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Measuring the efficiency of energy-intensive industries across 23 EU countries

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Motivation for Research

- Global energy consumption is expected to grow by 56% between 2010 and 2040 (IEO, 2014).
- Industry is expected to:
  - consume more than 50% of total delivered energy in 2040.
  - emit almost 46% of worldwide CO_2 emissions in 2040.

❖ **Industrial energy efficiency can move the world towards a more sustainable energy future.**

Subject of Research

- The evaluation of energy efficiency in 10 industrial sectors

Industrial sector
Mining and Quarrying
Electricity, Gas and Water Supply
Construction
Transport (Other Inland Transport, Other Water Transport, Other Air Transport, Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies)
Food, Beverages and Tobacco
Textiles and Textile Products, Leather, Leather and Footwear
Pulp, Paper, Printing and Publishing
Coke, Refined Petroleum and Nuclear Fuel, Chemicals and Chemical Products, Rubber and Plastics
Other Non-Metallic Mineral, Basic Metals and Fabricated Metal
Machinery, Electrical and Optical Equipment, Transport Equipment

Methodology of Research

- Models performed for energy efficiency evaluation
  - Data Envelopment Analysis (DEA)
    - Measurement of the relative efficiency of each sector
  - Malmquist Productivity Index (MPI)
    - Contribution of efficiency and technology change in sector's productivity
  - Cross-classified multilevel modelling
    - Analysis of the main drivers behind efficiency performance

Data Envelopment Analysis (DEA)

- The production technology set:

$$T = \{(K, L, E, Y) / (\mathrm{K, L, E}) \text{ can produce Y}\}$$

where capital (K), labor (L), and energy (E) are used as inputs to produce outputs (Y)

- Shephard distance function:

$$D(K, L, E, Y) = \sup\{a : (E / a, K, L, Y) \in T\}$$

- Energy Efficiency Index (EEI):

$$1 / D(K, L, E, Y)$$

  - **if EEI < 1 inefficient, otherwise efficient**

Data Envelopment Analysis (DEA)

- The maximum efficiency of a country can be estimated through the CCR model (Charnes, Cooper and Rhodes, 1978):

$$\min \qquad F = \theta_i - \varepsilon(1s_i^E + 1s_i^O)$$

$$\text{Subject to: } X_E\lambda - \theta_i x_i^E + s_i^E = 0$$

$$X_N\lambda \leq x_i^N$$

$$Y\lambda - s_i^O = y_i$$

$$\lambda, s_i^E, s_i^O \geq 0, \theta_i \in \Re$$

ϑ_i the efficiency score,
X_E and X_N the matrix with the energy and non-energy inputs,
Y the matrix with the outputs,
s^E and s^O vectors of slack variables for the inputs and outputs

$$\text{CCR} + [1\lambda = 1] \rightarrow \text{BCC}$$ (Banker, Charnes and Cooper, 1984)

Malmquist Productivity Index (MPI)

- MPI is defined as follows:

$$MPI_i(t,\ t+1) = \frac{\theta_i^{t+1}(\mathbf{x}_i^{t+1}, \mathbf{y}_i^{t+1})}{\theta_i^{t}(\mathbf{x}_i^{t}, \mathbf{y}_i^{t})} \times \sqrt{\frac{\theta_i^{t}(\mathbf{x}_i^{t+1}, \mathbf{y}_i^{t+1})}{\theta_i^{t+1}(\mathbf{x}_i^{t+1}, \mathbf{y}_i^{t+1})} \times \frac{\theta_i^{t}(\mathbf{x}_i^{t}, \mathbf{y}_i^{t})}{\theta_i^{t+1}(\mathbf{x}_i^{t}, \mathbf{y}_i^{t})}}$$

- MPI can be decomposed into:
  - efficiency change (first term)
  - technology change (square root term)

- MPI_i (t , t+1) > 1 (or MPI_i (t ,t+1) < 1) indicates productivity improvements (or declines)

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Variables (Inputs & Outputs)

