Impact of regulatory standards on the eco–efficiency of firms

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Motivation

- The internalisation of negative external effects is one of the most striking challenges in recent environmental research.
- One approach: Implementing environmental standards in the efficiency evaluation of firms.
- Eco–efficiency: We are looking for eco–efficient solutions such that the goods and services can be produced with less energy and resources and with less waste and emissions. (Heinz Felsner, see: Korhonen and Luptacik (2004))

$\Longrightarrow$ We want to discuss the impact of regulatory constraints, in terms of environmental standards, on the eco–efficiency of firms measured with DEA.

Relating Literature

- Basic literature:
  - Färe et al. (1989) and Shepard (1970): Introduced differentiation between strong and weak disposability.
  - Färe and Logan (1992): Using rate–of–return regulation, the authors were able to determine the relationship between measures of regulated and unregulated firms.
  - Golany and Roll (1994): Introduced the idea of implementing standards into the Data Envelopment Analysis (DEA) framework.
- Recent literature:
  - Korhonen and Luptacik (2004): Provided three different approaches for determining the eco–efficieny of firms.
  - Kuosmanen (2005): Formulation of weak disposability that allows for non–uniform abatement factors.
  - Yang and Pollitt (2010): Treated weakly and strongly disposable undesirable outputs.

Environmental Standards

Limiting emissions while taking into account weak disposability of emissions.

- Intensity–regulation (Dudenhöffer (1984)): $\frac{\textit{Emission}}{\textit{Input}} \leq \alpha_1$
- Emission per unit of output: $\frac{\textit{Emission}}{\textit{Output}} \leq \alpha_2$
- Set level of emissions (limitation on absolute amount): $Z \leq \alpha_3$

$\Longrightarrow$ See Helfand (1991) and Luptacik (2009)

Idea

- Environmental standards are introduced.
- Constraints on variables cannot be included in standard DEA framework, due to exogeneity.
- 2–step procedure:
  1. Identifying polluting firms not fulfilling the environmental standard and creating standard–meeting projections.
  2. Using DEA models for eco–efficiency on standard–meeting firms and projections.
- Difference in eco–efficiency scores between sample of regulated and unregulated firms as impact of the regulatory constraint for environmental standards.

Step 1: Standard–meeting projections

- Weak disposabilty of emissions:
  - Reducing emissions by increasing inputs
  - Reducing emissions by reducing outputs
- Iterative processes programmed in Matlab detecting firms not meeting the environmental standard and creating projections with respect to weak disposability of emissions.
- Creating two samples:
  1. Unregulated firms: Original data
  2. Regulated firms: Standard–meeting firms and projections

Step 2: Eco–efficiency Models

Korhonen and Luptacik (2004):

- Model A: Undesirable output (emissions) as negative output
- Model B: Undesirable output as input
- Model C: Undesirable output as input and input as negative output

$\Longrightarrow$ Applying eco–efficiency models on the samples of regulated and unregulated firms.

$\Longrightarrow$ Difference in eco–efficiency scores as impact of regulation.

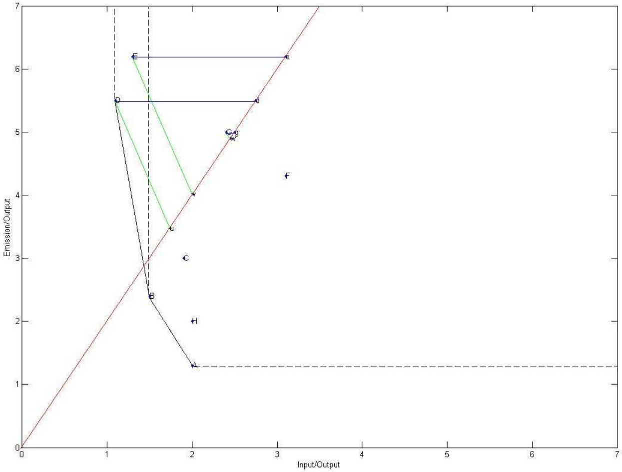
Explanatory Example

- 8 Decision Making Units (DMU)
- 1 input, 1 desired output and 1 undesired output (emissions)
- Intensity regulation: $\frac{Emission}{Input} \leq 2$

