Environmental and energy efficiency analysis of EU electricity industry: An almost spatial two stages DEA approach

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Outline

Introduction

- We focus on the relationship between the stringency of regulation (market and environmental) and total factor productivity (TFP) growth.
- Initially we take into account aggregate measures of regulation.
- We control for other aspects such as spatial interactions among countries and industry characteristics.

The Stringecy of Market Regulation

European Union reforms emphasise unbundling networks from generation and retailing, reducing collusion among large companies, eliminating entry barriers, guaranteeing an independent regulatory authority and ensuring the adequacy of supply.

- ⋆ H1 The more stringent the regulation, the higher the rate of scale efficiency change. Pompei (2013)
- ⋆ H2 The more stringent the regulation the higher the technical efficiency

The Stringecy of Environmental Regulation

- Reducing the risk of catastrophic climatic change requires the stabilisation of the concentration of green-house gases (GHGs)
- Focussing on power generation an effective climate change mitigation strategy for the short and medium run calls for the production of energy in the most efficient possible way.

In this context, the role of mitigation policies is to create incentives to follow carbon reducing practices:

- to develop and adopt new technologies
- to increase the overall efficiency of power generation.

⋆ H1 The more stringent the regulation, the higher the rate of technological change

⋆ H2 The more stringent the regulation the higher the technical efficiency

⋆ H3 The more stringent the regulation the higher the scale efficiency

⋆ H4 Spatial proximity positively affects the aggregated energy efficiency.

Empirical Strategy. Nakano & Managi (2008)

- **First stage**
  Malmquist Index based on Data Envelopment Analysis (**DEA**): it evaluate the productivity change of the decision making unit (DMU) between two time periods.
- **Second stage**
  Dynamic panel data specification including spatial autocorrelation

We deal with a set $(\boldsymbol{x_j}; \boldsymbol{y_j})^s$ where:

- $j = 1, .., n$ denotes the n DMUs: 19 countries
- $s = t, t + 1$ denotes two time periods with $t = 2006, ..., 2014$
- $\boldsymbol{x_j} \in R^m$ is the vector of m inputs of each DMU in period s
- $\boldsymbol{y_j} \in R^q$ denotes the vector of q output produced by each DMU in the period s

Notation $(\boldsymbol{x_j}; \boldsymbol{y_j})^t$ and $(\boldsymbol{x_j}; \boldsymbol{y_j})^{t+1}$ designates the DMU j in the two time periods t and $t + 1$ respectively.

Indirect approach, (Scheele, 2000)

Transforming the values of the undesirable output (Y^u) using a monotone decreasing function f such that the transformed data can be included as normal desirable outputs.

Additive inverse Model

$$f(Y^u) = -Y^u$$

- We perform the alternative model Multiplicative Inverse where $f(Y^u) = \frac{1}{Y^U}$. The results confirm the dynamic patterns of TFP found with the Additive Inverse Model.

The production possibility set is given by:

$$(X, Y)^t = \left\{ (\boldsymbol{x}, \boldsymbol{y}) | \boldsymbol{x} \geq \sum_{j=1}^{n} \lambda_j \boldsymbol{x_j^t}, \boldsymbol{0} \leq \boldsymbol{y} \leq \sum_{j=1}^{n} \lambda_j \boldsymbol{y_j^t}, L \leq \boldsymbol{e\lambda} \leq U, \boldsymbol{\lambda} \geq \boldsymbol{0} \right\}$$

where:

- $X^t = (\boldsymbol{x_1^t}, ..., \boldsymbol{x_n^t})$ are the input matrices: labor, capital (installed capacity), fuel for period t
- $Y^t = \begin{bmatrix} Y_{d1}^t & \cdots & Y_{dn}^t \\ f(y_{u1}^t) & \cdots & f(y_{un}^t) \end{bmatrix} = (\boldsymbol{y_1^t}, ..., \boldsymbol{y_n^t})$ are the output matrices of DMUs for period t: electricity and the transformed function of GHG emissions.

The directional efficiency measure resulting in increases in desirable outputs and reductions in undesirable outputs relative to the same amount of inputs.

