Aalto University
School of Economics

Cost efficiency analysis of electricity distribution networks:

Application of the StoNED method in the Finnish regulatory model

Timo Kuosmanen

BT seminar
12 Nov 2010

Motivation & background

- In Finland, firms and households are free to purchase electricity from any producer or intermediator, but the distribution remains a local monopoly

- The Finnish Energy Market Authority (EMV) regulates the distribution to counter abuse of monopoly power

- The acceptable rate of return for the invested capital based on the capital asset pricing model (CAPM)

- The acceptable cost level based on the efficient cost frontier estimated by DEA and SFA methods

Motivation & background

- Recent study by Kuosmanen, Kortelainen, Kultti, Pursiainen, Saastamoinen & Sipiläinen (2010) proposes several reforms for the 3rd regulation period in 2012-2015: (www.energiamarkkinavirasto.fi)

- Replace the average of DEA and SFA efficiency by the StoNED estimator that combines a nonparametric frontier with stochastic inefficiency and noise terms

General cost frontier model

$$x_i = C(\mathbf{y}_i) + u_i + v_i$$

x_i is the observed cost of firm i

C is the frontier cost function

$\mathbf{y}_i$ is the output vector of firm i

u_i is the inefficiency term of firm i

v_i is the noise term of firm i

DEA model

$$x_i = C(\mathbf{y}_i) + u_i$$

- Cost function *C* is not restricted to some specific functional form; it is only assumed to satisfy certain regularity conditions:
  - *C* is monotonic increasing, convex, and satisfies non-decreasing returns to scale (NDRS)

- Random noise term *v* is ignored. In practice, random noise assigned to inefficiency *u*.

