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Productivity development of Norwegian electricity distribution utilities

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Abstract

When regulating electricity distribution utilities, estimates of the past productivity improvement performance are very important for future requirements. A piecewise linear frontier technology, reflecting observed best practice, accommodating the multi-output nature of distribution utilities is specified. A Malmquist index and its components, shift in frontier technology and change in efficiency, have been calculated for the period 1983 to 1989. The main results are a positive productivity growth averaging nearly 2% per year, and that this is mainly due to frontier technology shift. Outliers are scrutinised, but do not influence results for non-outliers. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

The electricity sector of Norway has undergone rapid changes in the regulatory regime during the last years creating a very market-oriented sector concerning production and consumption of electricity. However, local electricity distribution

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is a natural monopoly and must be subject to some form of regulation if one is to reduce monopoly profits and inefficiency. The new Energy law of 1990 distinguishes clearly between the competitive activities of production and supply on the one hand, and the regulated activities of transmission and distribution on the other. This article is only concerned with the distribution utilities.

The question of the efficiency of local distribution is a key issue when determining the cost basis for cost-plus-regulation, or when determining the price cap if the transportation of electricity is to be regulated by maximal prices. The change in maximal price or allowable costs over time could be based on an '$\mathrm{RPI} - x$' formula, where the productivity element, x, plays a crucial role in addition to general price or cost increases. [1] The Norwegian Water Resources and Energy Administration (NVE) as the regulatory body has therefore commissioned a study of the efficiency and productivity development of the distribution utilities as a first step in setting up a regulatory regime. [2] When selecting a regulatory regime, and in particular for productivity improvement targets, for Norwegian electric distribution utilities it is of great interest to have information on the past productivity record.

The purpose of the paper is to study the total factor productivity development of distribution utilities between the two years 1983 and 1989 based on individual data. The incentives facing the utilities were stable in this period, as both these years are before introduction of the new Energy law. The basic assumption is that the utilities can differ in efficiency, made possible by their status as local monopolies and due in part to different incentives and objectives among the mainly public sector owners, management and employees. Productivity development is then measured relative to the best practice production frontier, and split into change in efficiency, i.e., movement of the individual units relative to the frontier, and technical change, i.e., shifts in the best practice, or frontier function.

Electricity distribution produces multiple outputs, and not all of them are priced in the market. In this study we specify three outputs; a distance index expressing density of customers, the number of customers and the total energy supplied, and four inputs; labour, energy loss, capital and materials. Without prices, productivity change can still be calculated using Malmquist indices if one has some estimate of the production technology. An approach based on specifying a piecewise linear production frontier is easy to implement even when one has multiple outputs and inputs. A similar approach has been applied to US generating plants in Färe et al. (1990) and to Swedish distribution utilities in Hjalmarsson and Veiderpass (1992).

[1] $\mathrm{RPI} - x$ is the basic formula used in the maximum prices in England and Wales, where RPI is the retail price index and x is the regulators' target for productivity improvement. In practice, numerous other variables enter the formula.

[2] The main report from the project in Norwegian is Kittelsen (1994), which in addition to the results of this article also summarises Kittelsen (1993), Kittelsen and Torgersen (1993) and nine other working papers on technical efficiency, cost efficiency and various aspects of regulating distribution utilities.

The Malmquist indices are defined in Section 2, data presented in Section 3, and results set out in Section 4. Some concluding comments and policy implications are offered in Section 5.

2. The Malmquist indices

The technology set of the multi-output multi-input operation of a unit is in general terms defined by the production possibility set

$$P^t = \{(\boldsymbol{y},\boldsymbol{x}) | \boldsymbol{y} \text{ can be produced by } \boldsymbol{x} \text{ at time } t\} \tag{1}$$

where $\boldsymbol{y}$ is the vector of M outputs and $\boldsymbol{x}$ the vector of R inputs. To represent production, the set should have certain desirable properties such as being closed, and exhibit monotonicity, i.e., having free disposability of outputs and inputs (see, e.g., Färe et al., 1985). Such a technology set is sufficiently regular for Shephard distance functions (Färe et al., 1985) to exist. We find it convenient to express the distance functions in an equivalent way as the efficiency measures of Farrell (1957). We will be assuming constant return to scale, so the orientation of the efficiency measure, either input or output, does not matter for the values of the scores, but for the actual calculations the input orientation will be used. The Farrell efficiency measure for an input–output combination $(y_j^\tau,\ x_j^\tau)$ for observation j at time τ, with technology P^t from the year t can be expressed as:

$$E_{j\tau}^t = E^t\left(y_j^\tau, x_j^\tau\right) = \mathrm{Min}_\theta\left\{\theta | \left(y_j^\tau, \theta x_j^\tau\right) \in P^t\right\} \tag{2}$$

where the first equality defines a convenient shorthand notation. An efficiency measure of less than one means that the observation is inefficient when compared to the technology in period t, while a value greater than one implies that the observed input–output combination is not feasible with the reference technology. [3]

The productivity index is based on binary comparisons for a production unit between two time points (or between two different units at the same point in time, as in Berg et al., 1993). The time periods to be compared, are denoted 1 and 2 for short. Only quantities are involved, and at least one technology has to be known. As a convention we will compare a unit observed in period 2 with the same unit observed in period 1, i.e., expressions involving period 2 observations will be in the numerator and expressions involving period 1 observations will be in the denominator.

