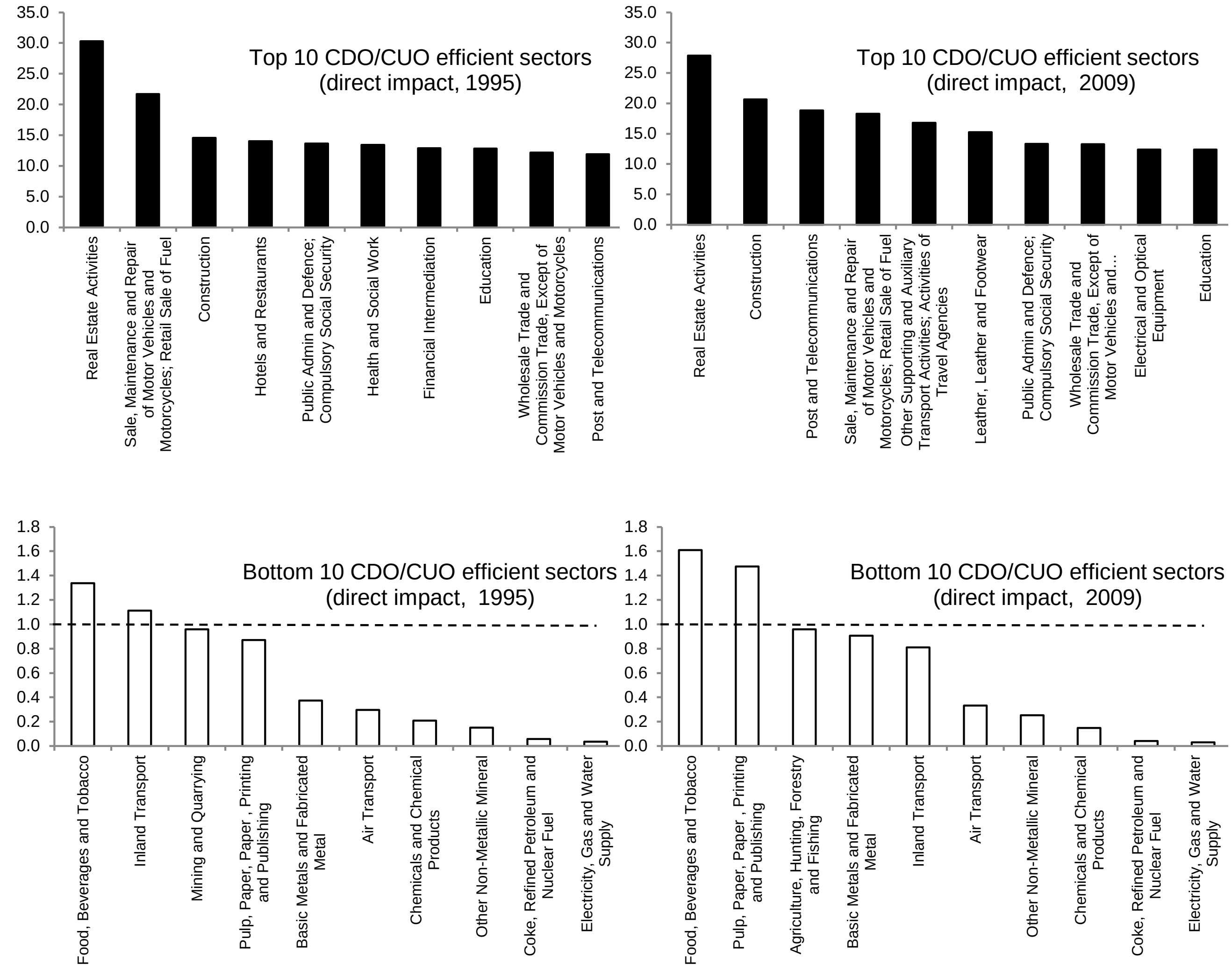

Figure 1. Top ten and bottom ten indexes of direct eco-efficiency for CUO and CDO.
Notes: Plots present sectoral data on direct efficiency measure defined as ratio of normalized composite desired output policy goal variable (CDO) to normalized composite undesired output policy goal variable (CUO).
Source: Own calculations based on WIOD 2013 Release.

Table 3. Results of linkage-based analysis of eco-efficiency of sectors operating in Polish economy (multi-dimensional case).

