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Investment and efficiency in electricity distribution networks

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Outline

- Power sector reform
 - Regulation of electricity networks
 - Optimal regulation
- Regulatory treatment of investment
 - Ex-ante model
 - Ex-post model
- Investment under ex-post model
 - No-impact efficiency
- Empirical model
 - Constraints
 - Econometric version
 - Efficiency effect of investment
 - Model specification
 - Data
- Results
- Conclusions

Power sector reform

- Power sector reform in 1980s resulted in unbundling of different segments of the sector.
- Wholesale and retail markets were opened to competition but networks (transmission and distributions) remained natural monopolies.
- A natural monopoly needs to be regulated otherwise it can abuse its monopoly power.
- However regulation of networks is challenging because of information asymmetry.
- Regulatory model has implications for investment and consequently long term reliability of network, risk allocation, profitability of firm, incentive to minimise costs etc.

Regulation of electricity networks

- Regulator faces uncertainty about firms inherent cost opportunities (adverse selection) and managerial effort (moral hazard) (Joskow, 2006).
- Regulator needs to take both the social costs of adverse selection and moral hazard into account, subject to the firm participation or budget-balance constraint.
- Two polar regulatory models (Joskow, 2006):
 - A price cap (or revenue cap) regime can incentivise managerial effort because firm is the residual claimant of production and managerial effort cost reductions.

Regulation of electricity networks

- “Cost of service” regulation where the firm is compensated for all of the costs of production that it actually incurs.
- A fixed price mechanism may deal well with the potential moral hazard problem but poor at “rent extraction”.
 - ❑ Thus, it incurs the full costs of adverse selection.
 - ❑ Also, due to a firm financial viability constraint, regulator will have to set a relatively high fixed price if there is uncertainty.
- In cost of service regulation since regulator compensate firm for all of its costs, there is no “rent” left to the firm.
 - ❑ Thus, while the adverse selection problem can be solved, but the costs associated with moral hazard are fully realized.

Optimal regulation

- Given above, the optimal regulatory mechanism will lie somewhere between these two extremes (Joskow, 2006).
- A generic model is:

$$RE_t = C_t + \lambda(C_t^* - C_t) \quad (1)$$

- where RE_t is firm's revenue, C_t is the actual cost, C_t^* is efficient cost and λ is power of incentive.
- It represents the trade off between cost reduction incentives and rent transfer to the consumer.

Regulatory treatment of investment

- The problem of investment is challenging because of their size, lumpiness, and indivisibility.
- Two important factors considered when dealing with investment : *predictability and controllability*.
- There are various models of regulatory treatment of investment:
- However there are two main approaches:
 - Ex-ante model
 - Ex-post model

Ex-ante model

- Under the ex-ante model, regulated companies submit their business plans to regulator prior to the next regulatory period.
- The regulator scrutinises the submitted plan to verify prudence of investments.
 - using engineering reports, auditing, and cost-benefit analysis.
- Thus, under ex-ante model regulator needs to form an opinion, a priori, on the level and type of investments.
- Operating costs will be benchmarked (different treatment of operating and capital costs).

Ex-ante model

- At the end of the regulatory period, regulator evaluates deviations of actual investments from the investment plans.
 - ❑ It may disallow, partially or totally, the excess investments.
 - ❑ Likewise, in the case of downward deviation from projected investments, regulator might reward the firm.
- For example, under RII0-ED1 model in the UK firms will be rewarded if they deliver the same output with less investment (Ofgem, 2012).
- **Advantages:**
 - ❑ Less financial risk for the regulated company.
 - ❑ Easier to implement (compared with ex-post).

Ex-ante model

➤ Disadvantages:

❑ Interventionist

- ❖ The regulator needs to interfere in details of operation of companies.

❑ Gaming the regulator

- ❖ Risk of overinvestment by reporting high volume of work or overestimating demand.
- ❖ Capitalising operational expenditure.
- ❖ Delaying investment.

❑ The consumers are more likely to be exposed to the actual cost of firms rather than their efficient costs.

Ex-post model

- Under ex-post model, regulator sums all the costs incurred to the company to construct a single variable as total cost.
- The total expenditure is then benchmarked against peer companies in each regulatory review period using frontier based benchmarking methods such as COLS, DEA, or SFA.
- Thus, regulator does not need to form an opinion, a priori, on the type and scale of investments needed in the next regulatory period.

Ex-post model

➤ **Advantages:**

- It is less interventionist.
- The consumers are more likely to be exposed to the efficient cost rather than actual cost of firms.
- It promotes an indirect competition among the firms to reduce their cost to the efficient level.