Caves et al. (1982) introduced productivity indices for discrete observations based on Malmquist (1953). The Malmquist productivity index, $M_{j1,2}$, for compar-

[3] The input distance function of Shephard (1953, 1970) is the *inverse* of the input efficiency measure of Farrell (1957) defined in Eq. (2).

ison between two time periods 1 and 2 for a unit j with frontier technology from period *1* as reference is: [4]

$$M_{j1,2}=M\left(y_j^1,x_j^1,y_j^2,x_j^2\right)=\frac{E_{j2}^1}{E_{j1}^1}=\frac{\mathrm{Min}_{\theta_2}\left\{\theta_2\middle|\left(y_j^2,\theta_2 x_j^2\right)\in P^1\right\}}{\mathrm{Min}_{\theta_1}\left\{\theta_1\middle|\left(y_j^1,\theta_1 x_j^1\right)\in P^1\right\}},1,2\in T \tag{3}$$

T is the set of time periods. The numerator shows the proportional adjustment, by the scalar θ_2, of the observed input vector of the period 2 observation required to be on the frontier function of the reference period 1 with observed outputs. The denominator shows correspondingly the adjustment by θ_1 of the observed input vector of period 1 for the observation to be on the same period 1 frontier function. Note that both measures may be greater than one, if the observation is not feasible within the technology in question. If $M_{j1,2}>1$, then the observation in period 2 is more productive than the observation in period 1. [5]

In the presence of inefficient observations change in productivity is the combined effect of change in efficiency and shift in the frontier production function. [6] Färe et al. (1994) [7] showed how the index used by Caves et al. (1982) in the case of inefficient observations could be decomposed when there are two time periods. [8] The Malmquist productivity index, $M_{j1,2}$, can be multiplicatively decomposed into two parts showing the catching up, $M_{\mathrm{C}j1,2}$, and the pure technology shift, $M_{\mathrm{F}j}^{1,2}$:

$$M_{j1,2}=\frac{E_{j2}^1}{E_{j1}^1}=\frac{E_{j2}^2}{E_{j1}^1}\cdot\frac{E_{j2}^1}{E_{j2}^2}=M_{\mathrm{C}j1,2}\cdot M_{\mathrm{F}j}^{1,2},1,2\in T \tag{4}$$

The catching-up effect, $M_{\mathrm{C}j1,2}$, expresses the relative movement of the observed unit to the frontier, a higher (lower) 'contemporary' efficiency score for the

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[4] Under the CRS assumption, the corresponding output-oriented index is the ratio between output-efficiency measures, defined by the inverse of maximal feasible scalar adjustment of the output vectors. It would be equal in value to the input-oriented index defined in Eq. (3). For simplicity, we omit subscripts that express the input-saving direction from all measures, and subscripts that express the reference period from the Malmquist indexes.

[5] In Färe et al. (1990), the inverse definition is used, i.e., improvement means that the index is less than one. Here we follow the original formulation of Caves et al. (1982).

[6] See, e.g., Nishimizu and Page (1982) for such a decomposition in the parametric frontier case.

[7] Originally circulated as a working paper in 1989.

[8] In the case of a fixed base technology, the frontier shift term has to be adjusted in order to obtain transitivity (see Frisch, 1936), as shown in Berg et al. (1992), and also applied in Kittelsen and Førsund (1992). Since we have only two time periods, the extended formulation does not apply. Note that in Färe et al. (1990) and Färe et al. (1994) a geometric mean is used. This means that it is the distance between the frontiers that is measured as a geometric mean between technologies 1 and 2 at both the two observations. Here we follow the original definition of Caves et al. (1982) of using Eq. (3). The geometric mean was introduced there in order to establish the connection between the Malmquist and the Törnqvist indices.

second period implying increased (decreased) efficiency. The frontier technology change is expressed by the ratio of the efficiency scores for the second period observation relative to the two technologies. The numerator expresses the scaling of period 2 inputs in order to be on period 1 technology, while the denominator expresses the scaling of the same input vector in order to be on period 2 technology, in both cases subject to period 2 observed outputs. This then serves as a measure of technology shift, and is greater than one if period 2 technology is more efficient relative to period 1 technology for the input–output mix of the period 2 observation.

