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Productivity Growth and Efficiency Change in Electricity Distribution

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Productivity Growth and Efficiency Change in Electricity Distribution

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1. Introduction. The decade since privatisation of the UK electricity industry provides an important sample over which to measure productivity growth and efficiency change in electricity distribution. The core idea of incentive based RPI-X regulation is to stimulate productivity growth and the convergence of efficiency change amongst the distribution companies. The X factor may represent the regulator's estimate of the potential for productivity growth, and may also be an instrument for yardstick regulation of these regional distribution monopolies. The expectations generated by the privatisation programme are of large increases in productivity.

Several measures of this factor have been carried out. For example, O'Mahony (1999) estimates that labour productivity in UK electricity supply rose at an annual rate of 7 percent from 1990-96 while in comparison labour productivity in manufacturing rose by 3.5 percent per year in the same period. Several earlier studies (e.g. Burns and Weyman-Jones (1994, 1996, and 1998)) have used mathematical programming (DEA) or stochastic frontier model (SFM) analysis to evaluate this efficiency change in the regulated electricity distribution industry with conflicting results. In the immediate aftermath of privatisation productivity growth seemed not to differ markedly from pre-privatisation experience, but, subsequently, considerable improvement can be seen. This study uses Total Factor Productivity (TFP) growth measured for the regulated companies using Malmquist indices. The TFP allows for both technical change and efficiency change and incorporates quality of supply variables. Previous work suggests the possibility of a correlation between efficiency change and productivity growth on the one hand and the state of the business cycle on the other. The full decade sample allows us to measure these effects over a whole business cycle, and to infer conclusions about the relevance of the timing of periodic regulatory reviews.

2. Models for Measuring Productivity Growth. The standard analysis of productivity growth in economics starts from the growth accounting approach used by O'Mahony. Productivity change measures the rate of increase in outputs (y_t) relative to inputs (x_t) by estimating total factor productivity, TFP:

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$$TFP = \frac{\sum_{r=1}^{r=s} w_r y_r}{\sum_{i=1}^{i=m} v_i x_i} \quad [1]$$

Under the assumption that output and input markets achieve productive efficiency (output prices equal to marginal cost, input prices equal to value of marginal product), the weights, w_r and v_i , applied to outputs and inputs are estimated by output and input shares in total revenue and costs, resulting in the discrete Tornqvist index. Productivity growth (the proportional rate of change of TFP) spills over to consumers in aggregate, and it represents the shift over time of the production correspondence between inputs and outputs, i.e. technological change. The underlying assumptions are unlikely to apply to the analysis of privatised utilities in network industries both because of their residual market power, and because of their known history of productive inefficiency under state ownership.

Färe, Grosskopf and Lovell (1994) indicate how equation [1] can also incorporate efficiency change as well as technological change if a Malmquist index approach is used instead. This requires that the output and input weights are estimated directly, and the non-parametric programming methods of data envelopment analysis (DEA) are useful³ for this. A set of panel data on the outputs and inputs of different firms observed over time is needed, and this is found in the present application to the productivity growth of regional electricity distribution companies, RECs, in England and Wales over the period 1990-98. There are 12 of these companies whose prices are controlled by RPI-X regulation.

3. Data employed in the study. Real operating expenditure, OPEX, is used as a proxy for variable input quantity, and is defined as revenue minus operating profit, current cost depreciation, and exceptional items. Data were collected from the regulatory accounts of the RECs for constructing operational expenditure. This is deflated by a producer price index obtained from the *Office of National Statistics Economic Trends*. The regulatory accounts also include data on tangible fixed assets. Costs allocated to the distribution system at the 31st March of each year provide a value of the capital stock. This is transformed into real terms by deflating by the gross investment deflator (GID also from *Economic Trends*) to obtain KSTOCK

The annual Distribution and Transmission System Performance reports from OFFER⁴ contain data on area size, customer numbers, overhead circuit, underground circuit, number of transformers in commission, and aggregate capacity of the transformers. The Electricity Association provided data on the number of units distributed (GWh), and maximum demand. *Condition 9 Reports*

³ Alternatively stochastic frontier measurement (SFM) can be used to estimate the efficiency change component of productivity growth if relatively strong assumptions are made about the production function and error distribution, and attention is focused on single output production.

