Data Envelopment Analysis and Stochastic Frontier Analysis of Slovak and Czech Electricity Distribution Utilities

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Introduction

- Electricity sector reforms are transforming the structure and operating environment of the electricity industries across many European countries.

- The main aims of reforms:

  - introduce market – oriented principles in generation, transmission and distribution of electricity

  - increase the efficiency of natural monopoly services by introducing the „right“ regulation scheme

Regulation and liberalisation of Slovak electricity sector

- The EU´s Electricity Directive 96/92/EC, 2003/54/EC

Objective: to improve efficiency and competitiveness of power sector

- 2001 : Establishment of Regulatory Office for Network Industries (ÚRSO)– independent regulator
- 2003 : ÚRSO performs price cap regulation (prices must involve reasonable profit and economically substantial costs) by publishing decrees and resolutions
- 2005 : entrepreneurs – elligible customers
- 2007 : - households - elligible customers
  - power generation and electricity supply become competitive activities

Structure of Slovak electricity sector

PRODUCTION
(Slovenské elektrárne)

TRANSMISSION
(Slovenská elektrizačná a prenosová sústava)

DISTRIBUTION
(Západoslovenská energetika, Stredoslovenská energetika, Východoslovenská energetika)

Regulation of distribution utilities

- Traditional Rate of Return regulation – little incentive to minimize costs
- Incentive Price–Cap regulation (RPI – X regulation)

Regulation of Slovak and Czech distribution utilities

- Based on incentive Price - Cap regulation
- Main issue: How to set efficiency factor X?
- Widely applied approach is benchmarking, that is measuring a company´s cost efficiency compared with a reference performance
- Inefficiency can results from technologigal deficiencies or non-optimal allocation of resources into production. Both technical and allocative inefficiencies are included in cost-inefficiency.
- The central goal of regulator is cost reduction of regulated firms ⇒ this study is oriented to problem of cost efficiency prediction

Main frontier benchmarking methods:

- Data Envelopment Analysis (DEA) – nonparametric method
- Stochastic Frontier Analysis (SFA) – parametric method

Our objective:

- Using DEA and SFA approach to obtain the relative cost efficiency of Slovak and Czech distribution utilities
- Sensitivity analysis of results (individual cost efficiency scores, utilities ranking, estimated parameters) to method and model renewal
- Posibilities of obtained resuts assimilation in regulation practice

Selected measures for Slovak (3) and Czech (8) distribution utilities in 2000 - 2004

	Mean	Median	Std. Dev.	Minimum	Maximum
Total annual costs (C) in mil. SKK	14876	14446	3824	7819	21308
Annual output (Y) in GWh	6051	6289	1481	3368	8840
Average capital price (PK) in thous. SKK per MVA of installed capacity	1740	1469	815	887	4501
Average annual labor price (PL) per employee in SKK	342516	342992	79151	204423	628603
Average price of input power (PP) in SKK/MWh	1547	1535	200	1077	2003
Number of customers (CU)	711702	666006	182709	401183	1018558
Service area (AS) in km sq.	11619	11242	4541	500	17978
Customer density (CUD)	179	60	383	35	1394

Source: Annual reports 2000 – 2004

Model specification (DEA)

- Input oriented CCR model (Constant Returns to Scale) and BCC model (Variable Returns to Scale) were modified to cost efficiency estimation (strategic behaviour – cost minimalization

$$\min_{\boldsymbol{\lambda}, \mathbf{x}_i^*} \mathbf{w}_i^T \mathbf{x}_i^*$$
$$-\mathbf{y}_i + \mathbf{Y}\boldsymbol{\lambda} \geq \mathbf{0}$$
$$\mathbf{x}_i^* - \mathbf{X}\boldsymbol{\lambda} \geq \mathbf{0}$$
$$\boldsymbol{\lambda} \geq \mathbf{0}$$

w_i and x_i are vectors respectively representing input prices and quantities for firm

X and Y are respectively input and output matrices

λ is a vector of non-negative constants to be estimated

- The VRS (Variable Returns to Scale) property is satisfied through the covexity constraint $\mathbf{e}^T \boldsymbol{\lambda} = 1$ in BCC model

- Cost efficiency for firm i : $CE = \mathbf{w}_i^T \mathbf{x}_i^* / \mathbf{w}_i^T \mathbf{x}_i$

- **Input variables**:

  - labor (L) – the average annual number of the utility´s employees
  - capital (K) - the total instaled capacity of the utility´s transformers in MVA
  - purchased energy (P) – the total purchased energy from the generator in MWh
  - labor price (PL) – the average annual salary of utility´s emploees
  - capital price (PK) – the ratio of capital expences to the total installed capacity of the utilitiy´s transformers in MVA
  - purchased energy price (PP) – average price of purchased energy from generator
- **Output variable**:

  - total output (Y) - measured as the total number of delivered electricity in MWh

Model specification (SFA)

- Frontier cost function: identifies the minimum costs at a given output level, input prices and existing production technology
- Stochastic frontier cost function (single output Cobb-Douglas form for panel data):

$$\ln C_{it} = \beta_0 + \beta_y \ln y_{it} + \sum_n \beta_n \ln w_{nit} + v_{it} + u_i \qquad u_i \geq 0$$

C_{it} - observed total costs of the *i*-th firm in year *t*,

y_{it} - a vector of outpusts of the *i*-th firm in year *t*,

w_{it} - an unput price vector of the *i*-th firm in year *t*,

u_i - time-invariant cost inefficiency,

v_{it} - random variables of *i*-th firm in year *t* reflecting effect of statistical noise

1. **Maximum likelihood estimation**

Distribution assumptions:

$$v_{it} \sim \mathrm{iidN}(0, \sigma_{\mathrm{v}}^2)$$

$$u_i \sim \mathrm{iidN}^+(0, \sigma_{\mathrm{u}}^2)$$

2. **Generalised Least Squares method**

Distribution assumptions:

$$v_{it} \sim \mathrm{iid}(0, \sigma_{\mathrm{v}}^2)$$

$$u_i \sim \mathrm{iid}(0, \sigma_{\mathrm{u}}^2)$$

- Cost inefficiency: deviation from the optimal point on the cost frontier
- Cost efficiency for firm i : $CE_i = \exp\{-u_i\}$

- Data: Panel data set for 3 Slovak and 8 Czech electricity distribution utilities over the 2000 – 2004 period
- Cost function specification:

$$\ln\left(\frac{C}{P_P}\right)_{it} = \beta_0 + \beta_Y \ln Y_{it} + \beta_K \ln\left(\frac{P_K}{P_P}\right)_{it} + \beta_L \ln\left(\frac{P_L}{P_P}\right)_{it} + \beta_{CUD} \ln CUD_{it} + v_{it} + u_i$$

$$i = 1,\ldots,N \qquad t = 1,\ldots,T$$

where C represents total costs, Y is the output, PK, PL, PP are the prices of capital, labor and input power respectively, CUD is customer density

Results

Cost frontier parameters

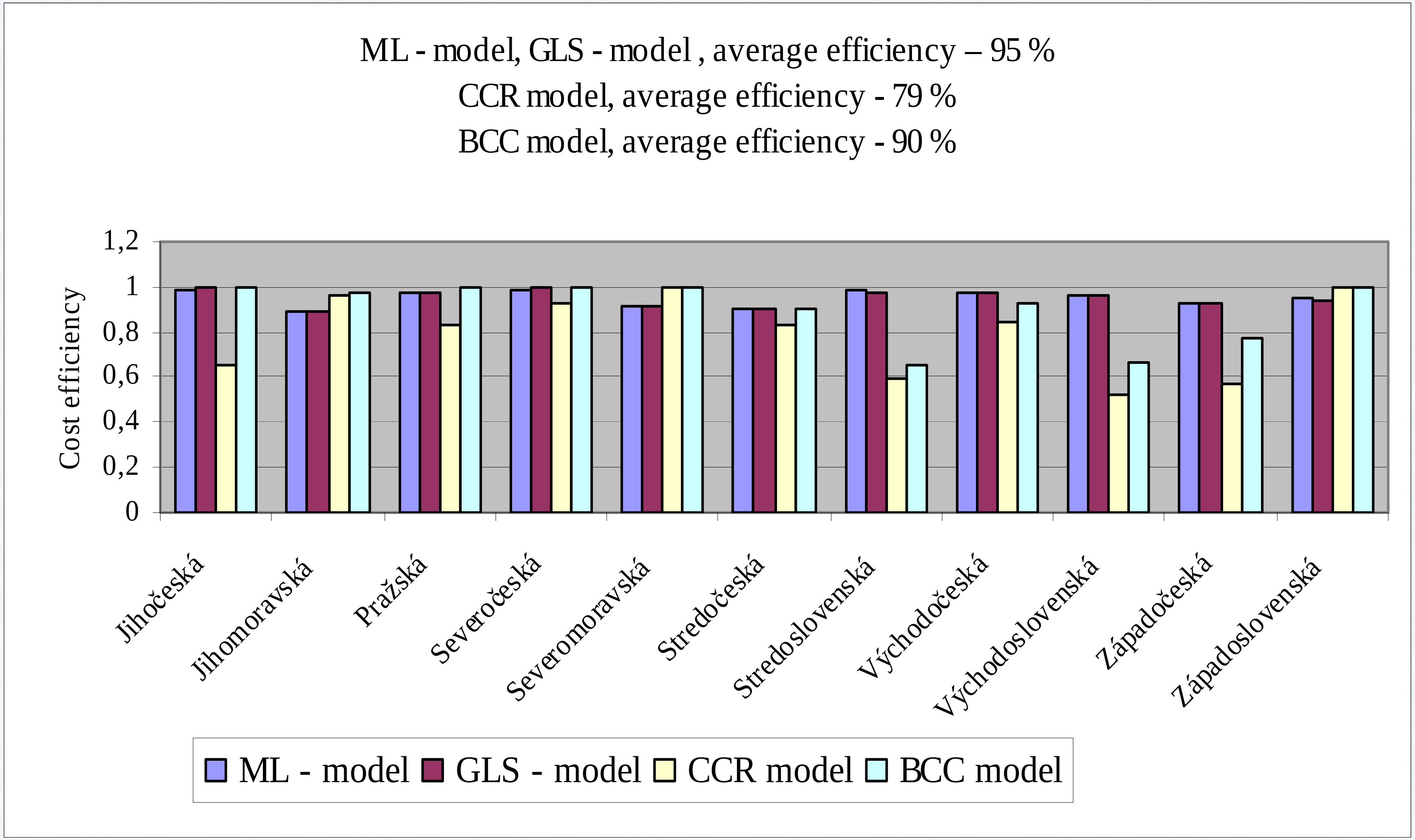
	MLE - model		GLS - model	
	Coeff.	**Std. Error**	**Coeff.**	**Std. Error**
Constant	-5,7196*	0,3038	-5,6117*	0,3583
ln*Y*	0,8673*	0,0337	0,8565*	0,0433
$\ln P_K/P_P$	0,2645*	0,0134	0,2667*	0,0115
$\ln P_L/P_P$	0,0684*	0,0217	0,0774*	0,0215
ln*CUD*	0,0010	0,0088	-0,0022	0,0139
σ^2	0,0045	0,0020		
γ	0,8475	0,0799		
Log-likelihood function	107,6564			
R-squared			0,9603	