2.1. DEA technology

So far the restrictions on the production technology have been quite general. However, the reason for the popularity of the Malmquist index in recent years is that Färe et al. (1994) demonstrated that distance functions for *piecewise linear* technology sets could easily be computed applying linear programming techniques as in DEA-type analysis. Changing now to the case of a piecewise linear frontier technology, the estimated production possibility set, P^t, is defined in the following way: Assuming a set of output indices Y and input indices X, and letting N_t be the set of observations in period t, imposing basic properties such as monotonicity, constant returns to scale (CRS), inclusion of all observations and minimum extrapolation (implying that the envelopment of best practice data is done as 'tight' as possible), the estimate of the production set is:

$$P^t = \left\{ (\boldsymbol{y},\boldsymbol{x}) \mid \sum_{m\in N_t} \lambda_m y^t_{mk} \geq y_k \; \forall k \in Y,\; x_l \geq \sum_{m\in N_t} \lambda_m x^t_{ml} \; \forall l \in X, \right.$$
$$\left. \lambda_m \geq 0, \forall m \in N_t \right\} \tag{5}$$

As in Färe et al. (1990), constant returns to scale is assumed. Since the Malmquist index calculated with this assumption is homogenous of degree 1 in $\boldsymbol{y}^2$ and $\boldsymbol{x}^1$, and homogenous of degree -1 in $\boldsymbol{y}^1$ and $\boldsymbol{x}^2$, the index can be interpreted as a total factor productivity (TFP) index (see, e.g., Grosskopf (1993) for discussion of adopting CRS when studying productivity change).

The programming approach originates with Farrell (1957) and was given its present form in Charnes et al. (1978), where the term Data Envelopment Analysis, DEA, was coined. Farrell efficiency scores $E^t_{j\tau}$ for unit j at time τ relative to the production set at time t are calculated by solving a linear program for each unit found by inserting the estimate of the production set (Eq. (5)) in the definition of the efficiency measure (Eq. (2)):

$$E^t_{j\tau} = \underset{\lambda,\theta}{\mathrm{Min}} \left\{ \theta \mid \sum_{m\in N_t} \lambda_m y^t_{mk} \geq y^\tau_{jk} \; \forall k \in Y,\; \theta x^\tau_{jl} \geq \sum_{m\in N_t} \lambda_m x^t_{ml} \; \forall l \in X, \right.$$
$$\left. \lambda_m \geq 0, \forall m \in N_t \right\} \tag{6}$$

The observations spanning the technology always belong to the same period (i.e., the units with index t). When the efficiency measure is calculated for an observation from another period than indicated by the technology index, the observation is not part of the set of observations defining the technology set, implying that the efficiency score may be greater than one.

The formulation of problem (Eq. (6)) implies that the benchmark technology is restricted to constant returns to scale, since no restriction on the sum of intensity weights is introduced. By introducing such restrictions DEA can also satisfy either non-increasing or variable returns to scale, see Grosskopf (1986), although the Malmquist index in that case cannot be interpreted as a TFP index. But when the performance of unit j is compared with a frontier generated from a sample excluding unit j, efficiency measures may not always exist in these formulations. Specifying CRS, as we do, is usually sufficient to ensure the existence of a solution to the LP problem in the input saving efficiency case. [9]

Kittelsen (1993) has found that an estimate of the variable returns to scale (VRS) production set for this data set is indistinguishable from the CRS estimate for most of the sizes observed, providing an additional reason for the assumption of CRS in this analysis.

3. Data

The data for the 181 electricity utilities engaged in local retail distribution is found in the official electricity statistics from Statistics Norway (see Statistisk sentralbyrå, 1991). The data for 1989 is documented and extensively studied in Kittelsen and Torgersen (1993). After eliminating utilities for which the data quality was insufficient, this analysis is based on 157 utilities in 1983 and 170 in 1989, all of which appear in the reference set of the respective years. Productivity indexes can only be calculated for the panel of 150 utilities which appear in both years. Data are used in quantities where available, but materials and capital are measured at fixed 1989 prices using sector and input specific price deflators from Statistics Norway (Statistisk sentralbyrå, 1991). Since metres are not usually read at the end of the year, and precise energy consumption therefore is measured with error, a weighted moving average is used to calculate the energy loss. [10]

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[9] If an input is strictly positive for all reference units from period t, then that input must be strictly positive also for the units to be measured from period τ. If output-increasing efficiency is adapted the frontier technology can be relaxed to constant and decreasing returns by introducing the restriction that the sum of weights shall be less or equal to one, as done in Färe et al. (1994).

[10] We only have observations of energy loss for the years 1983–1989, so truncated weighting is used, whereby the smoothed loss of 1983 is $(3\cdot \text{Loss}_{83}+2\cdot \text{Loss}_{84}+1\cdot \text{Loss}_{85})/6$ and the smoothed loss for 1989 is $(1\cdot \text{Loss}_{87}+2\cdot \text{Loss}_{88}+3\cdot \text{Loss}_{89})/6$.

