Timo Kuosmanen
StoNED method
in benchmark regulation
Evolution of benchmark regulation of electricity DSOs in Finland

• Late 1990s – 2004: DEA used on case by case basis if abuse of market power was suspected.

• 2005 – 2007: DEA used systematically to all firms to assign efficiency improvement targets

• 2008 – 2011: Efficiency improvement targets based on the average of DEA and SFA efficiency scores

• 2012 – 2015: Efficiency targets defined wrt a cost frontier estimated by StoNED
Classic benchmarking methods used in regulation of network industries

Established in the late 1970s:

- **Data envelopment analysis (DEA)**
  + axiomatic, nonparametric
  - deterministic

- **Stochastic frontier analysis (SFA)**
  - parametric
  + stochastic
Modern synthesis

• **Stochastic non-parametric envelopment of data (StoNED)**
  + axiomatic, nonparametric
  + stochastic

• **Data envelopment analysis (DEA)**
  + axiomatic, nonparametric
  - deterministic

• **Stochastic frontier analysis (SFA)**
  - parametric
  + stochastic
Do not let the labels mislead you

StoNED® can be equally well called

”stochastic DEA”

or

”nonparametric SFA”

Both characterizations are correct, but inherently biased.

(I do not advocate the term ”Kuosmanen’s method”, but I do not object it either.)
## Classification of methods

<table>
<thead>
<tr>
<th>Classification</th>
<th>Parametric</th>
<th>Nonparametric</th>
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<tbody>
<tr>
<td>Central tendency</td>
<td><strong>OLS</strong></td>
<td><strong>CNLS</strong></td>
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<td>Cobb and Douglas (1928)</td>
<td>Hildreth (1954)</td>
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<td>Deterministic frontier</td>
<td><strong>COLS</strong></td>
<td><strong>C^2NLS</strong></td>
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<td>Greene (1980)</td>
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<td>Sign constraints</td>
<td><strong>Param. Progr.</strong></td>
<td><strong>DEA</strong></td>
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<td>Aigner and Chu (1968)</td>
<td>Farrell (1957)</td>
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<td>Timmer (1971)</td>
<td>Charnes et al. (1978)</td>
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<tr>
<td>Stochastic frontier</td>
<td><strong>SFA</strong></td>
<td><strong>StoNED</strong></td>
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<td></td>
<td>Meeusen and Vanden Broeck (1977)</td>
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</table>
While it is common to call these mathematical programming formulations “DEA models”, these formulations should be rather seen as estimators of a true but unknown model. Banker’s (1993) was the first to prove statistical consistency of the DEA estimator under certain assumptions.
Unified frontier model

\[ y_i = f(x_i) - u_i + v_i, \quad i = 1, \ldots, n \]

where

- \( y_i \) is output of firm \( i \)
- \( f \) is production function
- \( x_i \) is input vector of firm \( i \)
- \( u_i \) is asymmetric inefficiency term of firm \( i \)
- \( v_i \) is random noise term of firm \( i \)

DEA model

\[ y_i = f(x_i) - u_i, \quad i = 1, \ldots, n \]

where

\( y_i \) is output of firm \( i \)
\( f \) is production function
\( x_i \) is input vector of firm \( i \)
\( u_i \) is asymmetric inefficiency term of firm \( i \)
\( v_i \) is random noise term of firm \( i \)

SFA model

\[ y_i = \beta' x_i - u_i + v_i, \quad i = 1, \ldots, n \]

where

- \( y_i \) is output of firm \( i \)
- \( \beta \) is parameter vector
- \( x_i \) is input vector of firm \( i \)
- \( u_i \) is asymmetric inefficiency term of firm \( i \)
- \( v_i \) is random noise term of firm \( i \)

Statistical consistency

Under the maintained assumptions of the model, DEA, SFA and StoNED are statistically consistent estimators of true but unknown production function $f$.

**Meaning:** The precision of DEA, SFA and StoNED estimators improves as the sample size increases, provided that the maintained assumptions hold.
The role of assumptions illustrated

Set of possible applications of benchmarking

DEA consistent

SFA consistent
The role of assumptions illustrated

Set of possible applications of benchmarking

- DEA consistent
- StoNED consistent
- SFA consistent
Statistical consistency

- **Unified model:** Only StoNED is consistent estimator, both DEA and SFA are inconsistent.
- **DEA model:** Both DEA and StoNED are consistent, SFA is inconsistent.
- **SFA model:** Both SFA and StoNED are consistent, DEA is inconsistent.