Type	Variable	Unit
Outputs	GHG emissions	Tonnes
	Gross value added	Millions of euros
Inputs	Number of employees	Thousands
	Real fixed capital stock	1995 prices
	Gross energy use	Terajoules

- ❑ Data collected by World Input-Output Database (WIOD)
- ❑ Cyprus, Estonia, Malta and Luxembourg are excluded
- ❑ Period: 2000-2009

BCC Efficiency Scores (Averaged over 2000–09)

Country	Constr.	Electr.	Mining	Transp.	Food	Textile	Pulp	Coke	Non-metal.	Mach.	AVG
AT	0.832	0.787	0.261	0.776	0.841	0.809	0.206	0.433	0.809	0.812	0.657
BE	0.840	0.428	0.268	0.487	0.802	0.693	0.674	0.480	0.476	0.696	**0.584**
BG	0.835	0.394	0.728	0.623	0.463	0.735	0.493	0.376	0.469	0.873	**0.599**
CZ	0.484	0.392	0.285	0.774	0.462	0.357	0.353	0.765	0.680	0.655	**0.521**
DK	0.540	0.669	0.630	0.207	0.640	0.828	0.696	0.652	0.798	0.712	0.637
FI	0.365	0.293	0.298	0.672	0.828	0.780	0.085	0.176	0.403	0.835	0.474
FR	0.650	0.787	0.323	0.722	0.850	0.823	0.577	0.517	0.822	0.875	**0.695**
DE	0.732	0.787	0.275	0.773	0.828	0.626	0.699	0.680	0.799	0.836	**0.703**
GR	0.571	0.458	0.493	0.514	0.668	0.813	0.595	0.128	0.581	0.535	**0.536**
HU	0.874	0.631	0.597	0.672	0.467	0.814	0.699	0.708	0.818	0.835	**0.712**
IE	0.835	0.816	0.721	0.565	0.844	0.827	0.697	0.677	0.389	0.808	**0.718**
IT	0.831	0.787	0.722	0.776	0.842	0.813	0.758	0.732	0.798	0.805	**0.786**
LV	0.835	0.787	0.733	0.779	0.730	0.814	0.706	0.679	0.776	0.837	**0.768**
LT	0.722	0.787	0.729	0.709	0.772	0.656	0.594	0.026	0.803	0.585	0.638
NL	0.855	0.709	0.724	0.402	0.601	0.618	0.534	0.253	0.798	0.469	**0.596**
PL	0.753	0.791	0.722	0.729	0.569	0.730	0.532	0.761	0.792	0.782	**0.716**
PT	0.830	0.658	0.762	0.463	0.699	0.367	0.111	0.244	0.827	0.870	**0.583**
RO	0.739	0.786	0.720	0.781	0.827	0.813	0.570	0.679	0.798	0.867	**0.758**
SK	0.831	0.651	0.337	0.776	0.728	0.770	0.135	0.264	0.277	0.787	**0.556**
SI	0.764	0.572	0.546	0.680	0.827	0.619	0.124	0.679	0.798	0.669	0.628
ES	0.830	0.596	0.736	0.464	0.758	0.620	0.529	0.562	0.728	0.583	0.641
SW	0.606	0.787	0.318	0.574	0.827	0.779	0.316	0.311	0.666	0.835	0.602
UK	0.826	0.724	0.721	0.774	0.834	0.525	0.697	0.687	0.741	0.537	**0.707**
AVG	0.738	0.656	0.550	0.639	0.726	0.706	0.495	0.499	0.689	0.743	0.644