The original data allow for numerous different specifications of inputs and outputs. In addition to the disaggregation of energy delivered by institutional sector and capital by type, there are a number of topographical and climatic differences between the regions to be served by each utility. Kittelsen (1993) has through a stepwise procedure used statistical tests of model specification to arrive at the set of included variables and level of aggregation used in this paper. [11] The information contained in a variable such as maximal power is in fact captured well in the interaction of the total energy delivered and the number of customers, since the average energy per customer is correlated with the number of residential household customers as a share of the total customer base, and this is again correlated with peak power (W) level compared to the average power level.

In principle the product of a distribution utility is a set of specific quantities of electricity transmitted to particular geographic locations. When aggregating to total energy and number of customers, one also needs an index to capture the extent of the geographical area to be served. Geography is a major cost driving factor since much of Norway is very sparsely populated. Geographic extent is clearly an output since an increase in the area served would either increase the use of resources or reduce the supply of other products. The distance index used is based on the populations' average travelling time to the municipal centres, and encompasses topographical difficulties such as mountains and water to be crossed as well as pure distance. Other studies have used the length of distribution lines to capture this aspect of the product, but since the actual network extent is an endogenous variable that can be more or less efficiently determined by the utility, our exogenous distance index is preferable. [12]

Average values for the three output and four input variables for the two years are given in Table 1, both for the complete samples and for the balanced panel. As local monopolies the quantities of energy and the number of customers are influenced by the utilities through the prices they set, but in practice the combination of compulsory delivery and inelastic demand makes it reasonable to view these product aspects as exogenous. The distance index is of course wholly external to the utilities. This makes it reasonable to use the input saving measures as the relevant direction of the productivity index.

Examining the change over the six-year period between the complete two yearly samples, we note for outputs that total energy delivered has had the largest increase of 31%, while the two other outputs have increased by half of that, implying increased energy consumption per customer, and benefits from economies of density. As to inputs, materials has increased the most with 33%, almost the

[11] In the stepwise analysis, two tests based on Banker (1993) are employed, in addition to an ordinary *t*-test. The model specification arrived at is reasonably robust with respect to type of test and level of significance.

[12] In addition, use of length of lines would have made this output automatically highly correlated with the capital input.

Table 1
Average output and input values for 1983 and 1989

	Whole sample			Balanced panel (150 units)		
	1983 (157 units)	1989 (170 units)	Change	1983	1989	Change
Outputs						
Distance index	74,294	87,292	17.5%	75,145	85,640	14.0%
No. of customers	5385	6376	18.5%	5437	6300	15.9%
Total energy delivered (MW h)	125,986	165,570	31.4%	127,889	162,244	26.9%
Inputs						
Labour (h)	54,828	62,682	14.3%	55,759	63,299	13.5%
Energy loss (MW h)	12,639	11,971	−5.3%	12,883	12,022	−6.7%
Materials (1000 NoK)	8138	10,806	32.8%	8274	10,570	27.7%
Capital (1000 NoK)	157,078	194,379	23.7%	159,145	190,366	19.6%

same rate as energy, while capital increases with 24% and labour with 14%, and most atypical a small *decrease* of 5% in energy loss. Reduced energy loss may result from investments in power lines and transformers, as well as change in weather conditions. The balanced panel averages follow closely those of the whole samples. The raw data indicates that we can expect productivity improvement on the average.

4. Empirical results

4.1. Overall impressions

We start with presenting summary statistics to give an overall impression of the results. Calculating Malmquist indices basing the reference technology on the year 1983 yields the main results set out in Table 2. The choice of the first year as basis

Table 2
Main results for productivity development from 1983(=1) to 1989(=2). Balanced panel (150 units)

	Index values			Annualised rates		
	Total productivity ($M_{j1,2}$)	Catching up ($M_{Cj1,2}$)	Frontier shift ($M_{Fj}^{1,2}$)	Total productivity ($M_{j1,2}$)	Catching up ($M_{Cj1,2}$)	Frontier shift ($M_{Fj}^{1,2}$)
Average	1.120	1.006	1.108	1.9%	0.1%	1.7%
Geometric average	1.084	0.988	1.098	1.4%	−0.2%	1.6%
Average unit	1.093	0.984	1.110	1.5%	−0.3%	1.8%
Minimum	0.709	0.598	0.600	−5.6%	−8.2%	−8.2%
Maximum	3.451	1.964	2.042	22.9%	11.9%	12.6%
Standard deviation	0.356	0.205	0.162			

seems natural when we have only two periods, and the basic question is whether there has been any change viewed from this year—a forward-looking approach. The frontier shift component M_F is calculated using the input–output mixes of period 2, i.e., the economically most relevant region of commodity space. Using the last period as technology basis would imply 'backward-looking,' and a geometric mean would mix the two types of information, and make an economic interpretation more difficult. The results will, of course, differ (see Berg et al., 1992 for an exploration of all types of bases), and the first period as a base produced results most close to the development believed to have taken place by the engineers working in the utilities following our project.