➤ **Disadvantages:**

- It is risky for the firms because their revenue also depends on the behaviour of their competitor.
- The choice of benchmarking model and interpretation of results are not straightforward.

Incentive under ex-post model

- We analyse the relationship between investments and efficiency under incentive model (1) with ex-post regulatory treatment of investment.
- Dividing both sides of (1) with C_t yields:

$$RE_t = C_t[1 + \lambda(e_t - 1)] \quad (2)$$

□ where $e_t = \frac{C_t^*}{C_t}$ is the firms' efficiency in period t

- The change in a firm's revenue due to an investment (In) can be computed from equation (3).

$$\Delta RE = RE_2 - RE_1 = C_2 - C_1 + \lambda[C_2(e_2 - 1) - C_1(e_1 - 1)] \quad (3)$$

No-impact efficiency

- We substitute for C_2 ($\Delta C = C_2 - C_1 = In$) in the bracket and rearrange (3) as presented in (4).

$$\Delta RE = \Delta C + \lambda [C_1(e_2 - e_1) + In \times (e_2 - 1)] \quad (4)$$

Revenue effect of investments due to benchmarking

- Minimum efficiency level that firm require following investment to avoid cost disallowance :

$$e_{no-impact} = e_2 = \frac{C_1 e_1 + In}{C_1 + In} \quad (5)$$

Empirical model

- We estimate the efficiency of firms before and after investments along with 'no-impact efficiency'.
- We use an input distance function with a heteroscedastic inefficiency variance which are estimated simultaneously.
- Distance function has several advantages.
 - It allows us to estimate the efficiency of the firms when input price data is not available.
 - It does not depend on explicit behavioural assumptions such as cost minimization or profit maximization.
 - It can accommodate multiple inputs and outputs (Kumbhakar and Lovell 2000; Coelli et al., 2005).

Empirical model

- An input distance function can be defined as in (6):

$$D^I(x, y) = \max \left\{ \psi : \left(\frac{x}{\psi} \right) \in L(y) \right\} \quad (6)$$

- Where $L(y)$ represents the set of input vectors x that produce the output vector y , and ψ indicates a proportional reduction in input vector.
- The function has the following characteristics:
 - ❑ (i) it is linearly homogenous in x ,
 - ❑ (ii) it is non-decreasing in x and non-increasing in y ,
 - ❑ (iii) it is concave in x and quasi-concave in y , and
 - ❑ (iv) if $x \in L(y)$ then $D^I \geq 1$ and $D^I = 1$ if x is on the frontier of input set.

Empirical model

- Input-oriented technical efficiency is the inverse of the distance function.

$$TE = 1/D^I(x, y), \quad 0 < TE \leq 1 \quad (7)$$

- We use a flexible functional form for (6):

$$\begin{aligned} \ln D_{it}^I = & \alpha_0 + \sum_{m=1}^M \alpha_m \ln y_{mit} + \frac{1}{2} \sum_{m=1}^M \sum_{n=1}^M \alpha_{mn} \ln y_{mit} \ln y_{nit} \\ & + \sum_{k=1}^K \beta_k \ln x_{kit} + \frac{1}{2} \sum_{k=1}^K \sum_{l=1}^K \beta_{kl} \ln x_{kit} \ln x_{lit} \\ & + \sum_{k=1}^K \sum_{m=1}^M \delta_{km} \ln x_{kit} \ln y_{mit} + \theta_1 t + \frac{1}{2} \theta_{11} t^2 + v_{it} \end{aligned} \quad (8)$$

Constraints

- Homogeneity:

$$\sum_{k=1}^K \beta_k = 1 \quad \sum_{l=1}^K \beta_{kl} = 0 \quad k = 1, 2, \dots, K$$

- Symmetry

$$\alpha_{mn} = \alpha_{nm} \quad m, n = 1, 2, \dots, M, \quad \text{and} \quad \beta_{kl} = \beta_{lk}, \quad k, l = 1, 2, \dots, K$$

Econometric version

- Imposing the homogeneity by deflating $K - 1$ inputs by K th input (we use other cost (C_1) to deflate) :

$$\ln D_{it}^I - \ln x_{Kit} = f[(\ln x_{kit} - \ln x_{Kit}), \ln y_{mit}, t] + v_{it} \quad (9)$$

- We rearrange the above equation as:

$$-\ln x_{Kit} = f[(\ln x_{kit} - \ln x_{Kit}), \ln y_{mit}, t] + v_{it} - u_{it} \quad (10)$$

- Where $\ln D_{it}^I = u_{it}$ represents the non-negative technical inefficiency. The error components have the following distributions.