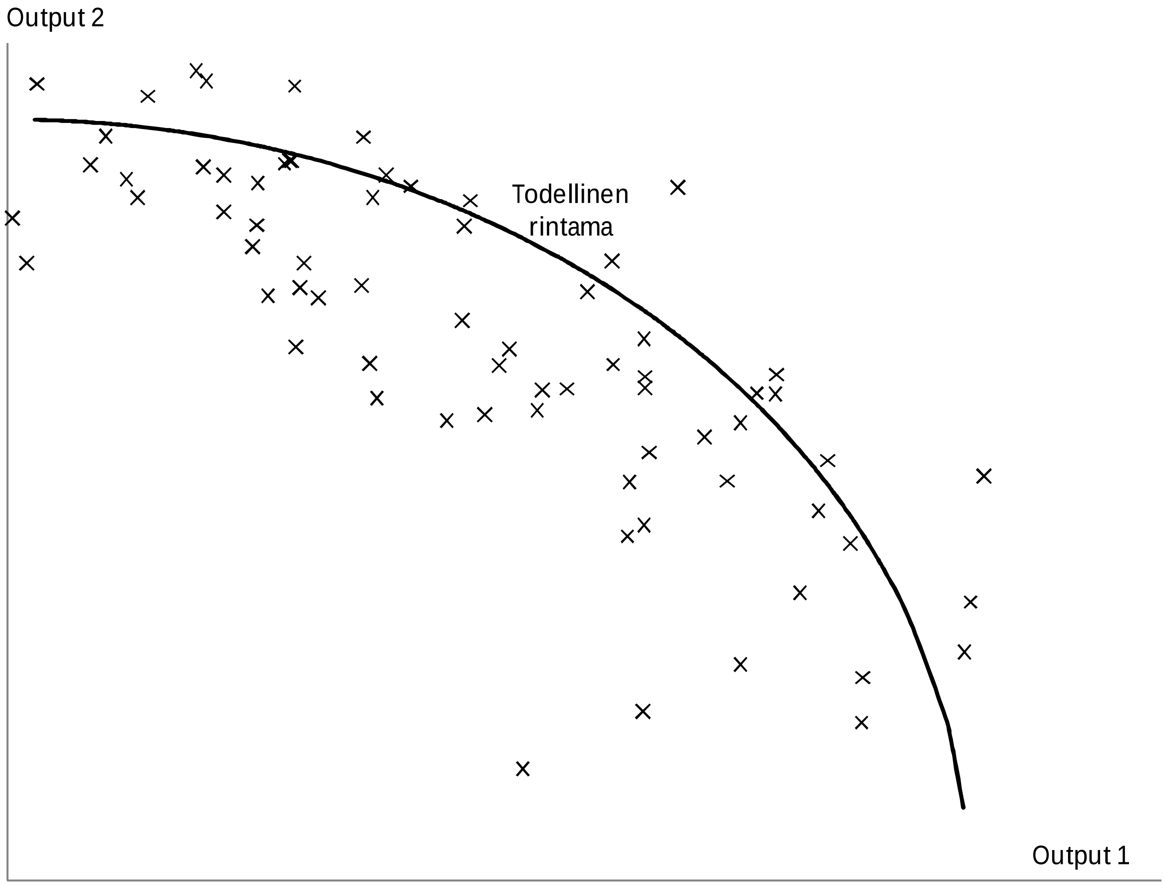
SFA model

$$x_i = \boldsymbol{\beta}\mathbf{y}_i + u_i + v_i$$

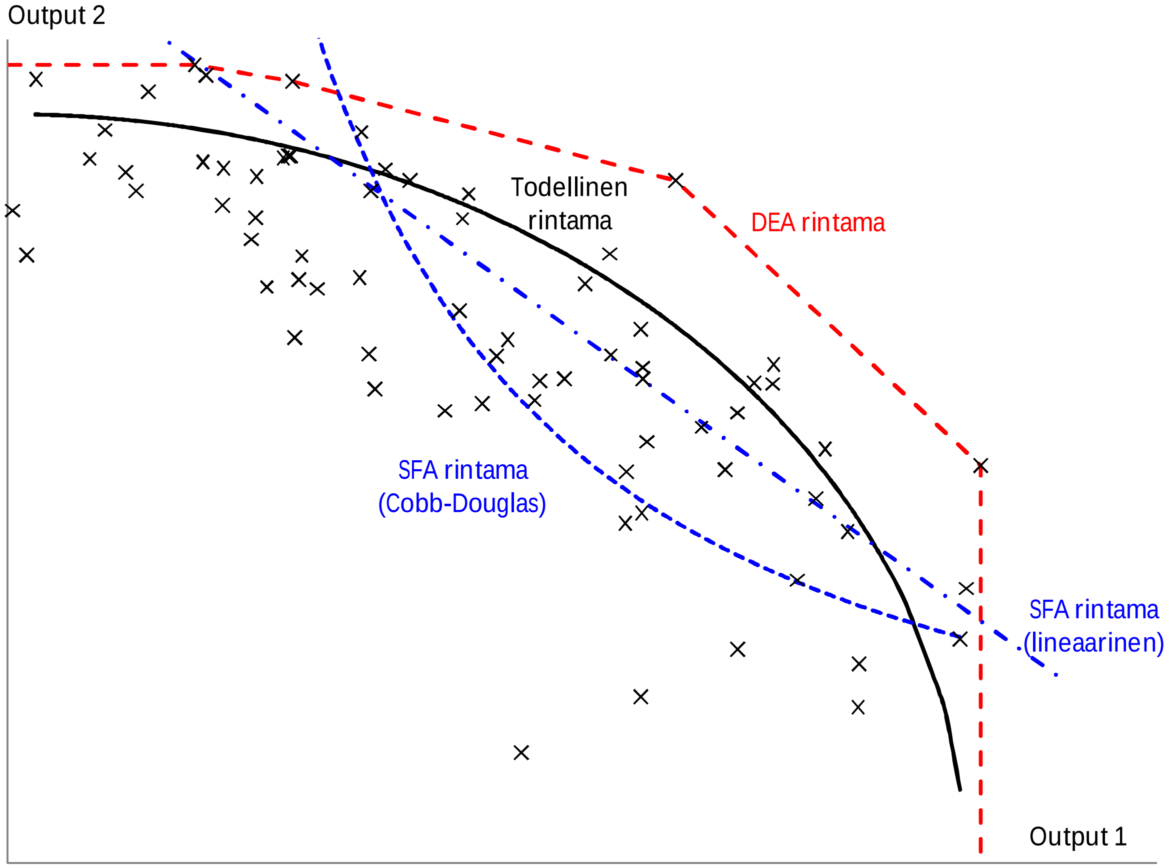
- Cost function *C* assumed to be linear

- Stochastic noise *v* filtered out from inefficiency *u* in a probabilistic manner.

Simulated example with two outputs



Simulated example with two outputs



Average of the DEA and SFA estimators

This estimator is *statistically consistent* if

- C is linear
- u is half-normal
- $v = 0$

(assumptions of DEA and SFA hold simultaneously)

- In that case, SFA estimator is more efficient.

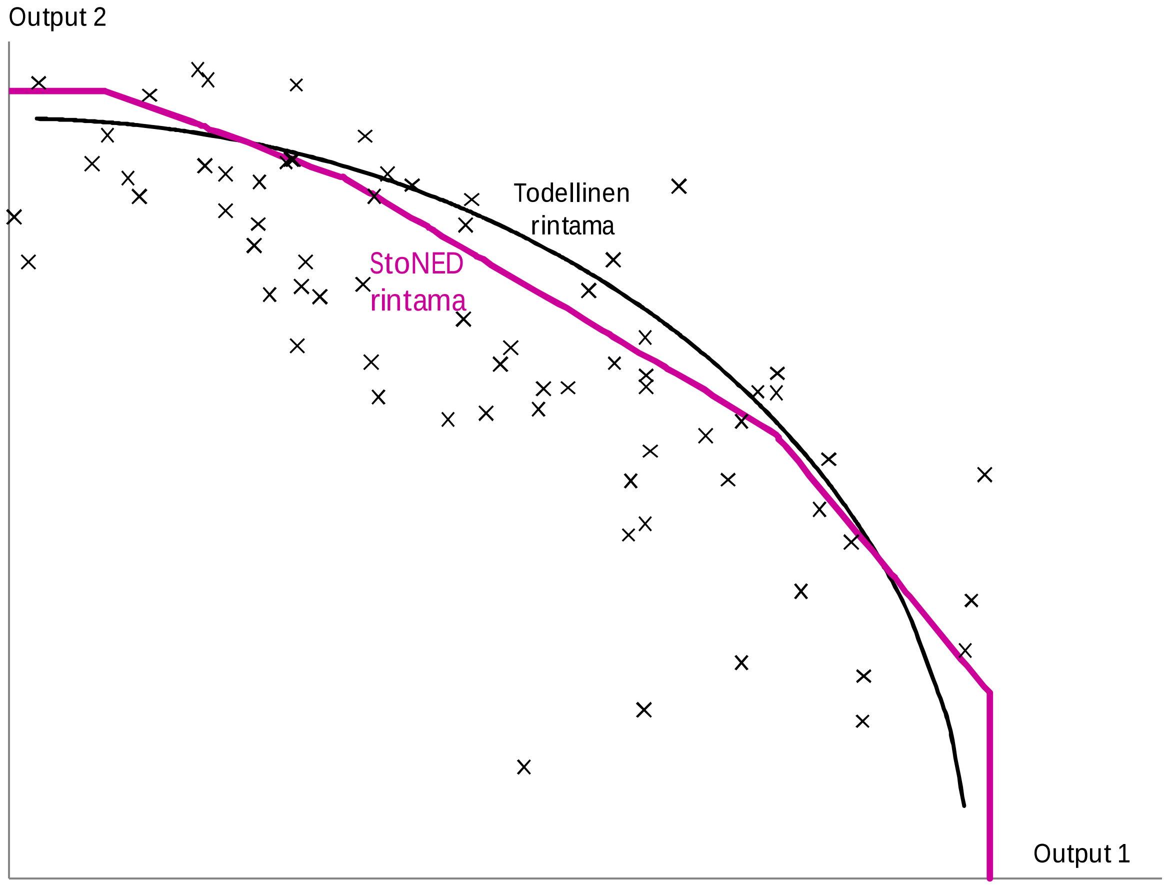
- In practice, at least one of the estimators (if not both) wrongly specified