In the left panel of Table 2, numbers greater than one mean productivity growth, while numbers smaller than one show regress. The (unweighed arithmetic) mean values in the first row show that the total productivity development has been positive for those utilities that appear in both years, and that this is almost entirely due to positive shifts in frontier technology. Translated to yearly averages in the right panel of the table the frontier shift is between $1\frac{1}{2}$ and 2% per year while total productivity has grown by a bit more. The mean of relative efficiency M_C is just positive, implying that the efficiency of the distribution utilities on average is quite stable but with a slight catching-up tendency. The geometric averages reported in the second row of the table show a similar picture, except for turning the efficiency change component into a small lagging-behind, with the total productivity progress reduced to $1\frac{1}{2}$% per year.

The distributions of the productivity measures are represented by the means, with minimum, maximum and standard deviations in the last rows of Table 2. The large maximal values are striking, indicating improvement of 245% for one unit in total productivity, technology shift of 104% for another unit, and a catching-up of 96% for a third unit. Close inspections of the units with especially high values reveal that it is the reduction of energy loss that is the cause of these extreme observations. The sensitivity of the results for the remaining utilities will be the subject of Section 4.4.

A summary measure of the efficiency of the sector is provided by the productivity measures for the average unit, calculated as the arithmetic average input and output levels across observations. This way of measuring *structural efficiency* is the implementation of Farrell's notion of ''...the extent to which an industry keeps up with the performance of its own best firms'' (Farrell, 1957, p. 262), introduced in Førsund and Hjalmarsson (1979). The calculation is shown in the third row of Table 2. The results are almost identical to the means. [13]

[13] Note, as pointed out in p. 262 of Farrell (1957), this measure is not an average efficiency, but reflects ''the extent... to which production is optimally allocated between firms in the short run''. If we want an expression for possible total input savings if all units become efficient, see the generalisation of Farrell's weighted average of technical efficiencies to the industry efficiency measure in Torgersen et al. (1996).

4.2. Productivity distributions

Getting individual information on productivity development is the great advantage with our approach. The distribution of total productivity growth from 1983 to 1989 is portrayed in Fig. 1. The width of the histograms are proportional to the unit's share of total energy delivered in 1983, in order to exhibit a size-distribution dimension. As seen from inspecting units above and below the no growth line of one, most of the utilities have positive growth; about 66% of the energy is delivered by utilities with growth in productivity. There is a tendency for small units to be over represented at the negative growth part, but small units are also found at the extreme high growth tail representing less than 1% of capacity. The large and medium-sized units are concentrated closer to the no growth line from above, with one noticeable exception represented by one of the largest utilities having negative growth.

The efficiency, or catching-up, distribution is shown in Fig. 2. The tendency is here different. The share of units with efficiency development contributing positively to productivity growth represents about 40% of total energy, while utilities with negative efficiency development have about 45% of energy deliveries. There are also units with no change, representing 15% of energy, meaning that these units are on the frontier in both 1983 and 1989. This group is dominated by medium-sized units, while the worst performers are dominated by small units, representing 10% of energy. Notice also that the upper tail (representing less than 1% of energy) is dominated by small units.

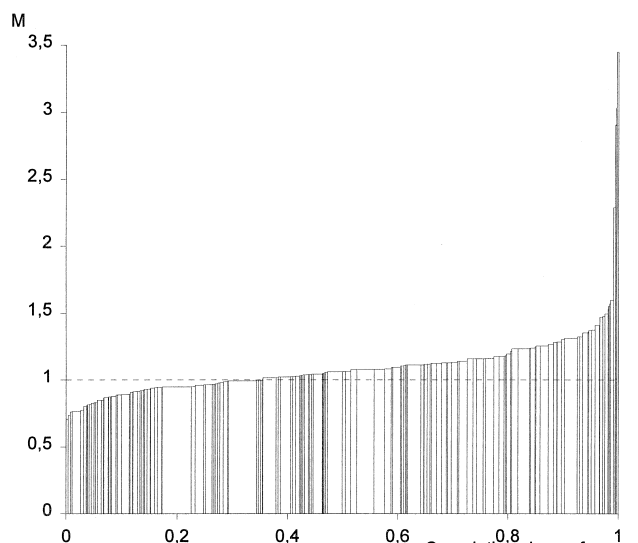

Fig. 1. Distribution of the Malmquist total productivity growth index, $M_{j1,2}$.

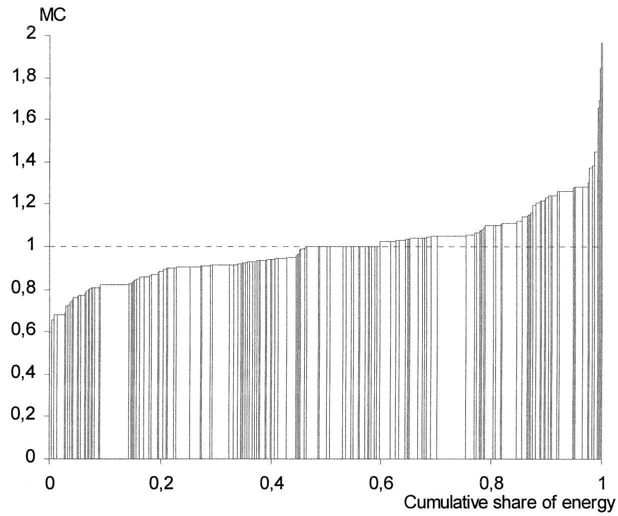

Fig. 2. Distribution of the Malmquist catching-up index, $M_{\mathrm{C}\,j1,2}$.