Linear Program

The within score in output orientation:

$$\begin{aligned} \delta^t(\boldsymbol{x_j}, \boldsymbol{y_j})^t &= min_{\theta,\boldsymbol{\lambda}}\theta \\ s.t. \qquad \boldsymbol{x_j^t} \geq X^t\boldsymbol{\lambda}; &\qquad (1/\theta)\boldsymbol{y_j^t} \leq Y^t\boldsymbol{\lambda} \\ L \leq \boldsymbol{e\lambda} \leq U; &\qquad \boldsymbol{\lambda} \geq 0 \end{aligned}$$

The inter-temporal score in output orientation:

$$\begin{aligned} \delta^t(\boldsymbol{x_j}, \boldsymbol{y_j})^{t+1} &= min_{\theta,\boldsymbol{\lambda}}\theta \\ s.t. \qquad \boldsymbol{x_j^{t+1}} \geq X^t\boldsymbol{\lambda}; &\qquad (1/\theta)\boldsymbol{y_j^{t+1}} \leq Y^t\boldsymbol{\lambda} \\ L \leq \boldsymbol{e\lambda} \leq U; &\qquad \boldsymbol{\lambda} \geq 0 \end{aligned}$$

For each DMU solving the two problems for the time pairs $(t, t+1)$ leads to four outputs:

Efficiency score

$$\delta^s(y_j, x_j)^r \leq 1 \text{ with } s, r = t, t+1$$

The distance function between the observation at time r and the frontier at time s.

- Efficiency measure within the same period t and $t+1$: $\delta^t(\boldsymbol{x_j}, \boldsymbol{y_j})^t$, and $\delta^{t+1}(\boldsymbol{x_j}, \boldsymbol{y_j})^{t+1}$;
- Efficiency measure for the inter-temporal comparison $\delta^t(\boldsymbol{x_j}, \boldsymbol{y_j})^{t+1}$ and $\delta^{t+1}(\boldsymbol{x_j}, \boldsymbol{y_j})^t$;
- Efficiency change measured by the period t technology: $\frac{\delta^t(\boldsymbol{x_j}, \boldsymbol{y_j}^{t+1}}{\delta^t(\boldsymbol{x_j}, \boldsymbol{y_j})^t}$;
- Efficiency change measured by the period $t+1$ technology: $\frac{\delta^{t+1}(\boldsymbol{x_j}, \boldsymbol{y_j})^{t+1}}{\delta^{t+1}(\boldsymbol{x_j}, \boldsymbol{y_j})^t}$.

The Malmquist Index

- MI is the geometric mean of the two efficiency ratios:

$$MI = \left\{ \frac{\delta^t(\mathbf{x_j}, \mathbf{y_j})^{t+1}}{\delta^t(\mathbf{x_j}, \mathbf{y_j})^t} \times \frac{\delta^{t+1}(\mathbf{x_j}, \mathbf{y_j})^{t+1}}{\delta^{t+1}(\mathbf{x_j}, \mathbf{y_j})^t} \right\}^{1/2} \quad (1)$$

- MI>1 indicates progress in the total factor productivity (TFP) of the DMU from period t to period $t+1$,
- MI=1 indicates the non variation of the TFP
- MI<1 indicates the deterioration of the TFP.

MI decomposition. Ray & Delsi(1997)

Under constant returns on scale, MI can be seen as the product of three component:

$$MI_C = Catch - up(V) \times Frontier - shift(V) \times Scale \quad Efficiency \quad Change$$

MI decomposition

Under constant returns on scale, MI can be seen as the product of three component:

the *catch-up* effect:

$$\frac{\delta^{t+1}(\mathbf{x_j}, \mathbf{y_j})^{t+1}}{\delta^{t}(\mathbf{x_j}, \mathbf{y_j})^{t}}$$

The progress in relative efficiency, the degree at which the DMU improves or worsens its efficiency

frontier shift - Innovation under variable returns on scale:

$$\left[\frac{\delta^{t}(\mathbf{x_j}, \mathbf{y_j})^{t}}{\delta^{t+1}(\mathbf{x_j}, \mathbf{y_j})^{t+1}} \times \frac{\delta^{t}(\mathbf{x_j}, \mathbf{y_j})^{t+1}}{\delta^{t+1}(\mathbf{x_j}, \mathbf{y_j})^{t+1}}\right]^{1/2}$$

The change in the efficient frontiers between two periods.