StoNED model

$$x_i = C(\mathbf{y}_i) + u_i + v_i$$

- Cost function *C* is not restricted to some specific functional form; it is only assumed to satisfy certain regularity conditions
- Stochastic noise *v* filtered out from inefficiency *u* in a probabilistic manner.

Simulated example with two outputs



Preferred model specification

$$x = C(y_1, y_2, y_3) \cdot \exp(\delta z + u + v)$$

Where

C is a convex, monotonic increasing cost function that exhibits CRS

y_1 is the weighted amount of energy transmission (GWh of 0.4 kV equivalents)

y_2 is the total length of the network (km)

y_3 is the total number of customers connected to the network

z is the proportion of underground cables

u is a half-normally distributed inefficiency term

v is a normally distributed noise term

StoNED estimator

Step 1: solve the CNLS problem

$$\min_{\gamma,\boldsymbol{\beta},\delta,\varepsilon} \sum_{i=1}^{n} \varepsilon_i^2$$

$$s.t.$$

$$\ln x_i = \ln \gamma_i + \delta z_i + \varepsilon_i \quad \forall i$$

$$\gamma_i = \boldsymbol{\beta}_i' \mathbf{y}_i \quad \forall i$$

$$\gamma_i \geq \boldsymbol{\beta}_h' \mathbf{y}_i \quad \forall h, i$$

$$\boldsymbol{\beta}_i \geq 0 \quad \forall i$$

StoNED estimator

Step 2: Estimate the variance of u based on the skewness of residuals (M_3)

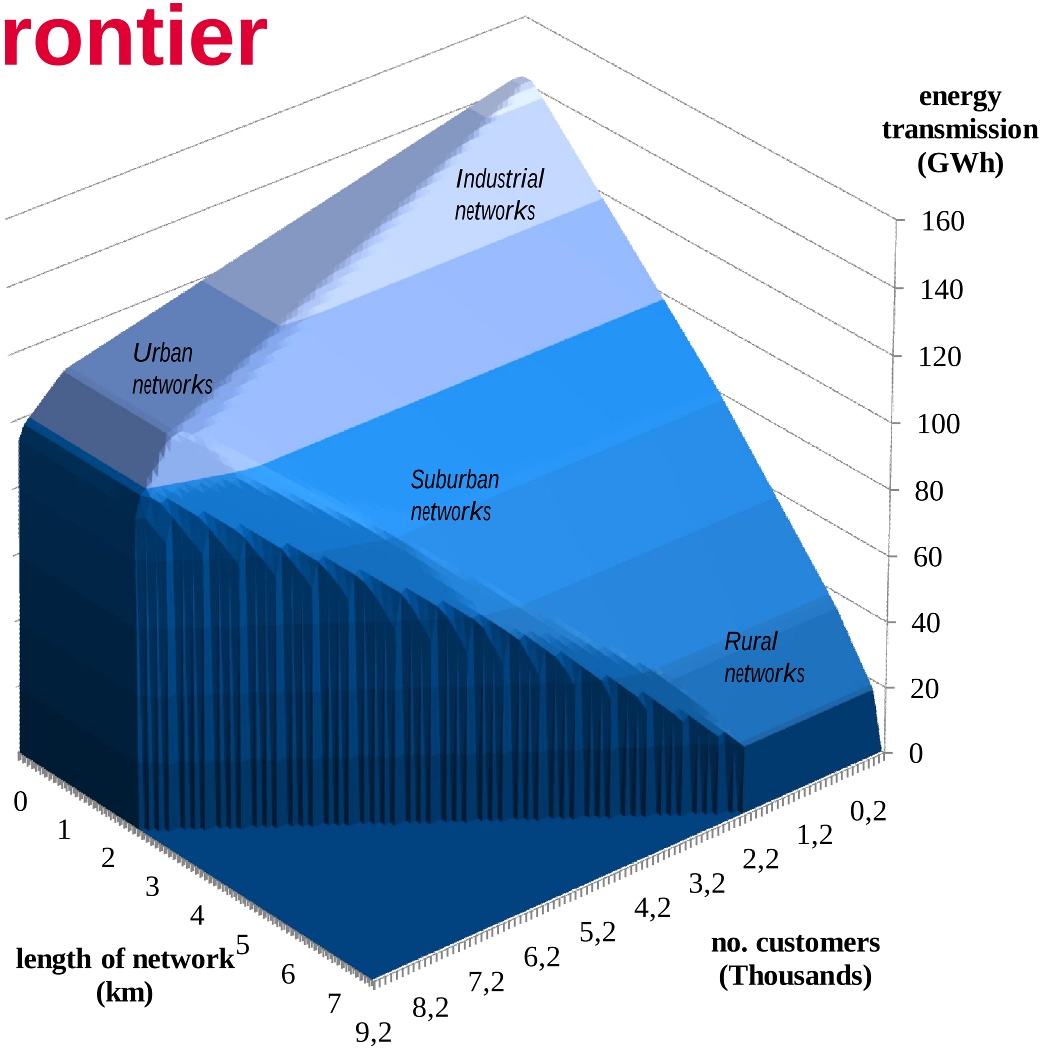
$$\hat{\sigma}_u = \sqrt[3]{\frac{\hat{M}_3}{\left(\sqrt{\frac{2}{\pi}}\right)\left[\frac{4}{\pi}-1\right]}}$$