The impact of the shifts of the frontier function is clearly illustrated in Fig. 3. The lion's share of units representing 78% of total energy deliveries has experienced a positive contribution to productivity growth due to shift of the frontier technology. Of these units, 24 are efficient in 1989, and are the firms that actually have shifted the frontier. It is difficult to see any systematic effect of size, but we

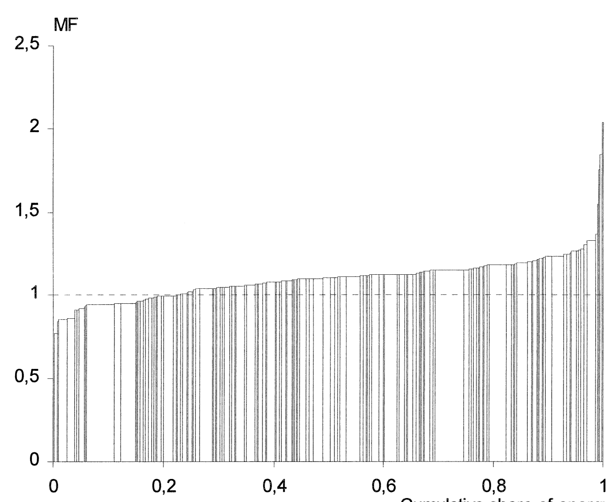

Fig. 3. Distribution of the Malmquist frontier shift index, $M_{\mathrm{F}j}^{1,2}$.

notice that a couple of large units have experienced a negative contribution from technology shift.

4.3. Joint distributions

In order to see more than one dimension of the productivity distribution simultaneously the total distribution is shown together with the efficiency distribution in Fig. 4, together with the frontier shift distribution in Fig. 5, and the two components of productivity together in Fig. 6. The horizontal and vertical lines of one divides the units into four quadrants with different combinations of growth and decline. For example, in Fig. 4 the first quadrant contains units with both positive total productivity growth and contribution from catching-up, the second contains units with total productivity regress, but positive contribution from efficiency, the third quadrant consists of the set of units with both dimensions being negative, and, finally, the fourth quadrant consists of the set of units with efficiency regress, but positive total productivity growth.

The size of the squares representing utilities is proportional to share of total energy deliveries in 1983, but in order not to get a too muddled picture, the units are aggregated according to being neighbours in the two dimensions within a 20×20 grid of the range of values of the corresponding partial distributions.

The picture of technology shift contribution and productivity growth in Fig. 5 shows a marked concentration around the no growth point compared with the stretched out impression in Fig. 4, caused by the lesser variance of the frontier

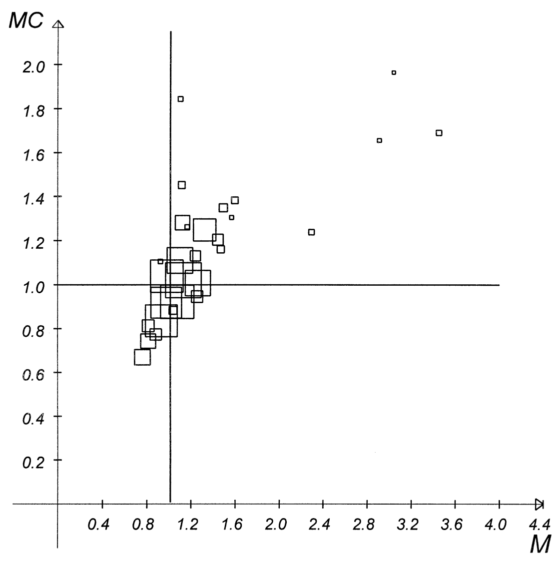

Fig. 4. Malmquist total productivity $M_{j1,2}$ and catching-up $M_{Cj1,2}$ indices.

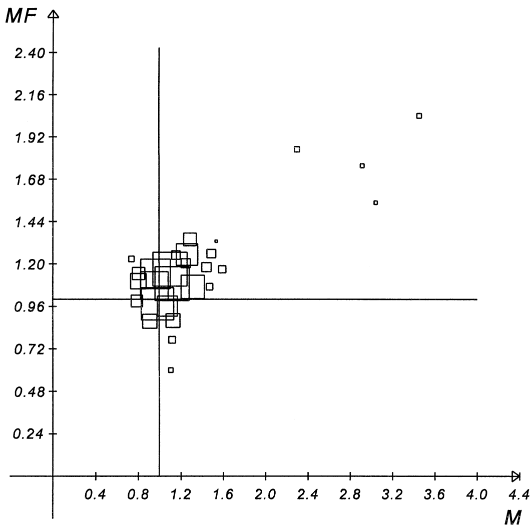

Fig. 5. Malmquist total productivity $M_{j1,2}$ and frontier shift $M_{Fj}^{1,2}$ indices.

shift component. As in the latter figure, the correlation is clearly positive, with the lion's share of units are located in the 'double positive' first quadrant. Again, the same four positive outlier units stand out. The quadrant with the smallest share of energy delivered is this time the 'double negative' third one.