⁴ Office of Electricity Regulation, otherwise known as the Regulator

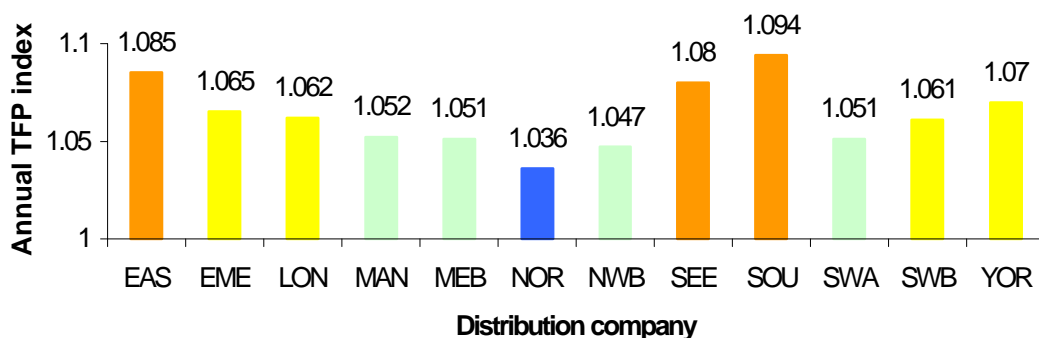
submitted by the distribution business to the regulator contain information on the quality of supply variables: supply interruptions per 100 customers, customer minutes lost per customer, and the number of interruptions per 100 customers not repaired within three hours.

4. The Models tested in the study. The basic model reported here is one of a set of possible input-output configurations. It incorporates three inputs: operating expenditure (OPEX), and the physical capital characteristics of the distribution network reflecting the total length of the distribution network in each of the REC's areas (NET), and the transformer capacity of each REC (CAP).

Distribution models have traditionally specified outputs as electricity units distributed across the network (UNITS), the number of customers served by each REC (CUST), and the maximum demand strain placed on each network (MAXD). All the models analysed in this study follow this approach.

Figure 1 describes mean annual total factor productivity growth for this model for each distribution business between 1990/91 and 1997/98. The industry attained average total factor productivity growth of 6.3%. However there are large variations within the industry. The results indicate a rapid increase in total factor productivity for some RECs, while others achieve a much slower increase. The annual increase of the total factor productivity index is 8.5%, 8%, and 9.4% respectfully for Eastern, Seeboard, and Southern. In contrast, Northern achieved modest productivity growth of 3.6% per annum. There were four companies who hovered around the industry average, and they were East Midlands, London, SWEB, and Yorkshire who accrued annual total factor productivity growth of 6.5%, 6.2%, 6.1%, and 7%. Manweb, Midlands, Norweb, and SWALEC were configured in a lower cluster rank ranging from 4.7% to 5.2%, considerably below the average rate of 6.3%.

Figure 1 Annual TFP growth between 1990/91 and 1997/98



Although figure 1 illustrates annual productivity growth, how does the total factor productivity index vary over this period? It would be useful to focus on the three clusters described above to see whether annual growth is consistent or has

changed between 1990/91 and 1997/98. Figure 2 below presents the total factor productivity results for Eastern, Seeboard, and Southern.