Estimate the cost frontier as

$$\hat{C}^{StoNED}(y) = \gamma_i + \hat{\sigma}_u \sqrt{2/\pi}$$

Firm-specific efficiency estimates obtained by using Jondrow et al. (1982) result of the conditional expected value of u

StoNED frontier



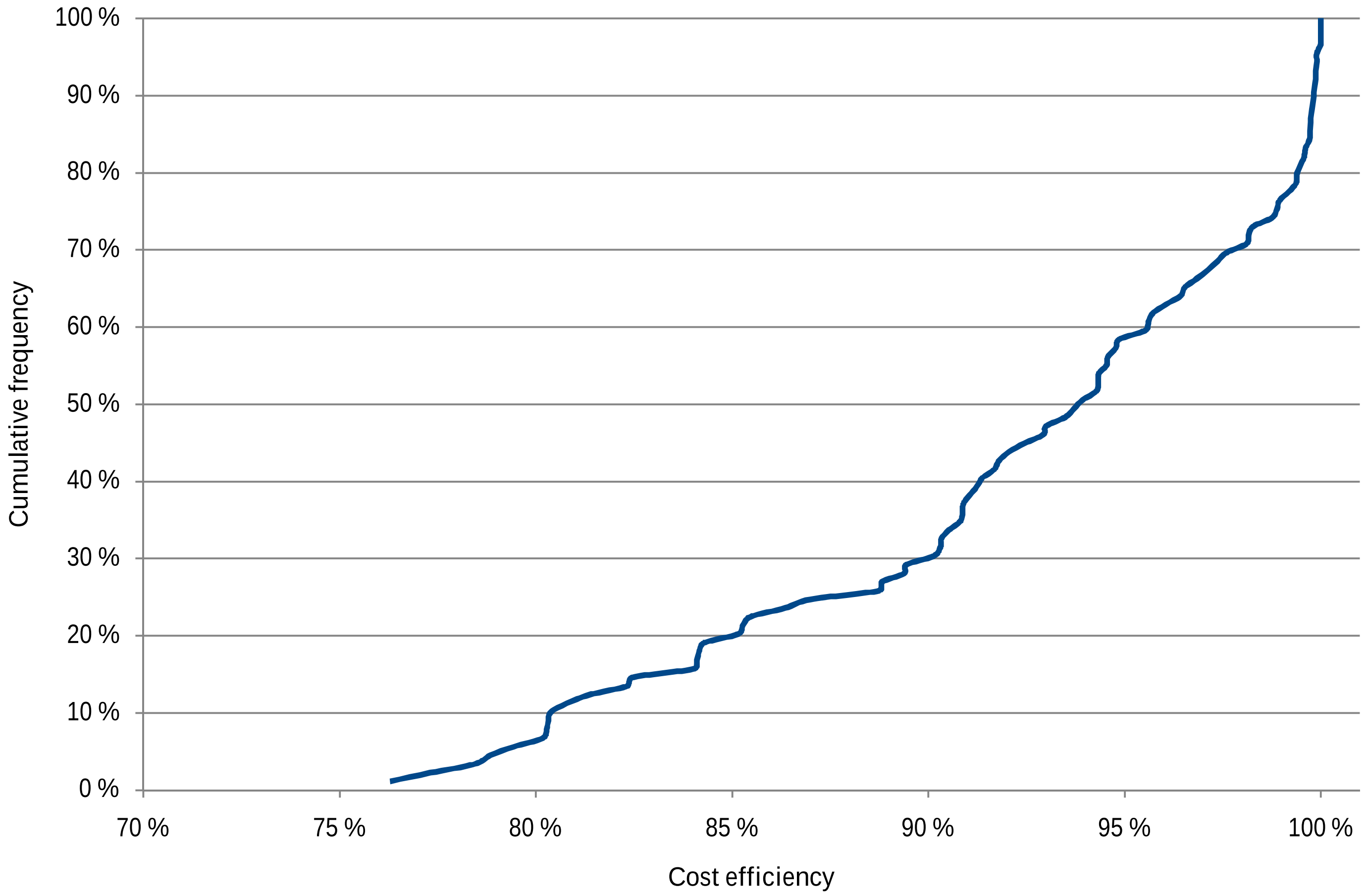
Estimated marginal costs (shadow prices)

	Energy transmission (c/kWh)	Length of network (€/km)	Number of customers (€/customer)
Average	0,4773	930,09	12,94
St. dev.	0,1222	172,09	18,33
Median	0,5686	985,44	0,00
Mode	0,6072	912,12	0,00
Min	0,0518	0,00	0,00
Max	0,6126	1045,25	76,36