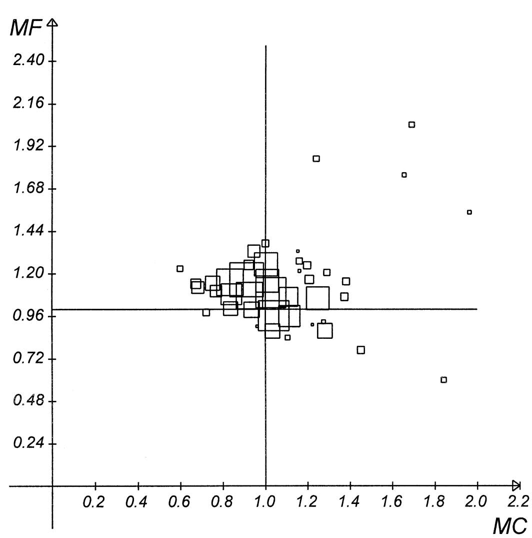

Fig. 6. Malmquist catching-up $M_{Cj1,2}$ and frontier shift $M_{Fj}^{1,2}$ indices.

The joint picture of the two productivity components shown in Fig. 6 naturally exhibit a negative correlation, when disregarding the four positive outliers. This is due to the multiplicative nature of the decomposition of the productivity measure. For a stationary unit a positive contribution of a shift in the frontier will be exactly balanced by a negative contribution from catching-up. The bulk of units is now in the second quadrant with efficiency regress, but frontier shift progress. There are very few units in the 'double negative' third quadrant, and a marked tail in quadrant four with negative frontier shift contribution, and the greatest spread of units in the 'double positive' first quadrant with the four outliers.

4.4. Outliers

The four units identified as positive outliers in the Section 4.3 are the ones with the highest values on the total productivity index M, and the frontier shift component M_F. Three of them have also the largest catching-up component M_C. The first step in outlier analysis is of course to recheck the data for measurement errors. These distribution utilities have all been contacted again, and the feasibility of their reported data have been checked with independent experts. [14] Their evidence is that there has been a clear reduction in the technically necessary energy loss as a percentage of energy transported, due mainly to new transformer technology. In addition, the outlier utilities have been particularly active in replacement investments in the relevant period.

The presence of negative frontier shifts for a few of the units need not be interpreted as a technical regress in the sense that know-how has been forgotten or even that government regulations or labour relations have increased the input usage necessary to produce a certain output. Since the DEA method measures the frontier as a best practice concept, a more plausible explanation is that the units that defined the frontier in this direction of input output space have shifted their mix either because of non-neutral technical change or simply in response to changing relative prices. If some efficient units are investing in modern lines and transformers, thereby substituting capital for energy loss, the inefficient units that are slower to invest will be left behind in a less capital-intensive input mix, and therefore measured with an efficiency improvement combined with a negative frontier shift (also see Førsund, 1993).

This point is illustrated in Fig. 7, showing a hypothetical unit isoquant for each of the two years 1983 and 1989. [15] The utilities A, B and C are observed (at corner points) with input combinations A_1, B_1 and C_1 in 1983 and A_2, B_2 and C_2 in 1989. Units A and C are frontier units that have reduced energy loss substan-

[14] Other units were excluded from the whole analysis as a result of these inquiries.

[15] The multi-output multi-input nature of our data set precludes the drawing of this figure with real observations. See also Førsund (1993) for a discussion of implications of intersecting isoquants over time.

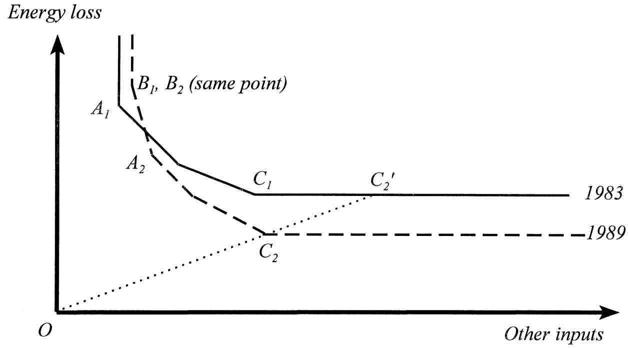

Fig. 7. Illustration of outliers in the unit isoquant diagram.

tially and increased the use of other inputs moderately, thereby showing a small technological progress. Unit B however, has not changed its input usage between the periods, and the measured total productivity index M_B will be equal to one. Since the referencing utility A has moved away in 1989, B is measured as an efficient frontier unit in period 2. Locally this is measured as frontier regress $(M_{FB} < 1)$ and a corresponding efficiency improvement $(M_{CB} > 1)$. It is difficult to conclude that an input mix such as A_1 is infeasible in 1989 even though it is not observed at that date.

