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Investment and efficiency in electricity distribution networks

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Power sector reform

- Power sector reform in 1908s resulted in unbundling of different segments of the sector.
- Wholesale and retails 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:

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

- ❑ 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 RIIO-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:

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

  - 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).

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

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).

$$\Delta RE = \Delta C + \lambda \underbrace{[C_1(e_2 - e_1) + In \times (e_2 - 1)]}_{\text{Revenue effect of investments due to benchmarking}} \qquad (4)$$

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

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

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 serval 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):

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

- 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.

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

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

$$lnD_{it}^I = \alpha_0 + \sum_{m=1}^{M} \alpha_m \, lny_{mit} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \alpha_{mn} \, lny_{mit} lny_{nit}$$

$$+ \sum_{k=1}^{K} \beta_k \, lnx_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \, lnx_{kit} lnx_{lit}$$

$$+ \sum_{k=1}^{K}\sum_{m=1}^{M} \delta_{km} \, lnx_{kit} lny_{mit} + \theta_1 t + \frac{1}{2}\theta_{11} t^2 + v_{it} \qquad (8)$$

Constraints

- Homogeneity:

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

- Symmetry

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

Econometric version

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

$$lnD_{it}^{I} - lnx_{Kit} = f[(lnx_{kit} - lnx_{Kit}), lny_{mit}, t] + v_{it} \qquad (9)$$

- We rearrange the above equation as:

$$-lnx_{Kit} = f[(lnx_{kit} - lnx_{Kit}), lny_{mit}, t] + v_{it} - u_{it} \qquad (10)$$

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

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

Efficiency effect of investment

- We model heteroscedastic inefficiency variance (${\sigma_u^2}^{het}$) as:

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

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

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

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

$${\sigma_u^2}^{hom} \times exp(\rho_1 Log(In) + \rho_2 Log^2(In)) \quad (13)$$

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:

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

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

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

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) (λ=0.6)

Table 1: Descriptive statistics

Variable Description	Name	Min.	Max.	Mean	Std. Dev.
Inputs					
Other costs*	C_1	1205.25	1178987	41260.63	67709.02
Capital expenditures*	In	6.82083	121042.4	13113.12	17518.02
Outputs					
Network length (Km)	NL	14	8111	558.27	779.13
Number of customers (#)	CU	18	515152	13054	26964
Geographical variables					
Snow condition	$snow$	0	1193.61	372.64	196.54
Wind /distance to cost	$wind$	0	0.1610	0.0164	0.0289
Forrest productivity	$forest$	0	0.5489	0.1566	0.1197