MI decomposition

scale efficiency change:

$$\left[\frac{\sigma^t(\mathbf{x_j},\mathbf{y_j})^{t+1}}{\sigma^t(\mathbf{x_j},\mathbf{y_j})^t} \times \frac{\sigma^{t+1}(\mathbf{x_j},\mathbf{y_j})^{t+1}}{\sigma^{t+1}(\mathbf{x_j},\mathbf{y_j})^t}\right]^{1/2}$$

The geometric mean of the two scale efficiency changes, one evaluated with the technology at time t and the other relative to the technology at $t+1$.

Scale efficiency

$$\sigma^s(\mathbf{x_j},\mathbf{y_j})^r = \frac{\delta^s_C(\mathbf{x_j},\mathbf{y_j})^r}{\delta^s_V(\mathbf{x_j},\mathbf{y_j})^r} \text{ with } r,s = t, t+1$$

The distance function between two frontiers at time s, one related to the constant returns on scale technology and one related to the variable return on scale technology.

Second stage

There are well-known problems in using the ML index as a dependent variable in econometric specifications. These scores are heavely affected by serial correlation.

Two possible solutions are available

- Bootstrap procedure in the first stage (Simar and Wlison, 2007)
- Econometric methods able to control for serial correlation in the second stage. ⟸

The spatial dynamic panel data approach

It allows to manage the speed of adjustment of the:

- Dynamic effect
- Spatial effect

of regulation on TFP growth by the lagged dependent variables.

The model

$$TFP_{i,t} = \alpha TFP_{i,t-1} + \rho WTFP_{i,t} + \beta_1 Regulation_{i,t} + \beta_2 EPS_{i,t} + \sum_{k=1}^{K} \gamma_k x_{ik} + \epsilon_{i,t}$$

$$\epsilon_{i,t} = \mu_i + \upsilon_{i,t}$$

$$E[\mu_i] = E[\upsilon_{i,t}] = E[\mu_i, v_{i,t}] = 0$$

where:
$i = 1 \dots 19$: countries.
t: 2006...2013.
k=1. . . 3: the number of control variables.
$TFP_{i,t-1}$: the lagged dependent variable.
W: the binary spatial panel weight matrix
$Regulation_{i,t}$: the overall regulatory indicator for the electricity sector.
$EPS_{i,t}$: the environmental regulatory indicator for the electricity sector.
$\sum_{k=1}^{K} x_{ik}$: the set of control variables.
$\epsilon_{i,t}$: the error terms including
$v_{i,t}$: idiosincratic error and
μ_i: fixed effect.

The model assumptions

The traditional assumptions in data generating process are the following (Roodman 2009):

- Country's specific fixed effect.
- Dynamic process: the left hand side variable (the Malmquist index) is regressed on its own past realizations which are correlated with the fixed effect.
- Heteroskedasticity: the idiosyncratic disturbances (the errors purged by the fixed effects) may have country specific patterns of heteroskedasticity.
- The instruments are internal: the lags of the instrumented (dependent) variables.

Spatial lag Arellano Bond model

This model may incur in endogeneity problems since the presence as regressor of lagged dependent variable $TFP_{i,t-1}$ correlated with the fixed effect error term μ_i.

First difference transformation

Remove the fixed effect.

$$\Delta TFP_{i,t} = \alpha \Delta TFP_{i,t-1} + \rho W \Delta TFP_{i,t} + \beta_1 \Delta Regulation_{i,t} + \\ \beta_2 \Delta EPS_{i,t} + \sum_{k=1}^{K} \gamma_k x_{ik} + \Delta v_{i,t}$$

Generalised Moment Method

Using as instrumental variable for $\Delta TFP_{i,t-1}$ its past realizations TFP_{t-r} with $r : 2, ..., t-1$ to eliminate the dynamic bias: the correlation between $\Delta TFP_{i,t-1}$ and $\Delta v_{i,t}$.

First stage

Balanced panel dataset of 171 observations, 19 European Union Countries between the 2006 and the 2014.

Input

- Fuels $\Longrightarrow$ Eurostat - Energy Database – (Nrg105a) refers to the Transformation input in Main Activity Producer Conventional Power Stations.
- Installed capacity $\Longrightarrow$ Eurostat - Energy Database (Nrg113a) proxies the capital.
- Labour $\Longrightarrow$ ILO Database and Amadeus Dataset proxied by the number of employees of electricity sector

Output

- Electricity production $\Longrightarrow$ Eurostat - Energy Database – (Nrg110a) refers to the net electricity generated by conventional thermal power station.
- Green House Gas emissions (GHGs) $\Longrightarrow$ OECD Database.