$$v_{it} \sim iid N(0, \sigma_v^2) \quad \text{and} \quad u_{it} \sim iid N^+(0, \sigma_u^2) \quad (11)$$

Efficiency effect of investment

- We model heteroscedastic inefficiency variance (σ_u^{2het}) as:

$$\text{Log}\sigma_u^{2het} = \rho_0 + \rho_1\text{Log}(In) + \rho_2\text{Log}^2(In)$$

$$\sigma_u^{2het} = \exp(\rho_0 + \rho_1\text{Log}(In) + \rho_2\text{Log}^2(In)) \quad (12)$$

- And separate heteroscedastic variance into its homoscedastic component (σ_u^{2hom}) and the element related to investments.

$$\begin{aligned} \sigma_u^{2het} &= \exp(\rho_0) \exp(\rho_1\text{Log}(In) + \rho_2\text{Log}^2(In)) = \\ &\sigma_u^{2hom} \times \exp(\rho_1\text{Log}(In) + \rho_2\text{Log}^2(In)) \end{aligned} \quad (13)$$

Efficiency effect of investment

- In terms of estimation, equations (10) and (12) are estimated simultaneously based on the only observed data in (10).
- Having estimated them, homoscedastic inefficiency can be easily obtained as follows:

$$u_{it} \sim N^+(0, \sigma_u^{2hom} \times \exp(\rho_1 \text{Log}(In) + \rho_2 \text{Log}^2(In)))$$

$$u_{it} \sim N^+(0, \sigma_u^{2hom}) \times \exp(\rho_1 \text{Log}(In) + \rho_2 \text{Log}^2(In))$$

$$\hat{u}_{it} = \exp(\hat{\rho}_1 \text{Log}(In) + \hat{\rho}_2 \text{Log}^2(In)) \times \hat{u}_{before} \quad (14)$$

Model specifications

- Our model consists of two inputs and two outputs.
- The inputs are capital expenditure (In) and other costs (C_1). Outputs are “total number of customers” and “length of network” (a proxy for the size of service area).
- We also use three weather and geographical variables in order to capture the heterogeneity among firms.
 - Snow, wind and distance to coast, and forest productivity
- The firm specific technical efficiency is computed by:

$$e_1 = \exp(-\hat{u}_{before}) \quad \text{and} \quad e_2 = \exp(-\hat{u}_{after})$$

- “No-impact efficiency” is calculated using Equation (5).

Data

- Our dataset is an unbalanced panel of 129 Norwegian distribution companies observed from 2004 to 2010.
 - Norwegian networks are regulated based on (1) ($\lambda=0.6$)

Table 1: Descriptive statistics

Variable Description	Name	Min.	Max.	Mean	Std. Dev.
Inputs					
Other costs*	<i>C₁</i>	1205.25	1178987	41260.63	67709.02
Capital expenditures*	<i>In</i>	6.82083	121042.4	13113.12	17518.02
Outputs					
Network length (Km)	<i>NL</i>	14	8111	558.27	779.13
Number of customers (#)	<i>CU</i>	18	515152	13054	26964
Geographical variables					
Snow condition	<i>snow</i>	0	1193.61	372.64	196.54
Wind /distance to cost	<i>wind</i>	0	0.1610	0.0164	0.0289
Forrest productivity	<i>forest</i>	0	0.5489	0.1566	0.1197

Results

Dependent variable: $-\text{Log}(C_1)$		
Variables	Coefficient	Std. Err
<i>Constant</i>	-5.799***	(0.911)
<i>Log(CU)</i>	0.428*	(0.233)
<i>Log(NL)</i>	0.625***	(0.218)
<i>Log(In)</i>	-0.924***	(0.170)
$0.5\text{Log}^2(\text{CU})$	0.235***	(0.025)
$0.5\text{Log}^2(\text{NL})$	0.134***	(0.049)
$0.5\text{Log}^2(\text{In})$	-0.073***	(0.016)
<i>Log(CU) * Log(NL)</i>	-0.159***	(0.036)
<i>Log(CU) * Log(In)</i>	-0.007	(0.020)
<i>Log(NL) * Log(In)</i>	0.026	(0.020)
<i>t</i>	-0.010	(0.010)
$0.5t^2$	0.011***	(0.003)
<i>snow</i>	0.075***	(0.021)
<i>wind</i>	0.022***	(0.005)
<i>forest</i>	0.064***	(0.013)
<i>snow * Log(CU)</i>	-0.003	(0.029)
<i>snow * Log(NL)</i>	0.073**	(0.035)
<i>wind * Log(CU)</i>	-0.019**	(0.008)
<i>wind * Log(NL)</i>	0.014	(0.009)
<i>forest * Log(CU)</i>	0.077***	(0.023)
<i>forest * Log(NL)</i>	-0.067***	(0.024)
$\text{Log}(\sigma_u^2)$		
<i>Log(In)</i>	-1.801***	(0.684)
$\text{Log}^2(\text{In})$	-0.261**	(0.124)
<i>Constant</i>	-5.605***	(1.005)

