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 – eligible customers
- 2007: - households - eligible 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 technological 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
- Possibilities of obtained results assimilation in regulation practice
Selected measures for Slovak (3) and Czech (8) distribution utilities in 2000 - 2004

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

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)

\[
\begin{align*}
\min_{\lambda, x^*, w^T} & \quad w^T x^* \\
- y_i + Y \lambda & \geq 0 \\
x^*_i - X \lambda & \geq 0 \\
\lambda & \geq 0
\end{align*}
\]

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

\(X\) and \(Y\) are respectively input and output matrices

\(\lambda\) is a vector of non-negative constants to be estimated

- The VRS (Variable Returns to Scale) property is satisfied through the convexity constraint \(e^T \lambda = 1\) in BCC model
Cost efficiency for firm $i$ : $CE = w_i^T x_i^* / w_i^T x_i$

**Input variables:**
- labor (L) – the average annual number of the utility´s employees
- capital (K) - the total installed 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 employees
- capital price (PK) – the ratio of capital expenses to the total installed capacity of the utility´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):

\[
\ln C_{it} = \beta_0 + \beta_y \ln y_{it} + \sum_{n} \beta_n \ln w_{nit} + v_{it} + u_i, \quad u_i \geq 0
\]

- $C_{it}$ - observed total costs of the $i$-th firm in year $t$,
- $y_{it}$ - a vector of outputs of the $i$-th firm in year $t$,
- $w_{it}$ - an input 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:
   \[ v_{it} \sim \text{iidN}(0, \sigma_v^2) \]
   \[ u_i \sim \text{iidN}^+(0, \sigma_u^2) \]

2. Generalised Least Squares method
   Distribution assumptions:
   \[ v_{it} \sim \text{iid}(0, \sigma_v^2) \]
   \[ u_i \sim \text{iid}(0, \sigma_u^2) \]

- 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:

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

\[
i = 1,..., N \quad t = 1,..., T
\]

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

<table>
<thead>
<tr>
<th></th>
<th>MLE - model</th>
<th></th>
<th>GLS - model</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coeff.</td>
<td>Std. Error</td>
<td>Coeff.</td>
<td>Std. Error</td>
</tr>
<tr>
<td>Constant</td>
<td>-5.7196*</td>
<td>0.3038</td>
<td>-5.6117*</td>
<td>0.3583</td>
</tr>
<tr>
<td>lnY</td>
<td>0.8673*</td>
<td>0.0337</td>
<td>0.8565*</td>
<td>0.0433</td>
</tr>
<tr>
<td>lnPK/Pp</td>
<td>0.2645*</td>
<td>0.0134</td>
<td>0.2667*</td>
<td>0.0115</td>
</tr>
<tr>
<td>lnPf/Pp</td>
<td>0.0684*</td>
<td>0.0217</td>
<td>0.0774*</td>
<td>0.0215</td>
</tr>
<tr>
<td>lnCUD</td>
<td>0.0010</td>
<td>0.0088</td>
<td>-0.0022</td>
<td>0.0139</td>
</tr>
<tr>
<td>$\sigma^2$</td>
<td>0.0045</td>
<td>0.0020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.8475</td>
<td>0.0799</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log-likelihood function</td>
<td>107,6564</td>
<td></td>
<td></td>
<td>0.9603</td>
</tr>
<tr>
<td>R-squared</td>
<td></td>
<td></td>
<td></td>
<td>0.9603</td>
</tr>
</tbody>
</table>

*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

<table>
<thead>
<tr>
<th>Utility</th>
<th>MLE - model</th>
<th>GLS - model</th>
<th>CCR – model</th>
<th>BCC - model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severočeská energetika</td>
<td>1 (0.9915)</td>
<td>1 (1,0000)</td>
<td>4 (0.927)</td>
<td>5 (0.996)</td>
</tr>
<tr>
<td>Jihočeská energetika</td>
<td>2 (0.9871)</td>
<td>2 (1,0000)</td>
<td>8 (0.655)</td>
<td>1 (1,000)</td>
</tr>
<tr>
<td>Stredoslovenská energetika</td>
<td>3 (0.9815)</td>
<td>3 (0.9783)</td>
<td>9 (0.600)</td>
<td>11 (0.650)</td>
</tr>
<tr>
<td>Pražská energetika</td>
<td>4 (0.9788)</td>
<td>5 (0.9694)</td>
<td>6 (0.829)</td>
<td>1 (1,000)</td>
</tr>
<tr>
<td>Východočeská energetika</td>
<td>5 (0.9756)</td>
<td>4 (0.9726)</td>
<td>5 (0.846)</td>
<td>7 (0.927)</td>
</tr>
<tr>
<td>Východoslovenská energetika</td>
<td>6 (0.9646)</td>
<td>6 (0.9642)</td>
<td>11 (0.519)</td>
<td>10 (0.663)</td>
</tr>
<tr>
<td>Západoslovenská energetika</td>
<td>7 (0.9531)</td>
<td>7 (0.9433)</td>
<td>2 (0.999)</td>
<td>1 (1,000)</td>
</tr>
<tr>
<td>Západnočeská energetika</td>
<td>8 (0.9284)</td>
<td>8 (0.9320)</td>
<td>10 (0.569)</td>
<td>9 (0.772)</td>
</tr>
<tr>
<td>Severomoravská energetika</td>
<td>9 (0.9174)</td>
<td>9 (0.9099)</td>
<td>1 (1,000)</td>
<td>1 (1,000)</td>
</tr>
<tr>
<td>Stredočeská energetika</td>
<td>10 (0.9041)</td>
<td>10 (0.8983)</td>
<td>7 (0.827)</td>
<td>8 (0.906)</td>
</tr>
<tr>
<td>Jihomoravská energetika</td>
<td>11 (0.8945)</td>
<td>11 (0.8866)</td>
<td>3 (0.968)</td>
<td>6 (0.969)</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>(0.9524)</strong></td>
<td><strong>(0.9504)</strong></td>
<td><strong>(0.794)</strong></td>
<td><strong>(0.898)</strong></td>
</tr>
</tbody>
</table>
ML - model, GLS - model, average efficiency – 95 %
CCR model, average efficiency - 79 %
BCC model, average efficiency - 90 %
Conclusions

- Efficiency scores, the estimated parameters of cost function and ranks are robust on estimation procedure 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)
  ⇒ we had to compare SFA panel data model with DEA cross section data model ⇒ 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 auxiliary 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