	1995				Change between 1995 and 2009			
	Traditional		Size-adjusted		Traditional		Size-adjusted	
	Backward	Forward	Backward	Forward	Backward	Forward	Backward	Forward
Agriculture, Hunting, Forestry and Fishing	KEY(3.26)	KEY(2.98)	W(3.19)	KEY(2.67)				
Mining and Quarrying	W(0.78)	KEY(0.43)	W(2.8)	W(0.64)				
Food, Beverages and Tobacco	KEY(2.19)	EFF(1.55)	EFF(5.59)	KEY(1.79)		⇨W	⇨W	
Textiles and Textile Products	W(1.6)	W(2.86)	W(1.21)	W(1.31)		⇨INEFF	⇨INEFF	
Leather, Leather and Footwear	W(1.18)	W(2.06)	KEY(0.72)	W(0.97)				
Wood and Products of Wood and Cork	KEY(1.65)	W(2.06)	KEY(1.79)	W(1.35)	⇨EFF	⇨EFF	⇨EFF	
Pulp, Paper, Printing and Publishing	W(0.99)	W(1.31)	EFF(3.88)	W(0.81)		⇨W	⇨W	
Coke, Refined Petroleum and Nuclear Fuel	W(0.45)	INEFF(0.55)	EFF(26.39)	W(0.37)	⇨INEFF			
Chemicals and Chemical Products	INEFF(0.48)	INEFF(0.61)	W(7.78)	INEFF(0.39)				
Rubber and Plastics	W(0.91)	W(1.2)	W(1.01)	W(0.74)				
Other Non-Metallic Mineral	INEFF(0.34)	KEY(0.63)	W(7.75)	W(0.28)				
Basic Metals and Fabricated Metal	INEFF(0.47)	KEY(0.55)	W(4.28)	INEFF(0.38)				
Machinery, Nec	W(0.87)	EFF(1.09)	W(1.15)	W(0.71)				
Electrical and Optical Equipment	W(0.9)	W(1.12)	W(0.72)	W(0.74)		⇨INEFF	⇨INEFF	
Transport Equipment	W(0.86)	W(1.46)	W(1.23)	W(0.7)				
Manufacturing, Nec; Recycling	W(1.34)	W(1.86)	INEFF(0.52)	W(1.09)				
Electricity, Gas and Water Supply	INEFF(0.08)	KEY(0.11)	W(7.51)	INEFF(0.06)				
Construction	EFF(2.39)	EFF(3.68)	W(0.56)	KEY(1.95)				
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	W(1.2)	EFF(1.58)	INEFF(0.19)	W(0.99)		⇨W	⇨W	
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	EFF(2.71)	EFF(2.01)	W(0.76)	EFF(2.22)				
Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	EFF(2.71)	EFF(2.54)	W(0.79)	KEY(2.22)				⇨EFF
Hotels and Restaurants	W(1.2)	W(1.81)	INEFF(0.29)	W(0.98)				
Inland Transport	W(0.85)	KEY(1.06)	W(2.6)	W(0.69)	⇨INEFF			⇨KEY
Water Transport	W(1.02)	W(1.31)	KEY(1.33)	W(0.84)				
Air Transport	W(0.9)	W(0.91)	EFF(10.3)	W(0.74)				
Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	W(1.07)	W(1.16)	INEFF(0.47)	W(0.87)				
Post and Telecommunications	W(1.09)	W(1.5)	INEFF(0.31)	W(0.89)		⇨W	⇨W	
Financial Intermediation	W(1.85)	W(1.87)	W(0.49)	W(1.51)				
Real Estate Activities	INEFF(0.63)	W(1.87)	INEFF(0.07)	INEFF(0.51)	⇨KEY			⇨KEY
Renting of M&Eq and Other Business Activities	W(1.17)	EFF(1.47)	W(0.54)	W(0.96)	⇨EFF			⇨EFF
Public Admin and Defence; Compulsory Social Security	W(1.99)	W(12.59)	W(0.5)	W(1.63)	⇨EFF			⇨EFF
Education	EFF(3.26)	W(10.45)	W(0.87)	W(2.67)				⇨EFF
Health and Social Work	EFF(3.03)	EFF(10.48)	W(0.77)	W(2.48)				⇨EFF
Other Community, Social and Personal Services	W(0.98)	W(2.6)	INEFF(0.51)	W(0.8)		⇨W	⇨W	⇨EFF

Notes: Sectoral classification is based on definitions given in Table 1. Numbers in brackets represent values of the linkage-based measures of eco-efficiency. In first four columns referring to 1995 IO table, I use shading to indicate eco-efficient sectors (abbreviation EFF – gray shading) and eco-inefficient sectors (INEFF – black). No shading was used for BI-WEAK (abbreviation W) and BI-KEY (abbreviation KEY) sectors. In four columns referring to classification change between 1995 and 2009, I use black shading to indicate sectors losing status of eco-efficient, gray shading to indicate sectors gaining ECO-EFF status, and black framing to indicate sectors gaining ECO-INEFF status.