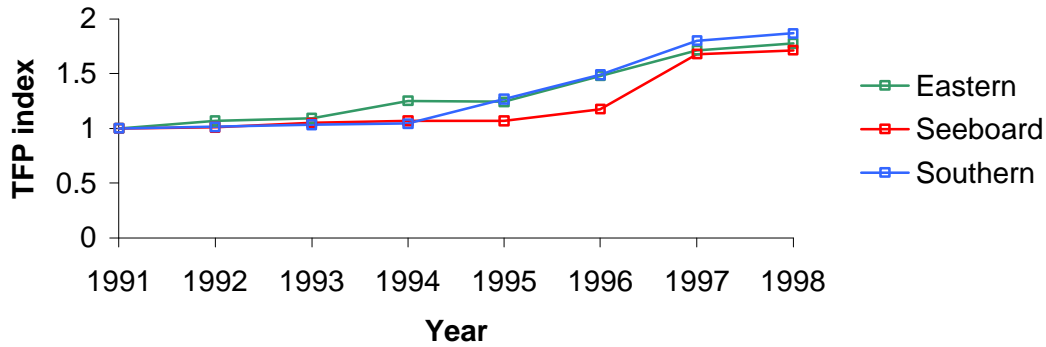


Figure 2 TFP index for the three leading performing distribution companies

Figure 3 TFP index for the middle ranking cluster of distribution companies

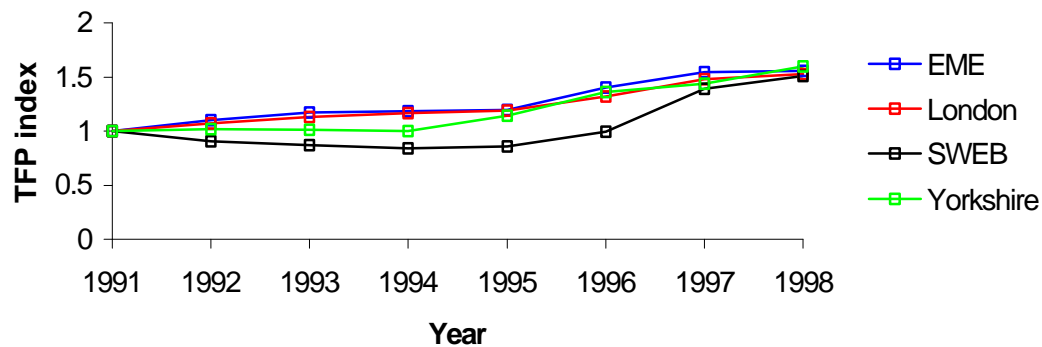


Figure 2 indicates that productivity growth for Eastern, Seeboard, and Southern is relatively flat from 1990/91 to 1992/93. Eastern start to increase the rate of total factor productivity in 1993/94, in contrast to Seeboard and Southern who continue to experience slow productivity growth. However it is clear that Southern significantly raise their rate of productivity in 1994/95 as the TFP index jumps from 1.046 in 1993/94 to 1.27, and this change in the rate of productivity is maintained until 1996/97. Seeboard experience a large jump in productivity as the TFP index increases from 1.18 in 1995/96, to 1.68 in 1996/97. Eastern continues to be a leading performer during the entire period since privatisation.

East Midlands, London, and Yorkshire display similar rates of productivity growth between 1990/91 and 1997/98. South Western electricity on the other hand display a different outcome. Initially the TFP index declines slightly between 1990/91 and 1993/94, but then increases rapidly particularly between

1995/96 and 1996/97. The performance of Manweb, Midlands, Norweb, and SWALEC is remarkably similar throughout the post-privatisation period as figure 4 demonstrates. Northern's performance shadows the trend of this cluster, but at a lower rate of productivity growth.