By the same token, the extremely high productivity improvements reported for some units is a natural result of some units moving into input mixes not observed in 1983, e.g., reducing dramatically their energy loss but possibly at the same time increasing the use of other input such as capital. It is inherent in the use of DEA frontiers in small samples that observations that are in some sense extreme, among them those that have the lowest relative usage of each input or the highest relative production of each output, will be automatically efficient. Small changes in the variable in question can have large consequences for the measured efficiency and productivity changes.

Again, Fig. 7 can illustrate. Utility C is efficient in both periods, but has decreased dramatically its energy loss. Even though the use of other inputs, which in fact account for a far greater share of costs, has not changed much, the frontier shift M_{FC} is measured as the fraction OC_2'/OC_2, approximately equal to the improvement in the partial productivity of energy loss. As can be seen from the figure, this is partially a result of how the DEA methodology treats observations with extreme input–output combinations.

Measures are probably much less sensitive for observations with more central input/output mixes, and average figures are clearly more reliable. To investigate this point one needs to detect the influence of outliers on the results of the non-outliers. One way of measuring this influence is to run a separate analysis without the most extreme units.

Table 3
Results for panel units except eight outliers (142 units)

	a) Outliers in reference sets (Main run)			b) Outliers excluded altogether (Alternate run)		
	Total productivity ($M_{j1,2}$)	Catching up ($M_{Cj1,2}$)	Frontier shift ($M_{Fj}^{1,2}$)	Total productivity ($M_{j1,2}$)	Catching up ($M_{Cj1,2}$)	Frontier shift ($M_{Fj}^{1,2}$)
Average	1.073	0.990	1.091	1.071	0.986	1.091
Geometric average	1.058	0.976	1.085	1.054	0.971	1.086
Average unit	1.093	0.984	1.110	1.089	0.981	1.111
Minimum	0.709	0.598	0.600	0.682	0.598	0.772
Maximum	1.598	1.843	1.371	1.598	1.808	1.371
Standard deviation	0.183	0.174	0.112	0.190	0.179	0.101

For symmetry, four negative outliers are also excluded in addition to the four positive outliers discussed previously.[16] Panel (a) of Table 3 give summary statistics for the 142 non-outliers from the same run as the main results of Table 2; the outliers are still in the reference sets and are only excluded from the reported figures. The main result of this exclusion is to reduce dramatically the standard deviations and maximal values of the indexes. The average of the total productivity index and the frontier shift component of the non-outliers is slightly lower than for the full balanced panel, while the efficiency component is essentially unchanged.

In panel (b) of Table 3, the outliers have been excluded altogether from the reference sets in both 1983 and 1989. The influence of these outliers on the non-outliers is therefore the differences between panels (a) and (b) of the table. The table shows no real signs of any influence. The correlations between the index values in the two runs are in fact all in excess of 0.965. When measuring productivity, the extreme index values for these outliers are a problem only for those units themselves.

5. Conclusions

The basic assumption of the study is that there is inefficiency in the operation of distribution utilities, and consequently productivity change can be decomposed into catching-up and frontier shift. Specifying a piecewise linear constant returns to scale frontier technology based on best practice observations, productivity development according to the Malmquist index approach shows an overall positive development of the magnitude of $1\frac{1}{2}$ to 2% per year. Decomposing the total productivity development identifies frontier production shift as the driving force.

[16] These are selected as the four units with the lowest values of M using period 2 technology.

The insignificant change in average efficiency for the period 1983 to 1989 conveys essentially a stability that is in accordance with the unchanged regulatory regime noted in the introduction. On the other hand, estimates of technological progress potentially allow a regulator with newly enlarged powers to demand that productivity continues to improve at least at the same rate.

Showing distributions for the individual units is a strength of the approach. In contrast to studies focusing on average tendencies complete micro distributions will alert one to the possibility of considerable variations. The individually based productivity distributions established for the utilities show a significant spread of performances, and especially at the best performance tail. The worst performance tails are dominated by small units, except in the case of frontier shift, where some large units also perform badly. The discussion of outliers would indicate the need for caution in relying on index values in the extremes of the distributions, without lessening the usefulness of the individual measures for non-outliers.

One implication for policy is that basing regulation on average performance could be too crude a policy. The spread of individually based distributions shows a scope for improving individual productivity performances by tailoring incentives accordingly. Although basing the required productivity improvement directly on the past productivity of each firm can give incentives for firms to reduce productivity, Bogetoft (1994) shows that by omitting the observation from the definition of the reference technology in each instance, this disincentive can be eliminated. This can also be achieved if the lag between observation and regulation is sufficiently long and the firm's rate of discount is sufficiently high (see Wunsch, 1995).

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