Source: Own calculations based on WIOD 2013 Release.

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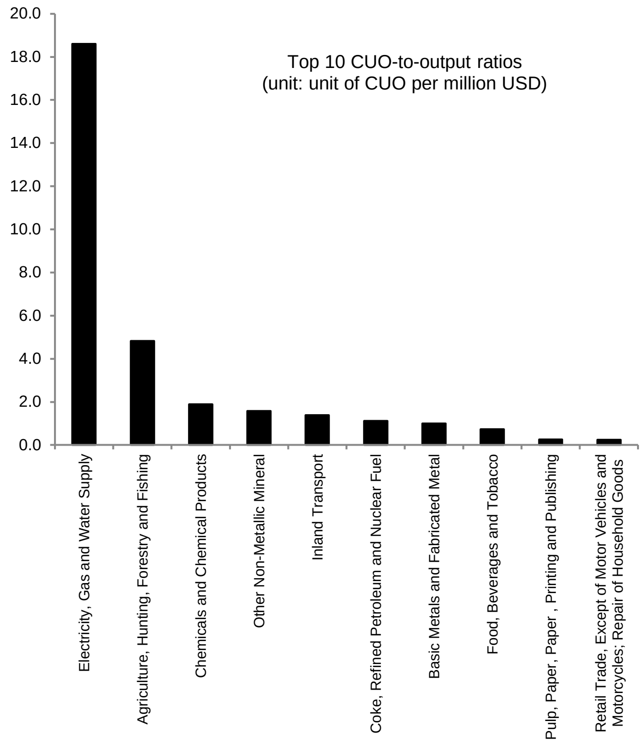
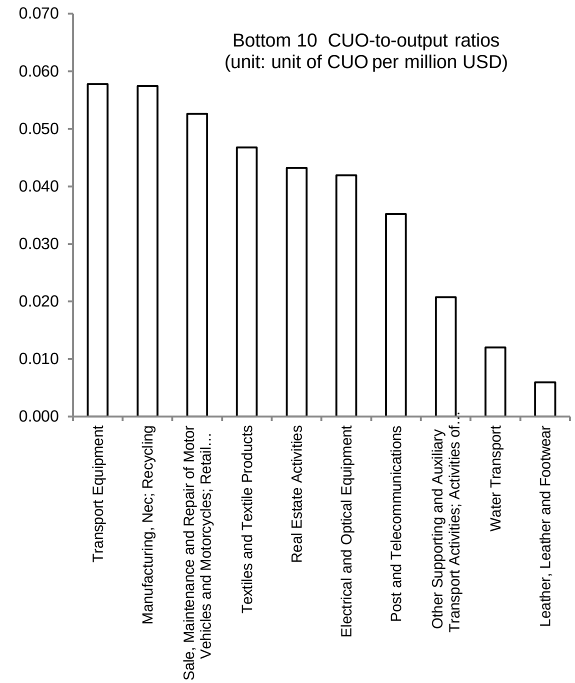
ELECTRICITY, GAS AND WATER SUPPLY – STRATEGY 1

Figure 2. Top ten and bottom ten sectoral CUO-to-output ratios in 2009.