*significant at p=0,05

Efficiency ranking for the utilities and efficiency scores, SFA (ML – model, GLS-model) and DEA (CCR – model, BCC – model)

Efficiency ranking for the companies and efficiency scores

Utilitiy	**MLE - model**	**GLS - model**	**CCR – model**	**BCC - model**
Severočeská energetika	1 (0,9915)	1 (1,0000)	4 (0,927)	5 (0,996)
Jihočeská energetika	2 (0,9871)	2 (1,0000)	8 (0,655)	1 (1,000)
Stredoslovenská energetika	3 (0,9815)	3 (0,9783)	9 (0,600)	11 (0,650)
Pražská energetika	4 (0,9788)	5 (0,9694)	6 (0,829)	1 (1,000)
Východočeská energetika	5 (0,9756)	4 (0,9726)	5 (0,846)	7 (0,927)
Východoslovenská energetika	6 (0,9646)	6 (0,9642)	11 (0,519)	10 (0,663)
Západoslovenská energetika	7 (0,9531)	7 (0,9433)	2 (0,999)	1 (1,000)
Západočeská energetika	8 (0,9284)	8 (0,9320)	10 (0,569)	9 (0,772)
Severomoravská energetika	9 (0,9174)	9 (0,9099)	1 (1,000)	1 (1,000)
Stredočeská energetika	10 (0,9041)	10 (0,8983)	7 (0,827)	8 (0,906)
Jihomoravská energetika	11 (0,8945)	11 (0,8866)	3 (0,968)	6 (0,969)
Average	**(0,9524)**	**(0,9504)**	**(0,794)**	**(0,898)**



ML - model, GLS - model , average efficiency – 95 %
CCR model, average efficiency - 79 %
BCC model, average efficiency - 90 %
Cost efficiency
1,2
1
0,8
0,6
0,4
0,2
0
Jihočeská
Jihomoravská
Pražská
Severočeská
Severomoravská
Stredočeská
Stredoslovenská
Východočeská
Východoslovenská
Západočeská
Západoslovenská
ML - model
GLS - model
CCR model
BCC model

Conclusions

- Efficiency scores, the estimated parameters of cost function and ranks are robust on estimation procedrure in SFA models (GLS – model, ML – model)
- It was not possible to estimate cross – section SFA model (only 11 observations – due to the small number of utilities in the sector)

  $\Rightarrow$ we had to compare SFA panel data model with DEA cross section data model $\Rightarrow$ possible source of differences in the results (efficiency scores and ranks) between parametric method (SFA) and nonparametric method (DEA)
- Benchmarking analysis can be used by regulator as an auxilliary instrument to establish a larger informational basis for more effective price cap regulation, but the results should be used with caution since the results can be influenced by the method and the model specification