Second stage

The key explanatory variables

- Overall regulatory index $\Longrightarrow$ OECD Database.
  Country-specific multidimensional measure of the rate of regulation in the electricity sector.
- Environmental policy stringency $\Longrightarrow$ OECD Database.
  Country-specific multidimensional measure of the degree to which environmental policies put an explicit or implicit price on polluting and environmentally harmful behaviour.

Second stage

The control variables

- Fuel mix principal component $\Longrightarrow$ Eurostat - Energy Database – (Nrg105a).
  The principal component analysis of the shares of sources used in each countries in the electricity generation process thought as a proxy of both the technology changes employed at country-level and the relative price changes of the fuels used in the generation process.
- R&D intensity $\Longrightarrow$ International Energy Agency database (2010).
  It proxies the unincorporated technical progress.
- CHP penetration rate (CHP)$\Longrightarrow$ International Energy Agency database (2010).
  It measures the country-specific rate of penetration of CHP technology

Table: Descriptive statistics of variables used in DEA Analysis

Variable		Mean	Std. Dev.	Min	Max	Obs.
Electricity Generation	overall	4667.70	7160.48	1.30	26693.99	N = 171
	between		7263.66	5.04	25219.78	n = 19
	within		997.30	468.18	7853.68	T = 9
Electrical Capacity	overall	21244.01	23498.89	439	87747	N = 171
	between		23991.31	451.11	77140.67	n = 19
	within		1923.84	12820.35	31850.35	T = 9
Employment	overall	49.31	62.33	.66	306.11	N =171
	between		63.15	.76	283.81	n = 19
	within		9.16	3.48	104.12	T = 9
GGE	overall	216.2852	286.94	1.62	1358.75	N = 171
	between		272.64	1.83	994.61	n = 19
	within		107.24	-80.73	898.70	T = 9
Input Fuels	overall	17562.5	21411.83	288.6	87610.8	N = 171
	between		21819.37	445.14	83783.84	n = 19
	within		2187.63	8202.09	24572.3	T = 9

TABLE: Average of the Malmquist Index and its main components

Country	Efficiency Ch.	Frontier Ch.	Pure Eff. Ch.	Scale Eff. Ch.	TFP Ch.
Austria	0.994	1.037	0.998	0.996	1.031
Belgium	1.054	1.075	1.050	1.003	1.133
Czech Republi	0.991	1.001	0.991	1.000	0.992
Denmark	0.989	0.998	0.990	0.999	0.986
Finland	0.985	0.989	0.980	1.005	0.974
France	1.065	1.050	0.977	1.090	1.118
Germany	1.002	0.996	1.000	1.002	0.998
Greece	1.007	0.999	1.013	0.994	1.006
Hungary	0.979	0.996	0.981	0.999	0.975
Ireland	0.995	1.000	0.996	1.000	0.995
Italy	1.000	1.040	1.000	1.000	1.040
Luxembourg	1.000	1.024	1.000	1.000	1.024
Netherlands	1.000	1.035	1.000	1.000	1.035
Poland	1.000	1.046	1.000	1.000	1.046
Portugal	0.975	1.025	0.977	0.998	0.999
Slovakia	0.980	1.032	0.980	0.999	1.011
Spain	0.989	1.012	0.996	0.993	1.001
Sweden	0.993	1.019	0.949	1.046	1.012
United Kingdom	0.997	0.991	0.986	1.011	0.987
mean	0.999	1.019	0.993	1.007	1.018

Note that all Malmquist index averages are geometric means.

Table: Change in total factor productivity and its component between 2006-2014

	TFP Ch=PEff. Ch.+Scale Eff. Ch.+ Frontier Shift Ch.			
Country	TFP Ch. %	Pure Efficiency Ch. %	Scale Eff. Ch. %	Frontier Shift Ch. %
Austria	1.962	-0.288	0.058	2.192
Belgium	1.868	0.492	-0.057	1.408
Czech Republic	-0.142	-0.311	0.114	0.057
Denmark	-0.857	-0.805	0.014	-0.071
Finland	-0.547	-0.899	0.085	0.260
France	4.264	1.446	0.775	1.977
Germany	-0.767	0.000	-0.890	0.129
Greece	0.694	1.120	-0.330	-0.085
Hungary	0.523	0.665	-0.202	0.071
Ireland	-0.564	-0.072	-0.214	-0.280
Italy	0.130	0.000	0.000	0.130
Luxembourg	-0.285	0.000	0.000	-0.285
Netherlands	-0.738	0.000	0.000	-0.738
Poland	2.849	0.000	0.000	2.849
Portugal	-0.654	-0.896	0.601	-0.348
Slovakia	-0.399	0.043	0.241	-0.666
Spain	-0.153	0.126	-0.014	-0.266
Sweden	-0.278	-1.942	1.444	0.241
United Kingdom	-0.313	-0.380	-0.067	0.157