**Note:** consistency of $\text{Max}(\text{DEA, SFA})$ estimator requires that both DEA and SFA are consistent!
Simulated example

Output 2

Output 1

True frontier
Simulated example: DEA and SFA

- DEA frontier
- SFA frontier (Cobb-Douglas)
- SFA frontier (linear)
Simulated example: StoNED

Output 2

True frontier

StoNED frontier

Output 1
### Impact of estimation method on cost targets in Finland (1000 € of year 2008)

Kuosmanen, Saastamoinen & Sipiläinen (2013), *Energy Policy*

<table>
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<tr>
<th>Method</th>
<th>Total</th>
<th>Average</th>
<th>St. Dev.</th>
<th>Min</th>
<th>Max</th>
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<td>DEA</td>
<td>141,382</td>
<td>1,589</td>
<td>2,223</td>
<td>0,000</td>
<td>27,654</td>
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<tr>
<td>SFA</td>
<td>95,481</td>
<td>1,073</td>
<td>3,888</td>
<td>0,024</td>
<td>12,830</td>
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<tr>
<td>Average (DEA,SFA)</td>
<td>118,431</td>
<td>1,331</td>
<td>2,959</td>
<td>0,016</td>
<td>20,242</td>
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<tr>
<td>StoNED</td>
<td>47,508</td>
<td>0,534</td>
<td>1,326</td>
<td>0,000</td>
<td>11,113</td>
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</table>
Comparison of StoNED vs Max(DEA, SFA), Finland 2005 - 2008

Graph showing the comparison of StoNED efficiency vs Max(DEA, SFA) efficiency over the years 2005 to 2008.
Monte Carlo simulations

It is recommended to validate the benchmark methods applied in regulation by running a series of calibrated Monte Carlo (MC) simulations.

Rationale:

• Test the benchmarking methods in a controlled environment where the true frontier $f$ and true inefficiencies $u$ are known.
• Data are randomly drawn.
• Fair game: no privileged treatment for any method.
Calibrated MC simulations

To ensure the validity in regulation, we recommend the use of calibrated data generating process takes into account:

- The benchmark technology of the regulation model as the "true frontier"
- Collinearity of output variables
- Exponential distribution of the firm size (outputs)
- Variance parameters calibrated to match the estimated values
- Other relevant features of the industry and the observed empirical data
Calibrated MC simulations

Kuosmanen, Saastamoinen & Sipiläinen (2013), *Energy Policy*

Replicate the DGP of EMV specification as closely as possible

Root mean squared error: \( \text{RMSE} = \frac{1}{nM} \sum_{m=1}^{M} \sqrt{\sum_{i=1}^{n} \left( \frac{\hat{C}_{im} - C_{im}}{C_{im}} \right)^2} \)

Bias: \( \text{BIAS} = \frac{1}{nM} \sum_{m=1}^{M} \sum_{i=1}^{n} \left( \frac{\hat{C}_{im} - C_{im}}{C_{im}} \right) \)

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<th>RMSE</th>
<th>BIAS</th>
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<td></td>
<td>n=25</td>
<td>n=50</td>
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<td>StoNED</td>
<td>0.072</td>
<td>0.057</td>
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<td>DEA</td>
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<td>SFA</td>
<td>0.469</td>
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<td>Average</td>
<td>0.254</td>
<td>0.464</td>
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Excel-spreadsheet application

http://www.energiavirasto.fi/tehostamiskannustin

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<td>Verkon kj-maakaapelointiaste (%)</td>
<td>Verkkopituu (km)</td>
<td>Käyttäjän määrä (lkm)</td>
<td>0,4 kv</td>
<td>1 – 70 kv</td>
<td>110 kv</td>
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<td>&quot;Keskiarvon Voima Oy&quot;</td>
<td>9 349 726</td>
<td>22,49 %</td>
<td>4 401,5</td>
<td>37 839</td>
<td>314,54</td>
<td>242,53</td>
<td>397,43</td>
<td>504,86</td>
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<td>Sallittu kustannus STOTEX (OPEX+HATP+0,5KAH (nimellishinnoin)</td>
<td>9 582 674 €</td>
<td>3,00 %</td>
<td>142,7</td>
<td>23,62 %</td>
<td>4 445,5</td>
<td>38 217</td>
<td>317,69</td>
<td>244,95</td>
<td>401,40</td>
<td>509,91</td>
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<td>Verkon kj-maakaapelointiaste (%)</td>
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<td>Verkkopituu (km)</td>
<td>145,6</td>
<td>24,80 %</td>
<td>4 489,9</td>
<td>38 600</td>
<td>324,07</td>
<td>249,87</td>
<td>409,47</td>
<td>520,16</td>
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<td>Käyttäjän määrä (lkm)</td>
<td>148,5</td>
<td>26,04 %</td>
<td>3 543,8</td>
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<td>327,31</td>
<td>252,37</td>
<td>413,57</td>
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<td>9 810 468 €</td>
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<td>Verkkopituu (km)</td>
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<td>535,92</td>
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<td>Käyttäjän määrä (lkm)</td>
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<td>260,02</td>
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<td>Siirretty energia jännitetasoittain (GWh)</td>
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<td>Sallittu kustannus STOTEX (OPEX+HATP+0,5KAH (nimellishinnoin)</td>
<td>9 946 859 €</td>
<td>3,00 %</td>
<td>163,9</td>
<td>33,23 %</td>
<td>4 766,2</td>
<td>40 974</td>
<td>340,60</td>
<td>262,62</td>
<td>430,36</td>
<td>546,70</td>
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<td>Verkon kj-maakaapelointiaste (%)</td>
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<td>167,0</td>
<td>33,15 %</td>
<td>4 794,5</td>
<td>40 974</td>
<td>340,60</td>
<td>262,62</td>
<td>430,36</td>
<td>546,70</td>
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Literature – StoNED method


Thank you!

Questions, comments, feedback?

Contact:

timo.kuosmanen@aalto.fi