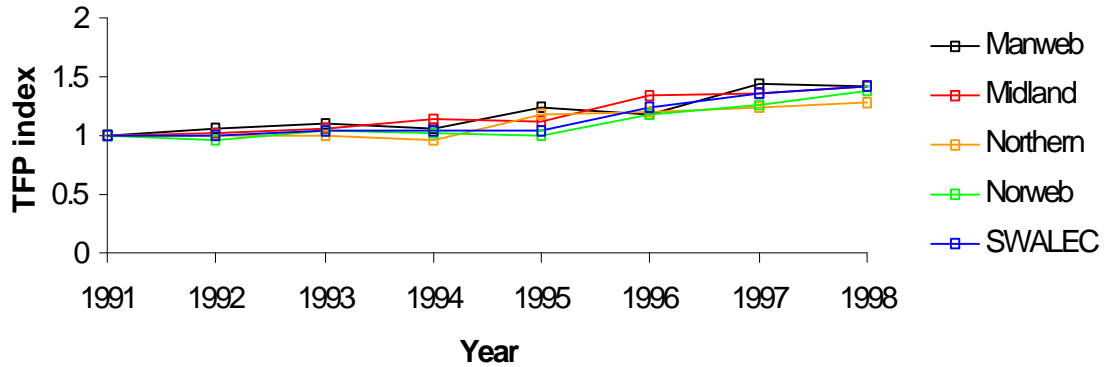


Figure 4 TFP index for the lower ranking cluster of distribution companies

Figure 5 presents annual productivity growth over the entire sample period and two sub-sample periods defined as 1990/91 to 1993/94 and 1994/95 to 1997/98. The general trend among distribution companies is for much faster productivity growth after the first distribution price review in 1994. Pollitt (1997) suggests that government protection from takeover of utilities after privatisation in the UK most probably reduced the pressure on distribution companies to remove costs. Utilities were able to reduce costs considerably after the government sold their golden shares in these companies. Alternatively Burns and Weyman-Jones (1998) interpret RPI-X incentive regulation as no more than a binding constraint on managers engaged in a principal-agent game with shareholders and argue that the relatively low productivity growth prior to 1994 reflects the lenient X-factor then in place.

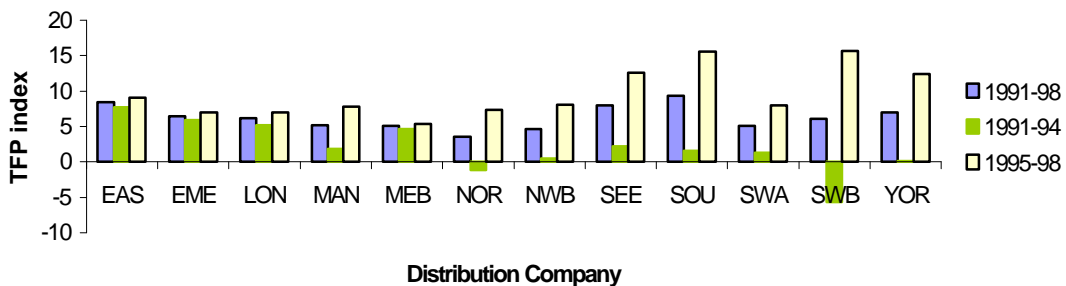


Figure 5 Productivity growth over different time periods for model 1

A downward trend in real OPEX from 1995/96 symbolises how distribution companies slim-lined their workforce, to improve shareholder value either as an independent company or as a function of an American holding company.

Productivity growth in the privatised electricity distribution industry is distinguished between innovation and diffusion of technology and best practice. It appears that all of the observed productivity growth is associated with the industry moving onto a higher frontier. Figure 6, in which the Malmquist index M is decomposed into efficiency change, MC , and technological change, MF , shows that in contrast, none of the productivity growth is due to improvements in efficiency. The relative importance of the frontier shift effect suggests that the industry as a whole is responding to the technical efficiency incentives of privatisation, but the different regional distribution companies are not experiencing the rivalry pressures which would ensure a greater number of RECs drew closer to the frontier.

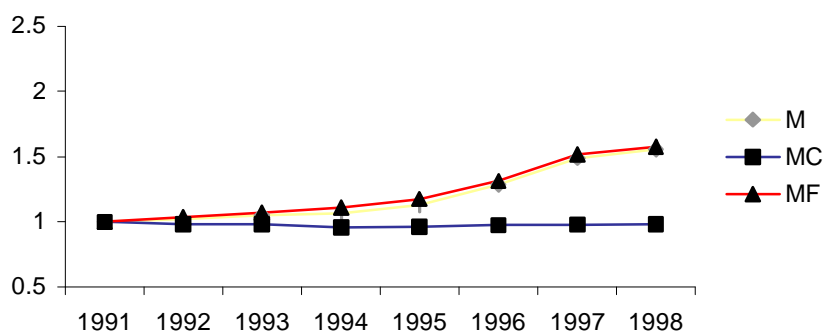


Figure 6 Malmquist indices for the average distribution company

Given the increases in productivity growth since 1994/95, it is difficult to believe that there has not been an increase in the concentration of the distribution businesses closer to the frontier. The process of privatisation which places more emphasis on managers to maximise profits, and a clearer incentive based regulatory system have encouraged the increase in technical efficiency across the industry. Yardstick competition envisaged by the regulator was supposed to increase incentives for managerial efficiency, and reduce the dispersion between the regions.

5. Panel Regression Analysis

The results⁵ can be used to investigate the sources of productivity growth. TFP indices for the twelve distribution companies are regressed against variables that may influence the rate of growth in a log-linear functional form. This does not require the use of limited dependent variable regression in contrast to a linear functional form where the TFP index will have to meet the condition of $TFP \geq 0$.