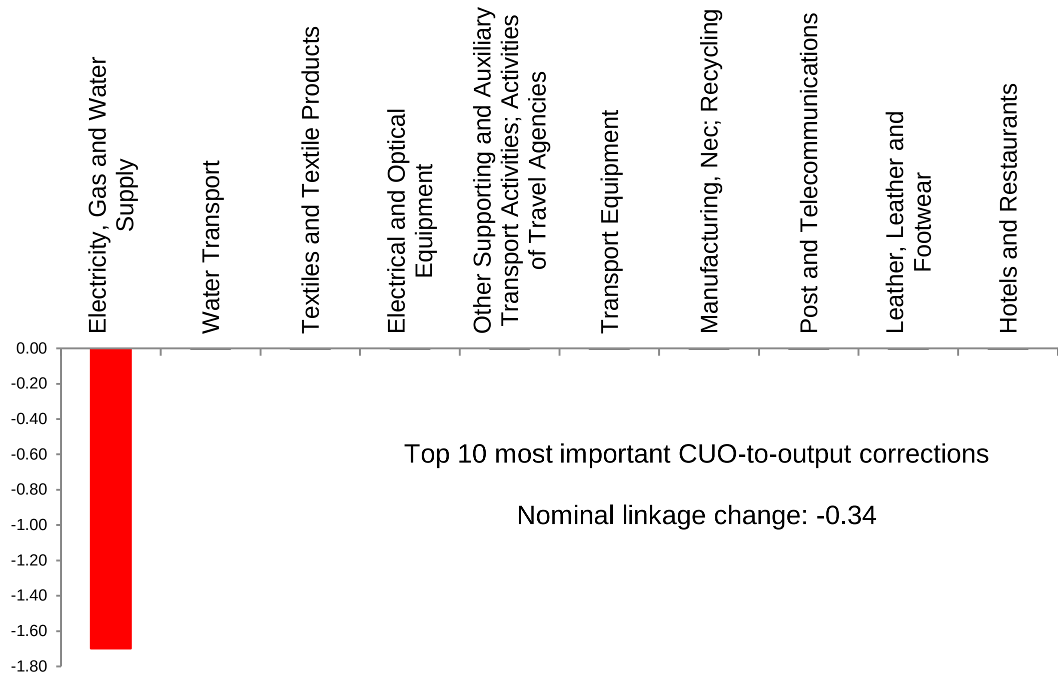


Notes: Plots present sectoral data on top ten and bottom ten CUO-to-output ratios. Data is expressed in one unit of CUO over million USD of output.

Source: Own calculations based on WIOD 2013 Release

Electricity, Gas and Water Supply – Strategy 1

Figure 3. Results of implementing **Strategy 1** for *Electricity, Gas and Water Supply* sector.



Notes: Plots present sectoral data on top ten most important changes of CUO-to-output ratios obtained after solving variant of **Optimization Problem No. 1** aimed and minimizing traditional backward undesired output linkage of *Electricity, Gas and Water Supply* sector (i.e., implementing a modified variant of **Strategy 1**) via changing elements of vector of composite undesired output policy goal variable. Data is expressed in one unit of CUO per million USD of output.

Source: Own calculations based on WIOD 2013 Release

ELECTRICITY, GAS AND WATER SUPPLY – STRATEGY 2

Table 4. Results of implementing **Strategy 2** aimed at reducing CUO traditional backward linkage of *Electricity, Gas and Water Supply* sector.

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Top five nominal decreases in IO coefficients		
Source sector	**Destination sector**	**Percentage change of IO coefficient**
Electricity, Gas and Water Supply	Electricity, Gas and Water Supply	-93%
Machinery, Nec.	Machinery, Nec.	-82%
Leather, Leather and Footwear	Leather, Leather and Footwear	-76%
Leather, Leather and Footwear	Inland transport	-51%
Agriculture, Hunting, Forestry and Fishing	Food, Beverages and Tobacco	-32%
Top five nominal increases in IO coefficients		
Source sector	**Destination sector**	**Percentage change of IO coefficient**
Air Transport	Air Transport	+97%
Construction	Construction	+89%
Construction	Electricity, Gas and Water Supply	+77%
Wood and Products of Wood and Cork	Wood and Products of Wood and Cork	+25%
Electricity, Gas and Water Supply	Real Estate Activities	+19%

Notes: Table presents interindustry flow data on the most important changes in input coefficients obtained after solving **OPTIMIZATION PROBLEM NO 2** aimed at minimizing the traditional CUO backward linkage of the sector *Electricity, Gas and Water Supply* via changing the elements of the Leontief inverse.

CONCLUDING REMARKS

The value added of this study is twofold:

- Methodological aspects: a new approach to measuring eco-efficiency in generalized input-output (gIO) models with **multiple policy goal variables** which may be used as a supplementary method to traditional DEA. Unlike DEA this approach takes into account detailed data on intersectoral flows in demand- and supply-oriented gIO models.

- Illustrative empirical case study: we demonstrated possible applications of the new approach by conducting an empirical analysis aimed at identifying eco-efficient sectors. This part of the study was based on the application of the 1995 and 2009 national input-output tables and environmental accounts for Poland, which were taken from the WIOD database.

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Thank you