Table: Descriptive statistics of MI from the additive model used in the second stage

Variable		Mean	Std. Dev.	Min	Max	Obs.
FMalma_ADD	overall	.950	.145	.435	1.99	N = 152
	between		.034	.885	1.004274	n = 19
	within		.141	.464	2.022	T = 8
Fscale_ADD	overall	.999	.078	.643	1.500	N = 152
	between		.025	.951	1.085	n = 19
	within		.074	.624	1.488	T = 8
Fpeff_ADD	overall	1.004	.145	.581	1.779	N = 152
	between		.028	.956	1.086	n = 19
	within		.143	.502	1.827	T = 8
Ftech_ADD	overall	.952	.085	.442	1.214	N = 152
	between		.029	.867	1.004	n = 19
	within		.080	.527	1.202	T = 8

Table: Descriptive statistics of regressors used in the second stage

Variable		Mean	Std. Dev.	Min	Max	Obs.
Regulation	overall	2.271	.805	.871	4.4345	N = 152
	between		.700	1.016	3.445	n = 19
	within		.425	1.512	3.796	T = 8
EPS	overall	2.318	.958	0	4.1	N = 152
regulation	between		.880	.77	3.41625	n = 18
	within		.4271335	.783	3.505	T = 8
CHP	overall	.163	.132	0	.786	N = 152
	between		.122	.030	.462125	n = 19
	within		.058	-.043	.583	T = 8
RDIntens.	overall	.037	.034	.0006	.193	N = 152
	between		.031	.002	.107	n = 19
	within		.016	-.011	.130	T = 8
pcaFUELMIX	overall	-2.74e-09	1.155	-2.682	2.717	N = 152
	between		.621	-1.304	1.052	n = 19
	within		.983	-3.461	4.022	T = 8

Results

Table: Regulation effect for the electricity sector, on the annual Malmquist index.

FMalm	(1) b/se	(2) b/se	(3) b/se	(4) b/se	(5) b/se	(6) b/se	(7) b/se	(8) b/se
L.FMalm	-0.052*** 0.017	-0.066*** 0.012	-0.003 0.074	-0.104*** 0.026	-0.049 0.047	-0.007 0.040	-0.052* 0.048	-0.078** 0.043
Regulation	-0.024** 0.005	-0.025** 0.012	-0.024** 0.013	-0.022** 0.012	-0.019** 0.014	-0.013*** 0.006	-0.014** 0.017	-0.013** 0.017
EPS	0.020** 0.010					0.034*** 0.010	0.008 0.013	0.014 0.019
EPSMarket		-0.016* 0.009		-0.011* 0.009				
EPSNonmark.		0.042*** 0.011	0.053*** 0.015					
Tax			0.027* 0.029		0.027** 0.023			
TradingSch.			-0.034*** 0.009		-0.030*** 0.010			
FeedinTariffs			0.017* 0.005		0.000 0.005			
Standards				0.109*** 0.026	0.038* 0.035			
R&Dsubsidies				-0.002 0.008	0.019*** 0.008			
CHP						-0.010 0.019	-0.044* 0.035	-0.046 0.045
R&Dintens.							1.343* 0.990	1.366 1.348
pcaFUELMIX								0.002* 0.002
N	114	114	114	114	114	114	114	114
j	23	24	26	25	27	24	25	26
ar1p	0.046	0.042	0.039	0.038	0.033	0.034	0.030	0.032
ar2p	0.579	0.524	0.667	0.352	0.444	0.288	0.395	0.390
hansenp	0.895	0.888	0.971	0.889	0.946	0.717	0.891	0.884

Table: Regulation effect for the electricity sector, on the annual Shift Frontier change.