Decomposition of inefficiency and noise terms (method of moments estimator)

Parameter	Estimate
σ^2 (variance of the composite error term)	0,0324
σ_u^2(variance of the inefficiency term)	0,0206
σ_v^2 (variance of the noise term)	0,0118
μ (expected value of the inefficiency term)	0,1146
Expected value of cost efficiency	89%

Distribution of efficiency estimates



Classification of networks based on marginal costs

Group	No. of firms	Energy transm. (c/kWh)	Length of network (€/km)	No. of users (€/user)	Average efficiency
1	11	0.6043	876.74	0.87	92 %
2	36	0.5597	984.94	1.23	92 %
3	3	0.4434	908.77	22.25	94 %
4	10	0.4566	1038.81	1.86	93 %
5	3	0.4200	970.69	21.00	92 %
6	4	0.3662	964.71	27.86	95 %
7	3	0.2929	232.21	60.11	92 %
8	7	0.3493	930.93	33.43	91 %
9	6	0.3324	983.05	29.61	90 %
10	6				96 %
Average		0.4773	930.09	12.94	92 %

Effect of underground cables (z)

Parameter	Estimate
δ coefficient	0,3600
standard error	0,0581
t-statistic	6,1942
p-value	0,0000
95% lower limit	0,2443
95% upper limit	0,4752
partial R^2	0,3060

Testing returns to scale

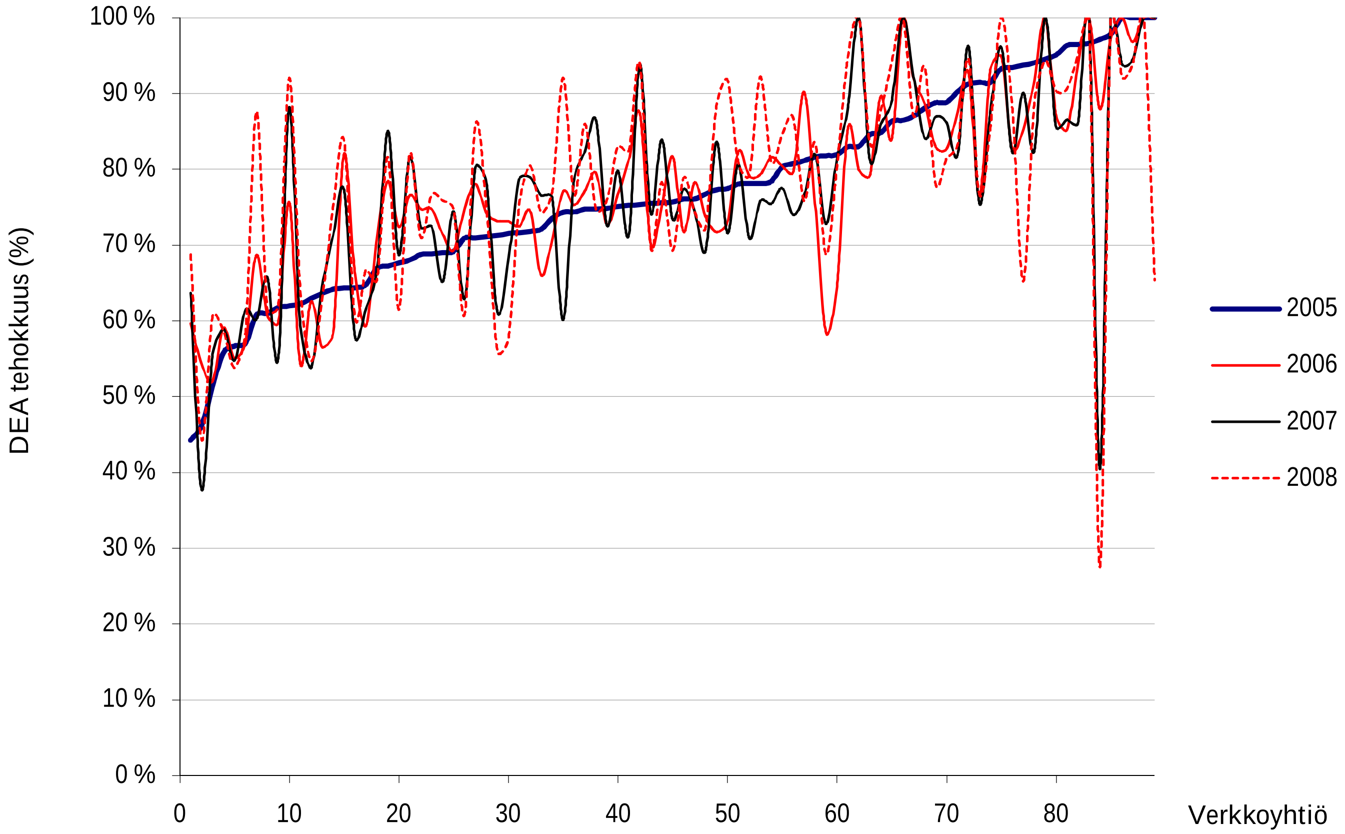
	R^2	δ	Correlation of residuals		
			CRS	NDRS	VRS
CRS	0.9864	0.3600	1	0.8994	0.8958
NDRS	0.9894	0.4162		1	0.9967
VRS	0.9895	0.4178			1

In the nonparametric Kolmogorov-Smirnov test, no significant difference in the distributions of residuals in the CRS and VRS specifications (p-value 0.937).