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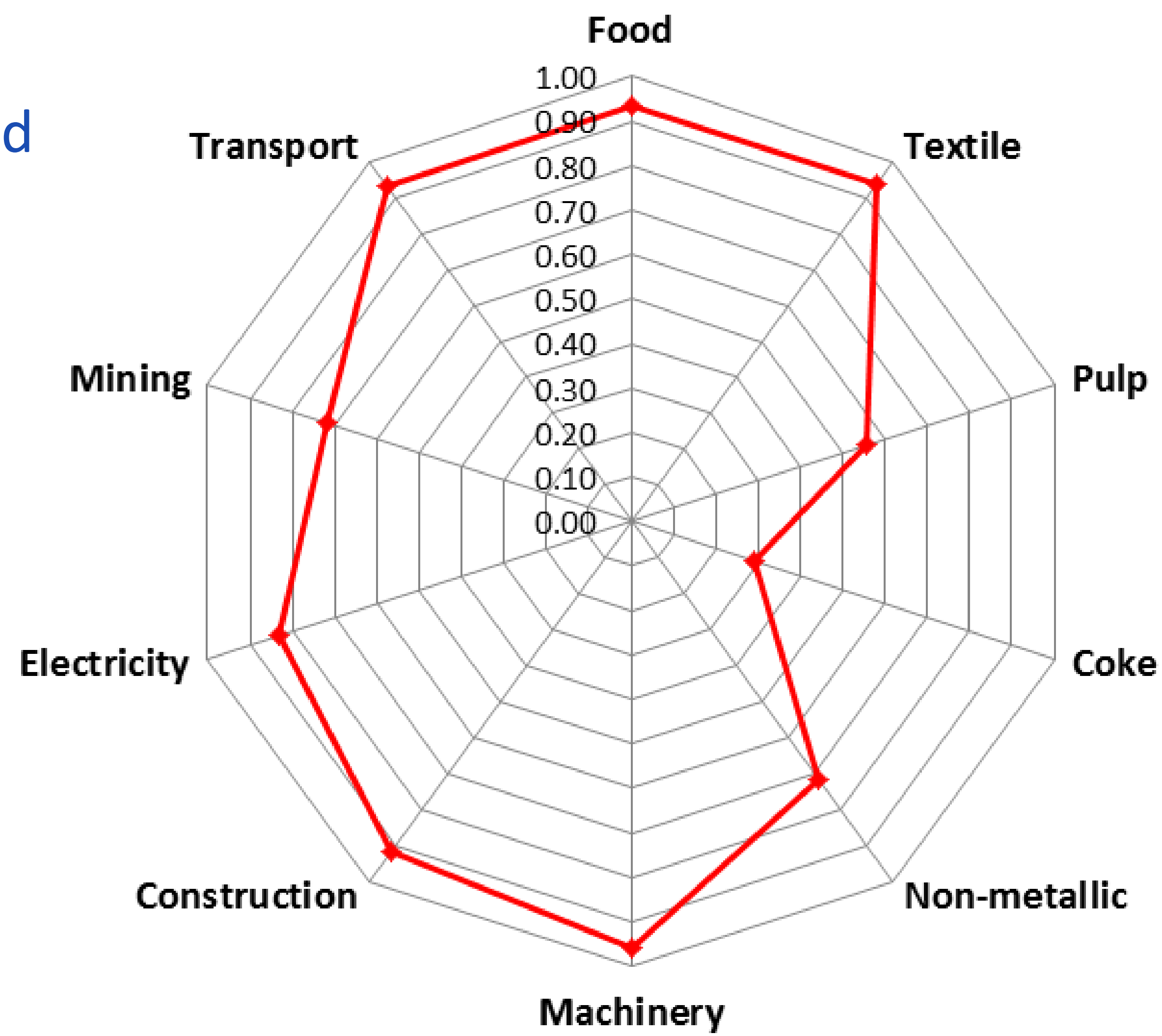
DEA Results

- Efficiency results
  - Sectors with the highest efficiency scores
    - Construction, Food, Textiles and Machinery
  - Sectors with the highest inefficiencies (more than 45%)
    - Mining, Pulp and Coke
  - Countries with the highest efficiency scores (above 70%)
    - Germany, Hungary, Ireland, Italy, Latvia, Poland, Romania and the United Kingdom
  - Countries with the lowest efficiency scores (below 60%)
    - Belgium, Bulgaria, the Czech Republic, Finland, Greece, Netherlands, Portugal and Slovakia

Scale Efficiency by Sector

- The scale efficiency ranges between 29% and 96%, on average, under all countries.
- It is higher than 70% in all sectors except pulp and coke.