Efficiency change following investment

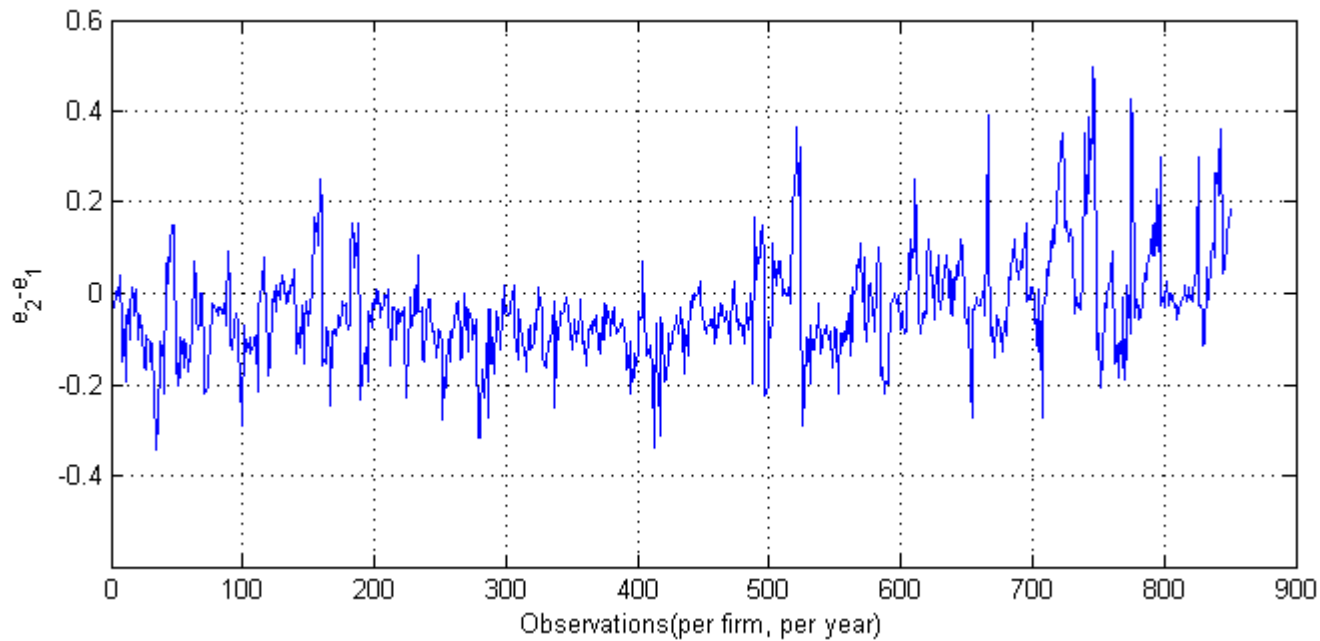


Figure 1: Efficiency change following investments

Distribution of efficiency change

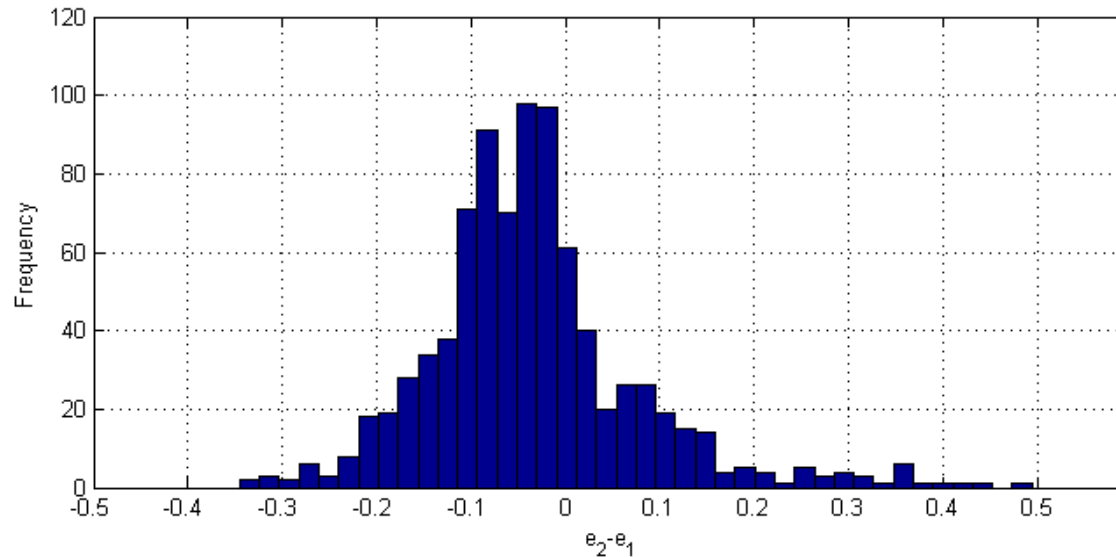


Figure 2: Distribution of efficiency change following investments

Mean	-0.035
Median	-0.043
Maximum	0.496
Minimum	-0.345
Std. Dev.	0.112

Which firms lost efficiency?

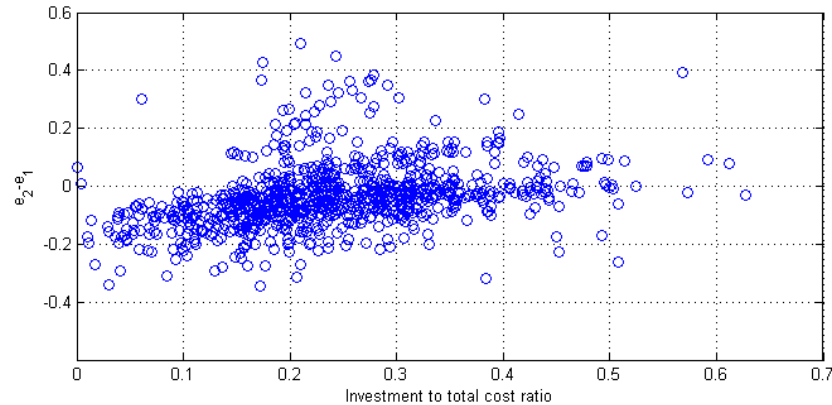


Figure 3: Efficiency change versus investments to total cost ratio

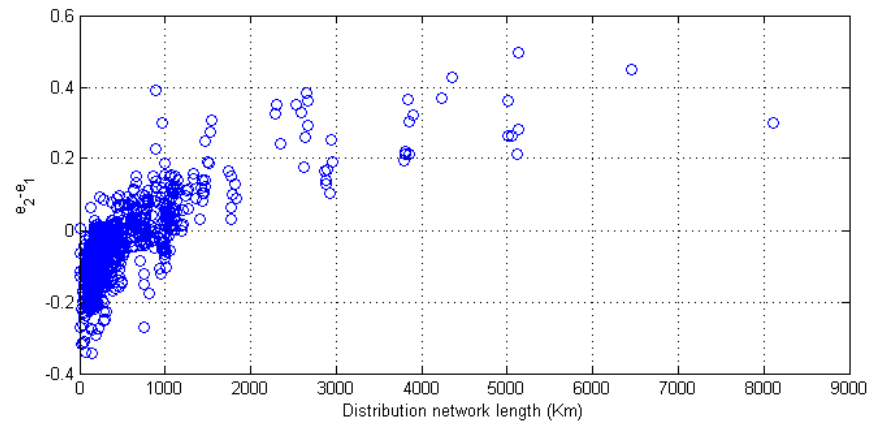


Figure 4: Efficiency variation versus network size (length)

Average 'before investment', 'after investment', and 'no-impact' efficiency

Table 2: Average 'before investment', 'after investment', and 'no impact' efficiency

Efficiency measured	2004	2005	2006	2007	2008	2009	2010
Average of e_1	0.951	0.953	0.948	0.949	0.947	0.946	0.943
Average of e_2	0.912	0.908	0.898	0.911	0.925	0.922	0.913
Average of $e_{no\ impact}$	0.962	0.965	0.960	0.962	0.962	0.962	0.959
Weighted average	$e_1 = 0.861$		$e_2 = 0.963$		$e_{no\ impact} = 0.899$		

Conclusions

- Ex-post regulatory treatment of investment based on (1) has improved investment efficiency of the Norwegian network companies.
- The results show that the weighted average efficiency gain of the networks from investments is 10%.
- However, the relationship between investment and efficiency is not straightforward.
- Efficiency loss following investments is mainly related to the smaller networks.
- The effectiveness of ex-post model relies on the reliability of benchmarking results which can be vulnerable to harmonised over- and under-investments.

Thank you for your attention!