White test of heteroskedasticity

	Coefficient	*Standard error*	*t test*	*p-value*	*95% lower limit*	*95% up. limit*
Intercept	0.02330994	0.00365391	6.37945896	0.00000001	0.01603703	0.03058286
y_1	0.00002317	0.00003720	0.62280247	0.53520808	- 0.00005088	0.00009722
y_2	-0.00000186	0.00000217	-0.85516659	0.39504505	-0.00000618	0.00000247
y_3	-0.00000036	0.00000055	-0.65661224	0.51333846	-0.00000145	0.00000073
y_1^2	0.00000013	0.00000008	1.55179174	0.12470920	-0.00000004	0.00000030
y_2^2	0.00000000	0.00000000	0.73985628	0.46158022	-0.00000000	0.00000000
y_3^2	0.00000000	0.00000000	1.36147090	0.17723537	-0.00000000	0.00000000
$y_1 \times y_1$	-0.00000000	0.00000000	-1.23166070	0.22172957	-0.00000001	0.00000000
$y_2 \times y_3$	0.00000000	0.00000000	0.82568616	0.41146869	-0.00000000	0.00000000
$y_1 \times y_3$	-0.00000000	0.00000000	-1.41976830	0.15960933	-0.00000001	0.00000000
R^2	0.13901004					
F-test	1.41720497			0.19504303		
White test stat (nR^2)	12.3718936			0.19314624		

DEA efficiency estimates



Aalto University
School of Economics

Effect of normalization in parametric models (estimated by OLS)

3 tuotoksen malli	*ei normeerausta*		*normeeraus energian suhteen*		*normeeraus verkop. suhteen*		*normeeraus käyttäjämäärän suhteen*	
	VRS	CRS	VRS	CRS	VRS	CRS	VRS	CRS
vakiotermi (t€)	-27,39		122,53**		506,85**		682,50**	
Energia (snt/kWh)	0,28**	0,28**	0,87**	0,96**	0,49**	0,60**	0,44**	0,47**
Verkkop. (€/km)	895,21**	895,42**	881,63**	1016,66**	481,50**	1218,03**	476,06**	11488,26**
Käyttäjämäärä (€/käyttäjä)	95,28**	95,24**	11,79	-0,01	68,04**	43,46**	47,18	-1474,97**
Tehottomuuden odotusarvo	*100%*	*100%*	84%	70%	*100%*	*0%*	*100%*	*0%*
Selitysaste R^2	0,997	0,997	0,898	0,866	0,980	0,943	1,000	0,980

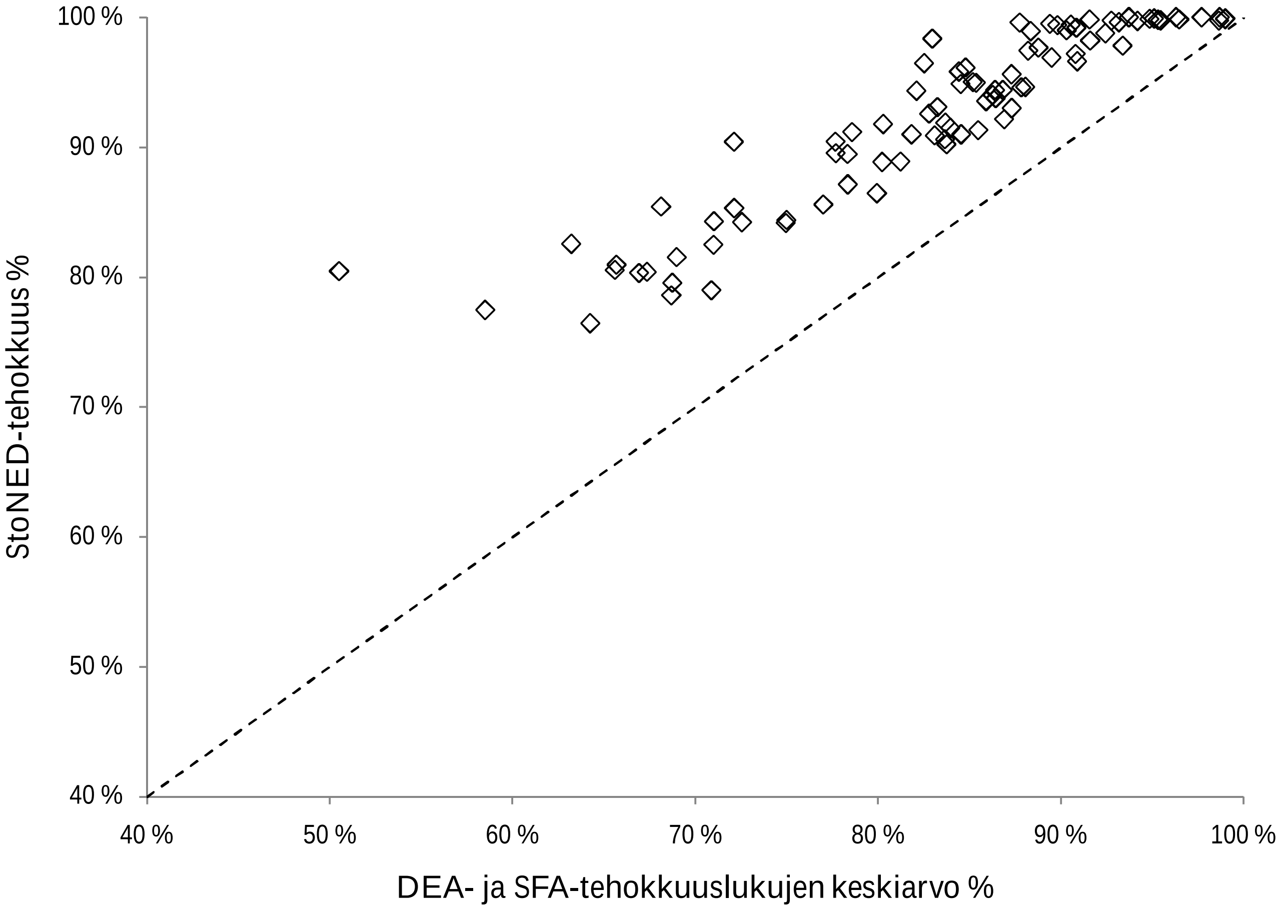
Effect of normalization in parametric models (estimated by OLS)