Cumulative MPI

	Constr.	Electr.	Mining	Transp.	Food	Textile	Pulp	Coke	Non-metal.	Mach.
2001	1.077	0.965	1.007	0.964	1.050	1.009	1.014	1.052	1.032	0.982
2002	1.054	0.972	1.064	0.969	1.037	1.013	0.987	1.112	1.043	1.028
2003	1.113	0.950	1.005	0.940	1.026	0.975	0.952	1.085	1.002	0.966
2004	1.097	0.966	1.024	0.894	1.064	0.998	0.992	1.015	0.974	1.039
2005	1.061	1.001	1.062	0.911	1.112	1.170	0.999	1.001	1.000	1.045
2006	1.055	1.037	1.109	0.917	1.166	1.207	1.006	1.089	1.002	1.068
2007	1.169	1.075	1.164	0.895	1.234	1.312	1.049	1.142	1.046	1.134
2008	1.120	1.090	1.245	0.908	1.266	1.451	1.098	1.129	1.112	1.156
2009	1.204	1.104	1.306	0.862	1.310	1.584	1.160	1.193	1.312	1.182

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Cumulative Efficiency Change

	Constr.	Electr.	Mining	Transp.	Food	Textile	Pulp	Coke	Non-metal.	Mach.
2001	1.045	0.998	0.992	0.998	1.018	1.031	1.100	0.925	1.079	1.020
2002	1.087	0.992	0.922	0.980	1.021	1.018	1.068	0.889	0.981	1.019
2003	1.072	1.003	0.921	0.993	1.028	0.994	1.107	0.985	1.018	1.027
2004	1.062	1.015	0.973	0.962	1.023	0.983	1.160	1.102	0.995	1.049
2005	1.093	1.048	1.012	0.986	1.102	1.048	1.105	1.064	1.016	1.055
2006	1.087	1.065	1.093	1.007	1.116	1.047	1.162	0.956	1.063	1.039
2007	1.120	1.052	1.069	0.997	1.120	1.028	1.043	0.956	1.096	1.039
2008	1.085	1.080	1.097	1.022	1.153	1.043	1.054	1.028	0.965	1.036
2009	1.094	1.080	0.936	1.013	1.139	1.106	1.241	1.062	1.026	1.065

Cumulative Technology Change

	Constr.	Electr.	Mining	Transp.	Food	Textile	Pulp	Coke	Non-metal.	Mach.
2001	1.037	0.970	1.045	0.976	1.037	0.984	0.964	1.372	0.968	0.968
2002	0.979	0.988	1.225	1.004	1.029	1.006	0.995	1.577	1.089	1.020
2003	1.055	0.961	1.181	0.972	1.020	0.998	0.972	1.581	1.018	0.959
2004	1.055	0.971	1.153	0.970	1.067	1.041	0.994	1.481	1.025	1.018
2005	0.999	0.980	1.167	0.973	1.040	1.158	1.091	1.543	1.042	1.022
2006	1.004	1.006	1.159	0.968	1.080	1.211	1.106	2.020	1.004	1.065
2007	1.086	1.059	1.262	0.961	1.145	1.352	1.325	2.390	1.023	1.133
2008	1.081	1.053	1.351	0.961	1.146	1.486	1.426	2.659	1.255	1.164
2009	1.161	1.077	1.703	0.946	1.207	1.552	1.432	3.125	1.421	1.162

Multilevel Model

- Model of 2 levels
  - 1st level is time
  - 2nd level is a combination of country and sector characteristics

- Null or Empty model

$$100 \times BCC_{tjk} = \gamma_{000} + u_{0j0} + \upsilon_{00k} + \delta_{0jk} + \varepsilon_{tjk}$$