DMU Data

	Input	Emissions	Output	$\frac{Input}{Output}$	$\frac{Emission}{Output}$	$\frac{Emission}{Input}$
A	20	13	10	2	1.3	0.7
B	15	24	10	1.5	2.4	1.6
C	19	30	10	1.9	3	1.6
D	11	55	10	1.1	5.5	*5*
D1 (u)	17.4	34.8	10	1.7	3.5	2
D2 (d)	11	22	4	2.8	5.5	2
E	13	62	10	1.3	6.2	*4.8*
E1 (v)	20.1	40.2	10	2	4	2
E2 (e)	13	26	4.2	3.1	6.2	2
F	31	43	10	3.1	4.3	1.4
G	24	50	10	2.4	5	*2.1*
G1 (w)	24.5	49	10	2.4	4.9	2
G2 (g)	24	48	9.6	2.5	5	2
H	20	20	10	2	2	1

Graphical Presentation of Data



Eco–efficiency scores and slacks using Model B

	Unregulated Firms			Regulated Firms				Regulatory Impact
	Score	Rank	Ref	Score	Slacks	Rank	Ref	
DMU A	1	1	A	1	0	1	A	
DMU B	1	1	B	1	0	1	B	
DMU C	0.79	6	A,B	0.79	0	5	A,B	
DMU D	1	1	D	0.86	6	4	B	0.14
DMU E	0.86	5	B,D	0.75	6	6	B	0.12
DMU F	0.51	8	A,B	0.51	0	8	A,B	
DMU G	0.59	7	B,D	0.61	6	7	B	-0.02
DMU H	0.89	4	A,B	0.89	0	3	A,B	
∅ *Efficiency*	0.83			0.80				**0.03**

Slack–Based–Measure (SBM) Models

- Slacks are included in efficiency scores
- Possible SBM models:
  1. Undesirable–output model
  2. Model B

Slack–Based–Measure (SBM) Model for eco–efficiency (Model B)

$$\min_{\lambda, s^-, s^b} \quad \rho = \quad 1 - \frac{1}{m + s_2} \left(\sum_{i=1}^{m} \frac{s_i^-}{x_{io}} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{ro}^b} \right)$$

s.t.:

$$x_o = X\lambda + s^-$$

$$y_o^b = Y^b \lambda + s^b$$

$$y_o^g \leq Y^g \lambda$$

$$\lambda, s^-, s^b \geq 0$$

Eco–efficiency scores using SBM of Model B

	Unregulated Firms			Regulated Firms			Regulatory Impact
	Score	Rank	Ref	Score	Rank	Ref	
DMU A	1	1	A	1	1	A	
DMU B	1	1	B	1	1	B	
DMU C	0.75	6	A,B	0.75	5	A,B	
DMU D	1	1	D	0.77	4	A,B	0.23
DMU E	0.82	5	B,D	0.66	6	A	0.16
DMU F	0.47	8	A	0.47	8	A	
DMU G	0.55	7	A	0.54	7	A	0.01
DMU H	0.83	4	A	0.83	3	A	
∅ *Efficiency*	0.80			0.75			**0.05**

Summary

- Internalising negative external effects by implementing environmental standards in benchmarking.
- Difference in eco–efficiency scores between sample of regulated and unregulated firms as regulatory impact of environmental standards.
- Could provide support for environmental policy makers in choosing appropriate instruments.
- Intensity of regulation could be assessed and adjusted.

SBM Model B for eco–efficiency including bounded variables (Intensity Regulation)

$$\min_{\lambda, s^-, s^b} \quad \rho = \quad 1 - \frac{1}{m + s_2}\left(\sum_{i=1}^{m} \frac{s_i^-}{x_{io}} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{ro}^b}\right)$$

s.t.:

$$x_o = X\lambda + s^-$$

$$y_o = Y^b\lambda + s^b$$

$$y_o^g \leq Y^g\lambda$$

$$0 \leq Y^b\lambda \leq \alpha_1 X\lambda$$

$$\lambda, s^-, s^b \geq 0$$

Eco–efficiency Results — SBM Model B bounded

	SBM Model B			SBM Model B bounded			Regulatory
	Score	Rank	Ref	Score	Rank	Ref	Impact
DMU A	1	1	A	1	1	A	
DMU B	1	1	B	1	1	B	
DMU C	0.75	6	A,B	0.75	4	$\tilde{D}$	
DMU D	1	1	D	0.70	6	$\tilde{D}$	0.3
DMU E	0.82	5	B,D	0.71	5	$\tilde{D}$	0.11
DMU F	0.47	8	A	0.47	8	A	
DMU G	0.55	7	A	0.55	7	A	
DMU H	0.83	4	A	0.83	3	A	
∅ Efficiency	0.80			0.75			**0.05**