⁵ The results analysed in this section come from a similar but not identical model in which the capital inputs are proxied by the real value of the capital stock, $KSTOCK$.

Endogenous growth theory says that TFP growth depends on the variables in the model and the system. In the context of this study they are the economic institutions (timing of the regulatory price control review), input scale and output scale. A panel regression is constructed to investigate what factors contribute to TFP growth, and to test for a structural break after the second distribution price control. The number of observations in the panel is $[t \times n = 8 \times 12 = 96]$. Figure 7 describes the disaggregated TFP growth function. Output growth is the summation of input growth and TFP growth, and TFP growth is efficiency change plus technical change.

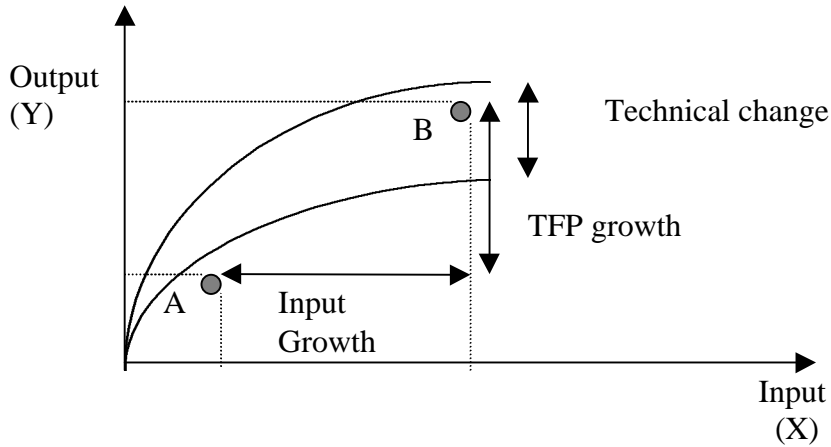


Figure 7 Endogeneous growth model

The model for each distribution company i is expressed as:

$$Y_{it} = \mathbf{a}_i^* + \mathbf{b}'x_{it} + u_{it} \quad [2]$$

where $[\mathbf{b}']$ is a $(1 \times K)$ vector of constants, $[\mathbf{a}_i^*]$ is a (1×1) scalar constant representing the effects of those variables peculiar to a distribution company, and $[u_{it}]$ explains the effects of omitted variables that are peculiar to individual distribution companies and time periods with the characteristics:

$$E(u_i) = 0, E(u_i u_i') = \mathbf{s}_u^2, E(u_i u_j') = 0 \text{ if } i \neq j \quad [3]$$

The fixed-effects model exhibits best linear unbiased estimates, while random effects assume there is correlation among residuals of the same distribution company. The covariance estimator from the fixed-effects model is unbiased, and is consistent especially when the time or cross-sectional observations are large.

An advantage of panel data is that if the effects of omitted variables are constant for a distribution company through time, this problem is eliminated by using dummy variables to capture the effects of individual-invariant and time-invariant variables. In panel data, the structure of the residuals is of interest. First the errors may be heteroscedastic across the cross-sectional properties. Three techniques are employed to test for groupwise heteroscedasticity, based on equality of variance across the cross-sections: Bartlett, Levene, and Brown-Forsythe. If there is evidence of groupwise heteroscedasticity, feasible generalised-least squares (FGLS) is applied to the panel regression.

The first panel regressed TFP⁶ against operating expenditure (OPEX), capital stock (KSTOCK), units distributed (GWH), maximum demand (MAXD), regulatory timing dummy (REG), customer density (CUSDEN), customer minutes lost (AVAIL), number of supply interruptions (SECUR), and the number of interruptions not restored after three hours (FAULT). The three tests of equality of variances between the distribution companies reject the null hypothesis of no cross-sectional heteroscedasticity at the 5% level of significance: Bartlett 33.4(0.0005), Levene 3.57(0.0004), and Brown-Forsythe 2.49(0.0092). Consequently FGLS estimators are used to correct for this.