Results

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

Efficiency change following investment

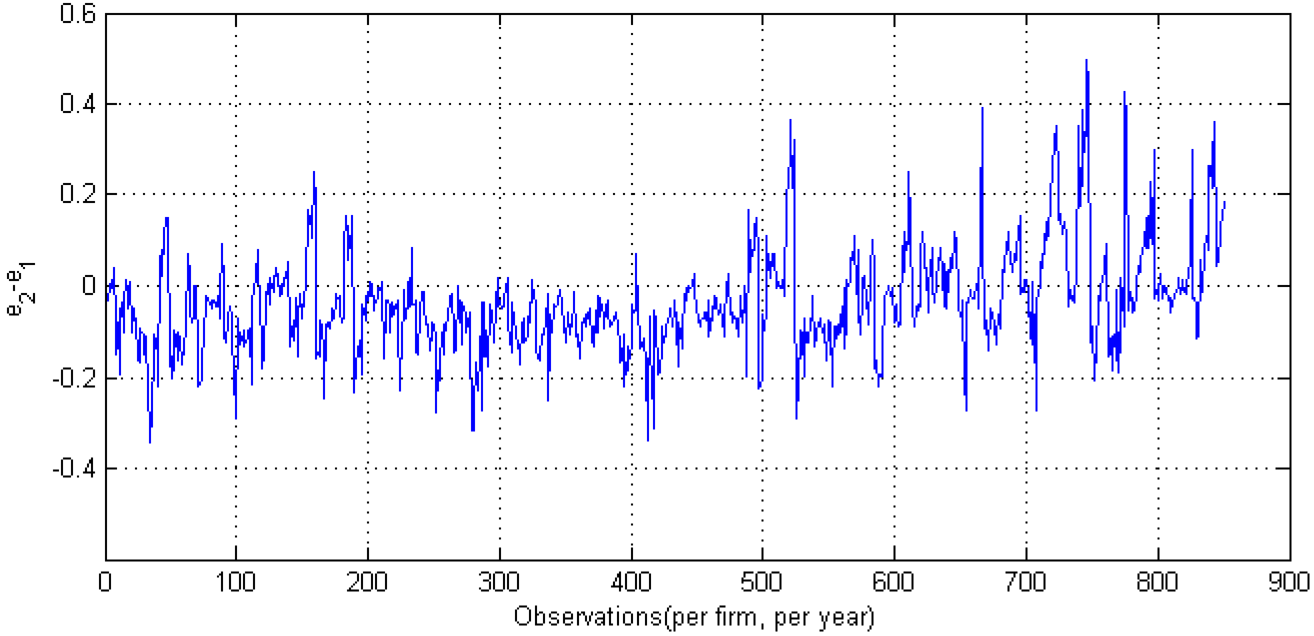

Figure 1: Efficiency change following investments

Distribution of efficiency change

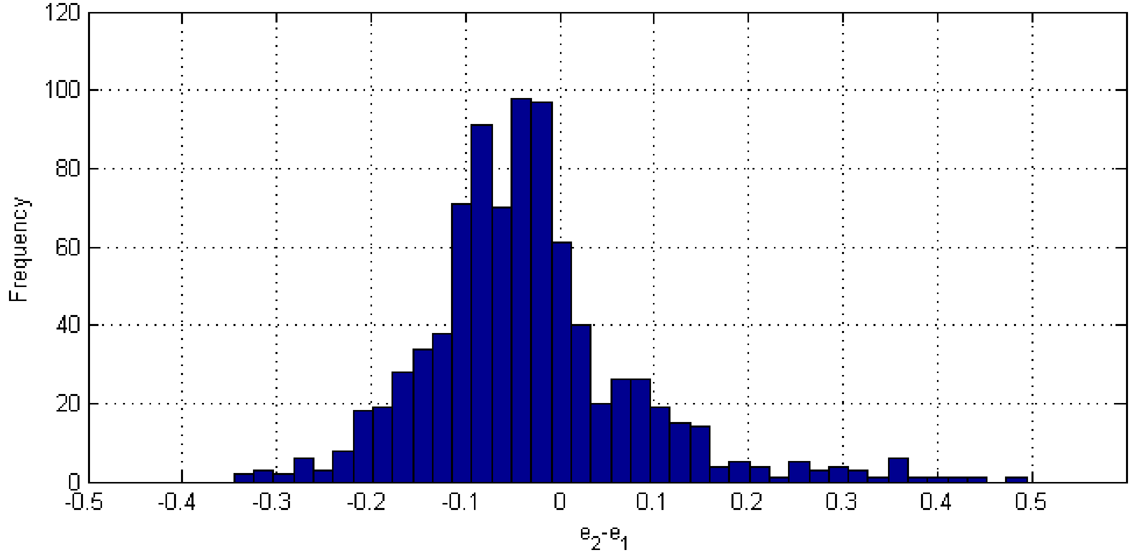

Figure 2: Distribution of efficiency change following investments

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

Which firms lost efficiency?

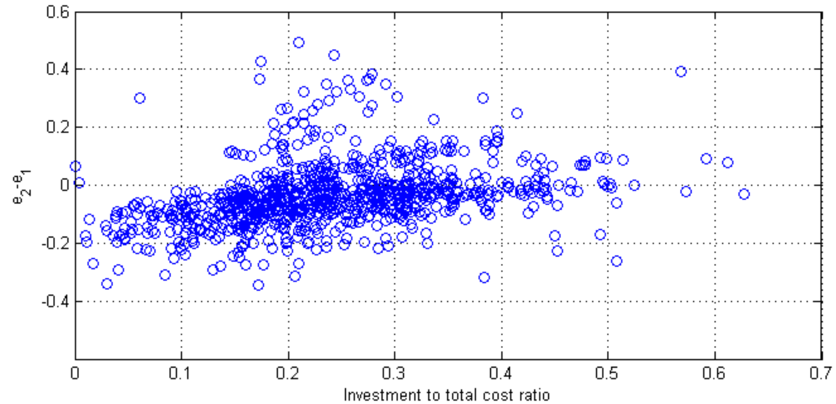

Figure 3: Efficiency change versus investments to total cost ratio

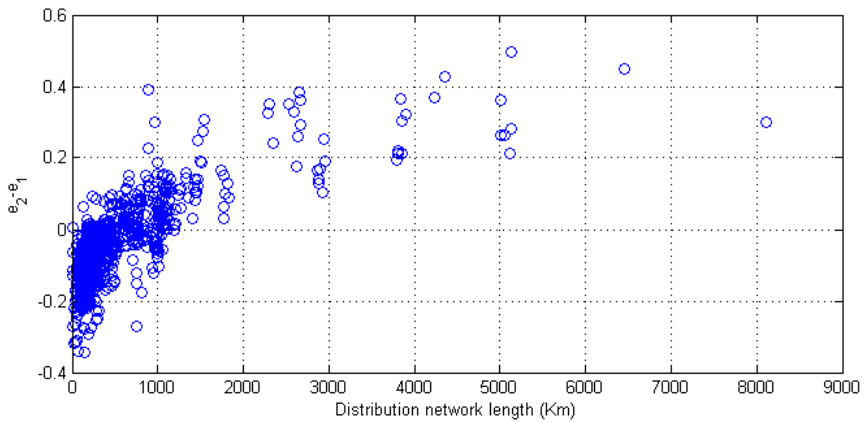

Figure 4: Efficiency variation versus network size (length)

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!