4 tuotoksen malli	*ei normeerausta*		*normeeraus energian suhteen*		*normeeraus muun verkon pituuden suhteen*		*normeeraus käyttäjämäärän suhteen*	
	VRS	CRS	VRS	CRS	VRS	CRS	VRS	CRS
vakiotermi (t€)	108,85		111,82**		-183,51**		713,27**	
Energia (snt/kWh)	0,08	0,09	0,90**	1,00**	0,56**	0,49**	0,44**	0,57**
Maakaap. verk. (€/km)	-534,79	-462,17	1067,59**	1464,38**	-994,90	-2445,20**	-279,20	16340,92**
Muu verkko (€/km)	1053,56**	1044,65**	854,50**	916,59**	1412,23**	1367,96**	578,94**	248,66
Käyttäjämäärä (€/käyttäjä)	113,82**	113,03**	10,50	-0,67	50,39**	56,00**	40,49	-62,62
Tehottomuuden odotusarvo	*100%*	*100%*	81%	72%	*0%*	*0%*	*100%*	*100%*
Selitysaste R^2	0,997	0,998	0,899	0,876	0,961	0,949	1,000	0,997

Correlations of efficiency estimates

	Pearsonin tulomomenttikorrelaatiokertoimet				Spearmanin järjestyskorrelaatiokertoimet			
	StoNED	DEA	SFA	ka*	StoNED	DEA	SFA	ka*
StoNED	1	0,9089	0,8956	0,9367	1	0,9338	0,8788	0,9498
DEA		1	0,8568	0,9726		1	0,8456	0,9732
SFA			1	0,9523			1	0,9329
ka*				1				1

Comparison of efficiency estimates



Efficiency improvement targets in Mill. € (prices of 2008)

	toimiala yht.	keskiarvo	keski-hajonta	minimi	maksimi
DEA	141,382	1,589	2,223	0,000	27,654
SFA	95,481	1,073	3,888	0,024	12,830
ka*	118,431	1,331	2,959	0,016	20,242
StoNED	47,508	0,534	1,326	0,000	11,113

Application of efficiency estimates in the regulatory model

Current model

$$SKO_{i,t} = \left(1+\Delta RKI_{t}\right)\times\left(1+\Delta K_{i,t}\right)\times\left(1-X_{yl}\right)\times\left(1-XV_{yr,i}\right)\times\left(SKO_{i,t-1}\right)$$

Proposed model

$$STOTEX_{i,t} = \left(1+\Delta RKI_{t}\right)\times\left(1-X_{yl}\right)^{t-2012}\times\hat{C}(y_{i,t},z_{i,t})$$

Allocating the efficiency improvement target to OPEX

Efficiency improvement target estimated based on TOTEX.

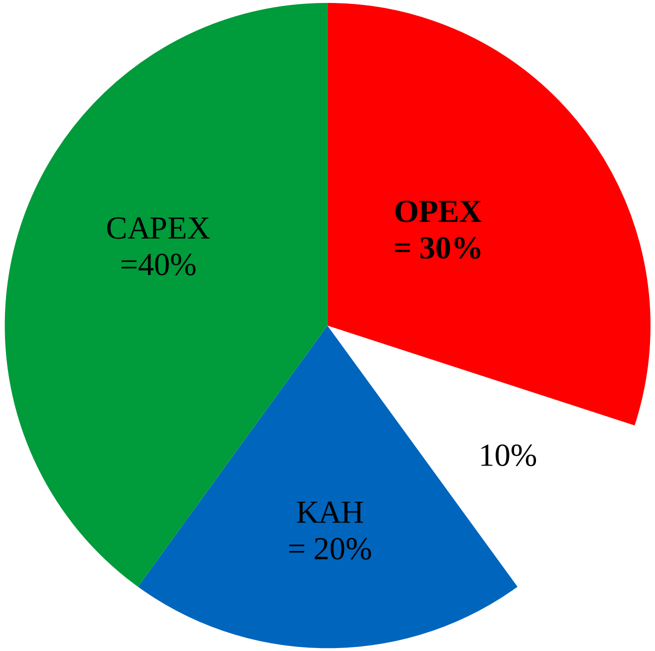
EMV adjusts the efficiency improvement target by multiplying it with the ratio OPEX/TOTEX.

