Empirical Analysis of Dynamic Efficiency and Innovation in Power Distribution Networks: The Case of Norway

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Introduction

Achieving a sustainable energy economy is highly dependent on decarbonising the electricity sector. The power network as the core of industry requires a transformation through expansion, adoption of new technologies etc. Such transformation can only be reached through substantial investments. The incentive regulation links investment with static cost efficiency of the firm in order to deter the possible overcapitalisation. This measure of cost efficiency is only appropriate for short run as it capture the firm's performance in a snapshot towards its long run equilibrium. Power network companies are working in a dynamic environment and invest in order to realise their long term objectives. The current incentive regulation incentivises investment through return on capital and at the same time accentuates the short run cost efficiency. As the investment is a long run objective and static efficiency is a short run concept these instruments send inconsistent signals to the regulated firm. This potentially limits the firms' ability for investment and innovation.

Methodology

Following Coelli and Perelman (1996) we define an input distance function as in (1).

$$D^I(x,y,t) = max\left\{\gamma: \left(\frac{x}{\gamma}\right) \in L(y)\right\} \qquad (1)$$

where $L(y)$ represents the input vectors x that can produce the output vector y at time t and γ indicates the proportional reduction in input vector. If $x \in L(y)$ then $D^I \geq 1$ however, $D^I = 1$ if x is on the frontier of input set. The technical efficiency is $TE_{it} = 1/D^I(x,y,t)$. Taking the logarithm of both sides and imposing the homogeneity of degree one by deflating $K-1$ inputs by Kth input will lead to an econometric version of this relationship as in (2).

$$-\,logx_{Kit} = logD^I_{it}\left[\left(\frac{x_{kit}}{x_{Kit}}\right), y_{mit}, t\right] + v_{it} + \log(TE_{it}) \qquad (2)$$

where v_{it} is a normally distributed idiosyncratic error term.

The logarithm of distance function can be written in terms of an estimable linear function of $\boldsymbol{x}_{it}$ and a vector its coefficients $\boldsymbol{\beta}$ as in (3).

$$y_{it} = \boldsymbol{x}'_{it}\boldsymbol{\beta} + v_{it} + \log(TE_{it}) \qquad (3)$$

As in Emvalomatis et al. (2011) we assume the following autoregressive process for the efficiency by making non-linear transformation of inefficiency as in (4), (5) and (6).

$$s_{it} = \log\left(\frac{1-TE_{it}}{TE_{it}}\right) \qquad (4)$$

$$s_{it} = \delta + \gamma s_{it-1} + u_{it} \qquad (5)$$

$$s_{i1} = \mu_1 + u_{i1} \qquad (6)$$

$$u_{it} \sim N(0,\sigma_u^2) \quad \text{and} \quad u_{i1} \sim N(0,\sigma_{u1}^2)$$

where s_{it} the ratio of inefficiency to efficiency and γ is an elasticity that measures the percentage change in inefficiency to efficiency that is transferred from a period to the next. Equation (6) initialises the stochastic process and assumes stationarity. Under this condition the two additional parameters can be obtained by (7) and (8).

$$\mu_1 = \frac{\delta}{1-\rho} \qquad (7)$$

$$\sigma_{u1} = \frac{\sigma_{u1}^2}{1-\rho^2} \qquad (8)$$

If the process is not stationary then the expected value of the firm efficiency over time goes to unity or zero. In a similar manner, the expected value of s_{it} goes to positive and negative infinity.

We need to estimate the parameters of hidden state model (5) and measurement equation (9) with only observed data in (9).

$$y_{it} = \boldsymbol{x}'_{it}\boldsymbol{\beta} + v_{it} + \log(TE_{it}) + \omega_i \qquad (9)$$

$$\omega_i \sim N(0,\sigma_i^2)$$

Thus, assuming s_i is the of $T \times 1$ vector of the latent state variable for firm i, we set up the likelihood function for the vector of all parameters, $\boldsymbol{\theta} = [\boldsymbol{\beta},\ \sigma_v, \delta, \rho, \sigma_u,\ \sigma_w]\,'$as follows:

$$\begin{aligned} p(\boldsymbol{y},\{\omega_i\},\{s_i\}|\boldsymbol{\theta},\boldsymbol{X}) &= p(\boldsymbol{y}|\{\omega_i\},\{s_i\},\beta,\sigma_v,\boldsymbol{X}) \times p(\{s_i\}|,\delta,\rho,\sigma_u) \\ &= \frac{1}{(2\pi{\sigma_v}^2)^{\frac{NT}{2}}} exp\left\{-\frac{\sum_{i=1}^N\sum_{t=0}^{T-1}(y_{it}-\omega_i-\boldsymbol{X}'_{it}\beta - logTE_{it})^2}{2\sigma_u^2}\right\} \\ &\times \frac{1}{(2\pi{\sigma_{u0}}^2)^{\frac{N}{2}}} exp\left\{-\frac{\sum_{i=1}^N(s_{i0}-\delta_0)^2}{2\sigma_{u0}^2}\right\} \\ &\times \frac{1}{(2\pi{\sigma_u}^2)^{\frac{N(T-1)}{2}}} exp\left\{-\frac{\sum_{i=1}^N\sum_{t=0}^{T-1}\left(s_{it}-\delta-\rho s_{i,t-1}\right)^2}{2\sigma_u^2}\right\} \\ &\times \frac{1}{(2\pi{\sigma_\omega}^2)^{\frac{N}{2}}} exp\left\{-\frac{\sum_{i=1}^N\omega_i^2}{2\sigma_\omega^2}\right\} \end{aligned} \qquad (10)$$

Which $\boldsymbol{y}$ and $\boldsymbol{X}$ represents the vector and matrix of independent and dependent variable respectively and δ_0 and σ_{u0}^2 are the mean and variance of s_{i1} in equation (6). The last term in likelihood function captures the heterogeneity effects.

The joint posterior density of the parameters, firms' effects and latent state using Bayesian rule can be obtained by (11).

$$\pi(\boldsymbol{\theta},\{\omega_i\},\{s_i\}|\ y,X) \propto p(y,\{\omega_i\},\{s_i\}|\theta,X) \times P(\boldsymbol{\theta}) \qquad (11)$$

We use social cost as single input (Soc) and number of customer(NC), length of network (LN) , distributed energy (DE) as outputs. We specify the following specification to estimate dynamic efficiency.

$$\begin{aligned} &-\log(Soc) \\ &= \beta_0 + \beta_1\log(NC) + \beta_2\log(LN) + \beta_3\log(DE) \\ &+ \frac{1}{2}\beta_4 log^2(NC) + \frac{1}{2}\beta_5 log^2(LN) + \frac{1}{2}\beta_6\log^2(DE) \\ &+ \beta_7\log(NC)\log(LN) + \beta_8\log(NC)\log(DE) \\ &+ \beta_9\log(LN)\log(DE) + \omega_i + \xi_1 t + \frac{1}{2}\xi_2 t^2 + v_{it} \\ &- logTE_{it} \end{aligned} \qquad (12)$$

Social costs include the cost of negative externalities. We use a dataset comprising a balanced panel of 128 Norwegian distribution companies from 2004 to 2010.

Table1: Estimation results

Variable	Simple random effect		Correlated random	
	Mean	Std. Dev.	Mean	Std. Dev.
β_0	0.34205	(0.053887)	0.23665	(0.051422)
β_1	0.28762	(0.046698)	0.11701	(0.104343)
β_2	0.36065	(0.029827)	0.21606	(0.093205)
β_3	0.24970	(0.036858)	0.11259	(0.056200)
β_4	0.09727	(0.038841)	0.03807	(0.070256)
β_5	-0.06312	(0.100805)	-0.28806	(0.182883)
β_6	-0.06084	(0.053950)	-0.21201	(0.071650)
β_7	-0.02394	(0.072697)	0.01034	(0.125549)
β_8	-0.00349	(0.030478)	-0.01356	(0.046992)
β_9	0.04121	(0.052897)	0.20701	(0.090193)
ξ_1	0.00007	(0.000210)	0.03050	(0.003544)
ξ_2	0.00000	(0.000000)	-0.00002	(0.000006)
σ_v	0.03418	(0.003877)	0.03899	(0.003730)
δ	0.26944	(0.057608)	0.46890	(0.106928)
ρ	0.76600	(0.038328)	0.69766	(0.064994)
σ_u	0.24952	(0.027429)	0.28747	(0.036909)
σ_ω	0.12275	(0.010901)	0.11816	(0.009491)
Long run TE	0.75832		0.82424	
Log likelihood	1071.00		1163.80	
Posterior probability	0.00000		0.00000	

Conclusion

The results of estimation show the ρ is less than unity (77 and 70% in simple random effect and correlated random effect respectively) which implies that the sector is approaching towards the long run equilibrium rapidly. The expected value of long run efficiency is also 76 and 82% in each estimation which suggests that the persistence of inefficiency is inevitable. This also complies with the adjustment cost theory of investments that says it is to the benefit of the firm to remain partially inefficient in presence of adjustment cost. The incentive regulation however, emphasises the static cost efficiency. The firms' investments are encumbered indirectly such that deviation from the sector best practice (measured by static efficiency) in process of benchmarking and revenue setting results in partial disallowance of investment costs. This means that the current form of incentive regulation adopted in Norway as well as many other countries is inadequate to deal with investment and innovation.

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