- γ_{000} the grand mean of BCC efficiency scores
- u_{0j0} , υ_{00k} , δ_{0jk} , e_{tjk} the residual random effects for sector, country, sector-by-country cell and time

Variable of Multilevel Model	Unit
Market share of the largest generator in the electricity market (MS)	%
Energy taxes (TAX)	% GDP
Electricity prices for industrial consumers (ELECPR)	EUR per kWh
Energy Mix (EM)	Simpson Index
Gross Value added of a sector / Gross Value added of Total Industries (VAIND)	%
Share of fossil fuels in total gross energy consumption (FF)	%
Real fixed capital stock / Gross Value added (CVA)	Euro/Millions of euro
Real fixed capital stock / Number of employees (CEMP)	Euro/ Thousands of employees
Gross Value added / Total hours worked by employees (PROD)	Millions of euro/ Millions of hours

- Data collected by WIOD (sector characteristics) and EUROSTAT (country characteristics)

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Multilevel Model

- Random intercept model

$$100 \times BCC_{tjk} = \gamma_{000} + \gamma_{0j1}(\mathrm{MS}_{tj}) + \gamma_{0j2}(\mathrm{TAX}_{tj}) + \gamma_{0j3}(\mathrm{ELECPR}_{tj})$$
$$+\gamma_{01k}(\mathrm{VAIND}_{tjk}) + \gamma_{02k}(\mathrm{EM}_{tjk}) + \gamma_{03k}(\mathrm{FF}_{tjk}) + \gamma_{04k}(C\,\mathrm{VA}_{tjk})$$
$$+\gamma_{05k}(C\,\mathrm{EMP}_{tjk}) + \gamma_{06k}(\mathrm{PROD}_{tjk}) + u_{0j0} + \upsilon_{00k} + \delta_{0jk} + \varepsilon_{tjk}$$

- γ_{000} the grand mean of BCC efficiency scores
- u_{0j0} , υ_{00k} , δ_{0jk} , e_{tjk} the residual random effects for sector, country, sector-by-country cell and time

Multilevel Model: Variance Decomposition Estimates

	Model 1: Empty Model	Model 2: Random Intercept Model
Variance decomposition		
Sector-level, u_{0j0}	74.461	63.774
Country-level, υ_{00k}	43.021	48.069
Sector x Country-level, δ_{0jk}	243.360	236.002
Time-level, e_{tjk}	60.750	58.505
Percentage of total variance		
Between sectors	17.66%	15.69%
Between countries	10.20%	11.83%
Between sectors & countries	**57.72%**	**58.08%**
Across time	14.41%	14.40%

Multilevel Model: Fixed Effects Estimates

Random intercept model	β	(p-value)
Sector Characteristics		
Gross Value Added of a sector/ Total Gross Value Added (VAIND)	159.280	**(0.000)**
Energy Mix (EM)	-1.705	(0.680)
Share of Fossil Fuels in Total Gross Energy Consumption (FF)	-12.377	**(0.000)**
Real Fixed Capital Stock/Gross Value Added (CVA)	-0.881	(0.018)
Real Fixed Capital Stock/Number of Employees(CEMP)	0.005	(0.113)
Gross Value Added/Total Hours Worked by Employees (PROD)	0.009	(0.097)
Country Characteristics		
Market Share of the Largest Generator in the Electr. Market (MS)	-0.053	(0.036)
Energy Taxes (TAX)	-1.405	(0.126)
Electricity Prices for Industrial Consumers (ELECPR)	-31.646	**(0.009)**

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Conclusions

- Energy efficiency strategies applied to pulp and coke could be more effective.
- The technology change was mainly responsible for the improvements observed in most of the sectors.
- The combination of sector and country levels is the most relevant in explaining the energy efficiency variance.
- Measures such as strengthening the private sector's contribution to the overall economy, promoting the gradual displacement of fossil fuels and opening up the electricity market should be part of the policy making.

Thank you!