Ftech	(1) b/se	(2) b/se	(3) b/se	(4) b/se	(5) b/se	(6) b/se	(7) b/se	(8) b/se
L.Ftech	-0.116***	-0.123***	-0.159***	-0.116***	-0.161***	-0.110***	-0.114***	-0.110***
	0.023	0.031	0.025	0.031	0.044	0.007	0.034	0.044
Regulation	-0.005	-0.006	-0.006	-0.004	0.000	-0.001	0.000	0.001
	0.007	0.010	0.013	0.010	0.011	0.008	0.008	0.011
EPS	-0.087***					-0.088***	-0.105***	-0.108***
	0.003					0.003	0.006	0.018
EPSmarket		-0.038***		-0.036***				
		0.006		0.007				
EPSNonmark.		-0.047***	-0.044***					
		0.003	0.003					
Tax			-0.031***		-0.028***			
			0.012		0.011			
TradingSch.			-0.020***		-0.014**			
			0.006		0.007			
FeedinTariffs			-0.002		-0.003*			
			0.002		0.002			
Standards				-0.007***	-0.016***			
				0.002	0.006			
R&Dsubsidies				-0.028***	-0.022***			
				0.003	0.003			
CHP						0.097***	0.091**	0.094**
						0.024	0.043	0.052
R&DIntens.							1.060***	1.258
							0.415	1.451
pcaFUELMIX								-0.008***
								0.002
N	114	114	114	114	114	114	114	114
j	23	24	26	25	27	24	25	26
ar1p	0.054	0.056	0.057	0.046	0.041	0.047	0.044	0.041
ar2p	0.469	0.471	0.468	0.488	0.506	0.523	0.513	0.753
sarganp	0.624	0.619	0.717	0.621	0.768	0.650	0.625	0.629
N	133	133	133	133	133	133	133 0	133
j	23	24	26	25	27	24	25	26
ar1p	0.054	0.056	0.057	0.046	0.041	0.047	0.044	0.041
ar2p	0.469	0.471	0.468	0.488	0.506	0.523	0.513	0.753
hansenp	0.624	0.619	0.717	0.621	0.768	0.650	0.625	0.629

Table: Regulation effect for the electricity sector, on the annual Pure Efficiency change.

Fpeff	(1) b/se	(2) b/se	(3) b/se	(4) b/se	(5) b/se	(6) b/se	(7) b/se	(8) b/se
L.Fpeff	-0.071***	-0.071***	-0.080***	-0.100***	-0.098***	-0.065***	-0.057***	-0.073***
	0.004	0.005	0.009	0.003	0.016	0.003	0.007	0.013
Regulation	-0.005***	0.000	-0.016***	-0.006***	0.003	-0.007***	-0.004*	0.004
	0.002	0.003	0.004	0.002	0.014	0.002	0.003	0.004
EPS	0.089***					0.089***	0.096***	0.064***
	0.004					0.007	0.012	0.015
EPSmarket		0.040***		0.028***				
		0.005		0.005				
EPSNonmark.		0.047***	0.042***					
		0.008	0.013					
Tax			0.079***		0.080***			
			0.014		0.015			
TradingSch.			-0.009**		-0.002			
			0.005		0.009			
FeedinTariffs			0.005*		0.005*			
			0.004		0.004			
Standards				0.065***	0.061***			
				0.012	0.020			
R&Dsubsidies				0.008***	0.012**			
				0.004	0.006			
CHP						-0.133***	-0.117***	-0.012
						0.047	0.053	0.060
R&DIntens.							-0.168	0.274
							0.221	0.580
pca								-0.001
								0.001
N	114	114	114	114	114	114	114	114
j	23	24	26	25	27	24	25	26
ar1p	0.033	0.051	0.056	0.055	0.040	0.049	0.030	0.034
ar2p	0.921	0.720	0.658	0.629	0.959	0.732	0.937	0.819
hansenp	0.621	0.711	0.969	0.935	0.970	0.621	0.640	0.963
N	133	133	133	133	133	133	133 0	133
j	23	24	26	25	27	24	25	26
ar1p	0.040	0.032	0.039	0.043	0.39	0.052	0.045	0.058
ar2p	0.265	0.253	0.246	0.292	0.268	0.470	0.541	0.448
sarganp	0.731	0.776	0.752	0.876	0.957	0.689	0.891	0.758

Table: Regulation effect for the electricity sector, on the annual Efficiency Scale change.