Table 1 Panel Regression Results for Fixed Effects Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
OPEX	-0.003014	0.000129	-23.40091	0.0000
KSTOCK	-2.18E-05	6.35E-06	-3.430713	0.0010
GWH	1.23E-05	4.50E-06	2.726879	0.0080
MAXD	1.11E-05	1.16E-05	0.960921	0.3397
REG	0.013662	0.005598	2.440587	0.0170
CUSDEN	-3.17E-05	0.000174	-0.182294	0.8558
AVAIL	-1.04E-05	3.57E-05	-0.292005	0.7711
SECUR	-0.000231	0.000114	-2.022228	0.0467
FAULT	0.000699	0.000740	0.945344	0.3475

Generalised least squares fixed-effects panel regression (1)

The results show that real OPEX, capital stock and the number of supply interruptions are negatively correlated with log(TFP), whereas the number of electricity units distributed (GWh) is positively correlated with log(TFP). Furthermore the results support the view that there is a structural break in the TFP index after the second distribution price control in 1995. After 1995, the TFP index is significantly higher, and provides statistical support to comments made by Pollitt (1997) suggesting the government's holding of golden shares in the newly privatised electricity companies acted as a constraint on productivity, because there was no threat of takeover.

⁶ Both panel regressions have log(TFP) index as the dependent variable .

A Wald test is used to test the following restrictions on the coefficients of some of the variables:

$$\text{MAXD} = 0, \text{CUSDEN} = 0, \text{AVAIL} = 0, \text{FAULT} = 0$$

with test statistics $F = 1.22(0.31)$ and $\chi^2 = 4.89(0.3)$. Therefore removing these four variables will not significantly change the nature of the panel regression at the 5% level of significance.

A growing economy will increase the number of new business opportunities and create confidence for market players reflected in higher levels of investment. A knock-on effect of higher economic activity is an increase in the level of electricity demand. Therefore periods of high economic growth between 1993 and 1997 will impact favourably on the total factor productivity (TFP) index from the panel regression in table 1 above. Conversely when the economy is in a downward phase of the business cycle in 1991 and 1992 electricity units distributed can be expected to decline, thus having a negative impact on the (TFP) index. Table 2 reports the effect of using real GDP to explain TFP, and a similar effect is obtained if a relative business cycle variable is used instead⁷.

Table 2 Panel Regression Results for Fixed Effects Model with Business Cycle

Variable	Coefficient	Std. Error	t-Statistic	Prob.
OPEX	-0.003002	9.34E-05	-32.12958	0.0000
KSTOCK	-1.86E-05	3.65E-06	-5.094956	0.0000
GDP	2.64E-05	3.29E-06	8.023070	0.0000
REG	0.013445	0.003032	4.434511	0.0000
SECUR	-0.000125	4.61E-05	-2.699029	0.0085

Generalised least squares fixed-effects panel regression (2)

Following the procedures by Fare and Grosskopf (1996), the bias of technical change is decomposed into an output bias and an input bias. Input bias is unitary but most of the productivity gains caused by the frontier shift, which explain industry gains, are due to the presence of an output bias. This confirms that electricity output (kWh distributed) plays a significant part in the advancements in productivity.

6. Some Conclusions. The price control after privatisation allowed for higher revenues to be collected from customers to reinforce the network and capital stock increased considerably between 1990/91 and 1994/95. Therefore a conclusion

⁷ $output\ cycle = \frac{Y_{RT}^*}{Y_{RT}}$, where Y_{RT}^* is the fitted time trend of real GDP for region

that may be drawn is that the distribution companies have used the generous price cap to undertake investment in the local networks, and have presided over improvements to all three quality indicators. Progress in the quality of supply was greatest during the first year after privatisation, which coincided with very large increases in capital stock by the RECS averaging 24%.

The RECs appear to have compensated for a tightening in the price control by reducing capital stock in 1995/96 and 1996/97, which may be due to improvements in operating efficiency. The present price control includes a capital expenditure allowance of £2.30 per customer per annum at today's prices, for quality of supply measures. A survey in early 1999 for OFFER showed that customers were not prepared to accept reductions in quality levels.

More generally we can see that:

- productivity growth is still relatively dispersed which suggests more scope for yardstick regulation
- the business cycle impacts on measured productivity growth which makes forward looking regulation problematic
- calculation of relevant incentive based X factors will remain a difficult problem for the foreseeable future in the regulated network distribution industries.

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