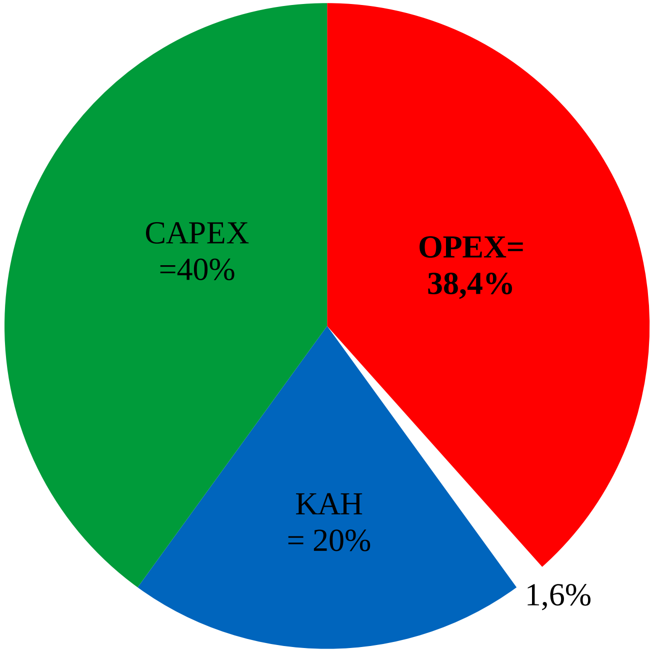
Example: Cost efficiency is 90%, improvement target 10%
OPEX / TOTEX = 40%

- EMV calculates the improvement target for OPEX as 10% x 40% = 4%
- This amounts to 4% x 40% = 1.6% of TOTEX

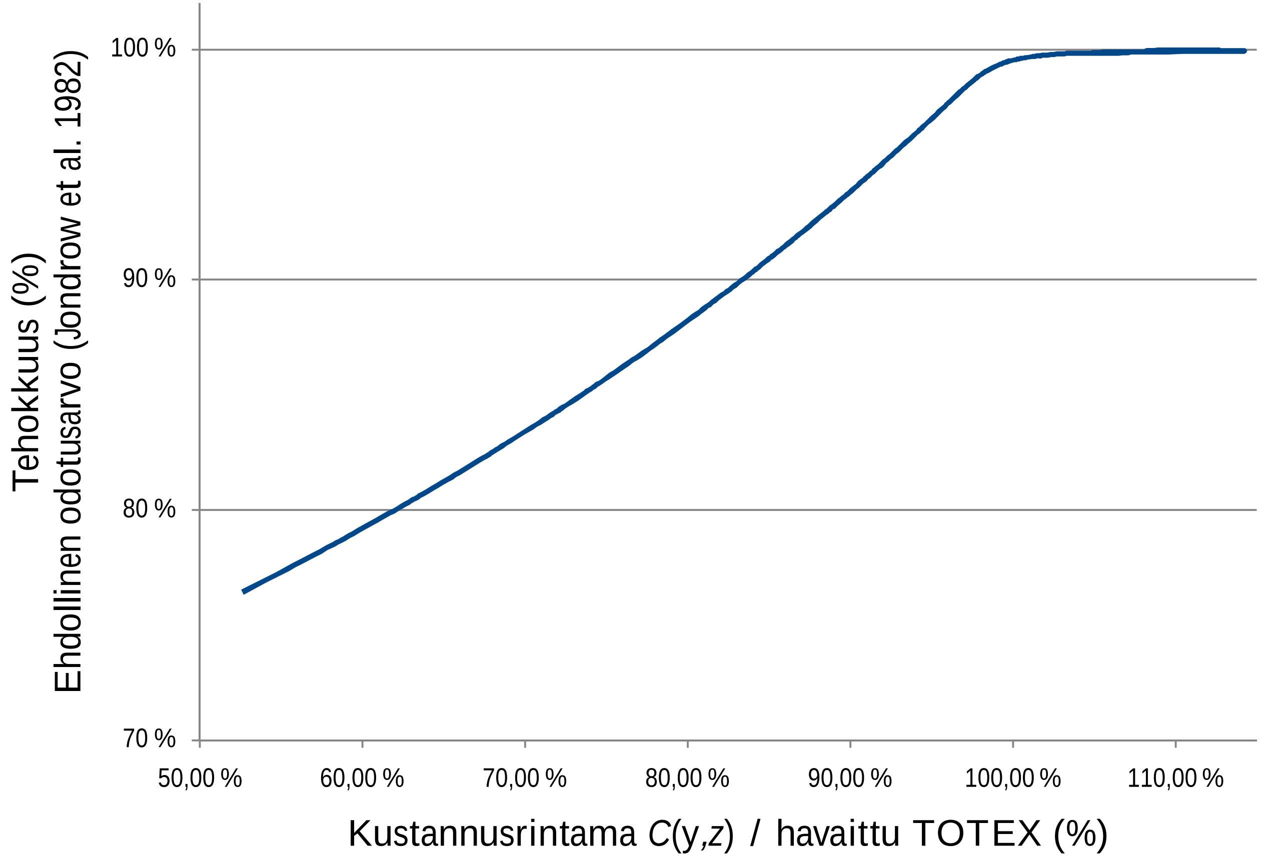
- In fact, the firm should decrease its OPEX by 10% / 40% = 25% to reach the 10% reduction of TOTEX

Electricity distribution example





Dynamic inconsistency of the efficiency improvement targets



Conclusions

Key advantages of the StoNED method include:

1) Stochastic noise is modeled explicitly in a probabilistic manner.
2) Heterogeneity of the firms and their operating environments is taken into account.
3) Conventional statistical tests and confidence intervals apply.
4) The method is relatively user-friendly compared to other semi-parametric alternatives.

Thank you!

The report available in Finnish at

www.energiamarkkinavirasto.fi

Aalto University
School of Economics
Helsinki, Finland