Fscale	(1) b/se	(2) b/se	(3) b/se	(4) b/se	(5) b/se	(6) b/se	(7) b/se	(8) b/se
L.Fscale	-0.157*** 0.005	-0.178*** 0.005	-0.196*** 0.014	-0.171*** 0.003	-0.193*** 0.010	-0.160*** 0.007	-0.159*** 0.011	-0.091*** 0.023
Regulation	0.052*** 0.003	0.053*** 0.005	0.054*** 0.007	0.049*** 0.005	0.053*** 0.006	0.052*** 0.003	0.050*** 0.005	0.045*** 0.009
EPS	0.091*** 0.003					0.089*** 0.005	0.080*** 0.012	0.084*** 0.010
EPSmarket		0.021*** 0.002		0.020*** 0.009				
EPSNonmark.		0.066*** 0.004	0.047*** 0.011					
Tax			-0.021* 0.013		-0.012 0.018			
TradingSch.			0.017*** 0.003		0.016*** 0.003			
FeddinTariffs			0.007** 0.004		0.004* 0.003			
Standards				0.009** 0.005	0.009* 0.006			
R&Dsubsidies				0.038*** 0.007	0.025*** 0.009			
CHP						0.016*** 0.005	0.019*** 0.007	0.013* 0.007
R&DIntens.							0.193 0.252	-0.389 0.406
pcaFUELMIX								0.012*** 0.001
N	114	114	114	114	114	114	114	114
j	23	24	26	25	27	24	25	26
ar1p	0.032	0.031	0.035	0.032	0.046	0.033	0.034	0.030
ar2p	0.338	0.339	0.275	0.298	0.262	0.331	0.315	0.310
hansenp	0.626	0.721	0.852	0.757	0.896	0.644	0.671	0.747

Table: Spatial effect for the electricity sector on the annual Malmquist index.

FMalm	(1) b/se	(2) b/se	(3) b/se	(4) b/se	(5) b/se	(6) b/se	(7) b/se	(8) b/se
wFMalm	0.080***	0.166***	-0.099	0.181***	0.124**	0.044	0.109*	0.087
	0.03	0.06	0.1	0.07	0.07	0.07	0.08	0.09
LFMalmadd	-0.193***	-0.187***	-0.354***	-0.210***	-0.394***	-0.188***	-0.118*	-0.075*
	0.03	0.04	0.09	0.05	0.08	0.05	0.09	0.06
Regulation	-0.177**	-0.160**	-0.029	-0.100**	-0.216**	-0.165**	-0.123**	-0.088**
	0.04	0.04	0.13	0.04	0.12	0.03	0.04	0.04
EPS	0.073***					0.087***	0.088***	0.072***
	0.02					0.02	0.02	0.03
EPSmarket		0.036*		0.009				
		0.03		0.04				
EPSNonmark.		0.092***	0.067*					
		0.03	0.05					
Tax			0.091**		0.095*			
			0.05		0.09			
TradingSch.			-0.053*		0.032			
			0.03		0.03			
FeedinTariffs			0.073*		-0.006			
			0.04		0.03			
Standards				0.096**	0.043			
				0.05	0.09			
R&Dsubsidies				0.029*	-0.006			
				0.02	0.03			
CHP						0.341***	0.275***	0.222*
						0.08	0.11	0.19
R&DIntens.							0.912***	-0.399
							0.4	0.89
pca								0.005*
N	114	114	114	114	114	114	114	114
j	23	24	26	25	27	24	25	26
ar1p	0.058	0.056	0.057	0.053	0.044	0.043	0.61	0.39
ar2p	0.009	0.005	0.002	0.007	0.005	0.004	0.006	0.008
sarganp	0.762	0.769	0.863	0.790	0.890	0.697	0.727	0.794

CONCLUSIONS

Stringency of Market Regulation

- Negative effects on the aggregated measure of TFP growth;
- Negative effects on the Catch-up term (the pure efficiency change);
- Positive effects on the Scale efficiency.

Conclusions

Stringency of Environmental Regulation

- Positive effects on the aggregated measure of TFP growth;
- Negative effects on the Frontier-shift (Innovation);
- Positive effects on the Catch-up term (the pure efficiency change),
- Positive effects on the Scale efficiency.

Spatial Contiguity

- Adding the spatial contiguity as explanatory variable does not change the previous results for the TFP growth;
- Spatial contiguity positively affects the aggregated energy efficiency.

Research Agenda

- To apply the spatial analysis to the single components of Malmquist Index
- Manage time invariant regressors