SBM Model B for eco–efficiency including bounded variables (emission per unit of output)

$$\min_{\lambda, s^-, s^b} \quad \rho = \quad 1 - \frac{1}{m + s_2}\left(\sum_{i=1}^{m} \frac{s_i^-}{x_{io}} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{ro}^b}\right)$$

s.t.:

$$x_o = X\lambda + s^-$$

$$y_o = Y^b\lambda + s^b$$

$$y_o^g \leq Y^g\lambda$$

$$0 \leq Y^b\lambda \leq \alpha_2 Y^g\lambda$$

$$\lambda, s^-, s^b \geq 0$$

SBM Model for eco–efficiency including bounded variables (level–of–emission)

$$\min_{\lambda, s^-, s^b} \quad \rho = \quad 1 - \frac{1}{m + s_2}\left(\sum_{i=1}^{m} \frac{s_i^-}{x_{io}} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{ro}^b}\right)$$

s.t.:

$$x_o = X\lambda + s^-$$

$$y_o^b = Y^b\lambda + s^b$$

$$y_o^g \leq Y^g\lambda$$

$$0 \leq Y^b\lambda \leq \alpha_3$$

$$\lambda, s^-, s^b \geq 0$$

Possible additional constraints to account for weak disposability of undesirable outputs

- Constraints in radial DEA models (Yang and Pollitt (2010)):

$$\rho y_o^b = Y^b \lambda; \qquad \rho y_o^g \leq Y^g \lambda$$

- Our first trial for SBM framework (Input increase):

$$\frac{(y_o^b - Y^b \lambda)}{y_o^b} = \frac{(X\lambda - x_o)}{x_o}$$

$$\frac{s^b}{y_o^b} = \frac{s_x^{WD}}{x_o}$$

- Our first trials for SBM framework (Output reduction):

$$\frac{(y_o^b - Y^b \lambda)}{y_o^b} = \frac{(y_o^g - Y^g \lambda)}{y_o^g}$$

$$\frac{s^b}{y_o^b} = \frac{s_y^{WD}}{y_o^g}$$

SBM Model B for eco–efficiency including bounded variables and weak disposability (Intensity Regulation)

$$\min_{\lambda, s^-, s^b} \quad \rho = \quad 1 - \frac{1}{m + 2s_2}\left(\sum_{i=1}^{m} \frac{s_i^-}{x_{io}} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{ro}^b} + \sum_{i,r=1}^{s_2} \frac{s_r^{WD}}{x_{io}}\right)$$

s.t.:

$$x_o = X\lambda + s^-$$

$$y_o = Y^b\lambda + s^b$$

$$y_o^g \leq Y^g\lambda$$

$$0 \leq Y^b\lambda \leq \alpha_1 X\lambda$$

$$\frac{s_r^b}{y_{ro}^b} = \frac{s_r^{WD}}{x_{io}}$$

$$\lambda, s^-, s^b, s_r^{WD} \geq 0$$

Undesirable–output model including bounded variables and weak disposability (Intensity Regulation)

$$\min_{\lambda, s^-, s^+} \quad \rho = \frac{1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{io}}}{1 + \frac{1}{s_1 + 2s_2}\left(\sum_{r=1}^{s_1} \frac{s_r^g}{y_{ro}^g} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{ro}^b} + \sum_{r=1}^{s_2} \frac{s_r^{WD}}{y_{ro}^g}\right)}$$

s.t.:

$$x_o = X\lambda + s^-$$

$$y_o^b = Y^b\lambda + s^b$$

$$y_o^g = Y^g\lambda - s^g$$

$$0 \leq Y^b\lambda \leq \alpha_1 X\lambda$$

$$\frac{s_r^b}{y_{ro}^b} = \frac{s_r^{WD}}{y_{ro}^g}$$

$$\lambda, s^-, s^g, s^b, s_r^{WD} \geq 0$$

Thanks for your attention!

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