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International Benchmarking of Electricity Distribution Utilities

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INTERNATIONAL BENCHMARKING
OF ELECTRICITY DISTRIBUTION UTILITIES[1]

by

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and

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December 12, 2001

Abstract: Benchmarking by means of applying the DEA model is appearing as an interesting alternative for regulators under the new regimes for electricity distributors. A sample of large electricity distribution utilities from Denmark, Finland, Norway, Sweden and the Netherlands for the year 1997 is studied by assuming a common production frontier for all countries. The peers supporting the benchmark frontier are from all countries. New indexes describing cross country connections between peers and their inefficient units are developed, as well as productivity measurements between units from different countries.

Keywords: Electricity utility, benchmarking, efficiency, DEA, Malmquist productivity index

JEL classification: C43, C61, D24, L94.

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1. Introduction

Improvement of efficiency in electricity distribution utilities has come on the agenda, as an increasing number of countries are moving towards deregulation of the sector in the last decade. A key element in assessing potentials for efficiency improvement is to establish benchmarks for efficient operation. A standard definition of benchmarking is a comparison of some measure of actual performance against a reference performance. One way of obtaining the latter is to establish a frontier production function for a utility, and then calculate efficiency scores relative to the frontier.

In this study a piecewise linear frontier is used, and technical efficiency measures (Farrell, 1957) and Malmquist productivity measures (Caves et al., 1982a) are calculated by employing the DEA model (Charnes et al., 1978). The DEA model has been used in several studies of the utilities sector recently (see a review in Jamasb and Pollitt, 2001). A special feature of this study is that the data is based on a sample of utilities from five different countries: Denmark, Finland, The Netherlands, Norway, and Sweden. Most of the efficiency studies of utilities are focussing on utilities within a single country, but some studies have also compared utilities from different countries (see Jamasb and Pollitt, 2001). In some cases an international basis for benchmarking is a necessity due to the limited number of similar firms, like benchmarking for the single Norwegian national grid transmission company where the similar company for Sweden is used. When the number of units is not the key motivation for international sample for benchmarking, the motivation may be to ensure that the national best practice utilities are also benchmarked[2].

There are some extra problems with using an international data set for benchmarking. The main problem is that of comparability of data. One is forced to use the strategy of the least common denominator. A special issue is the correct handling of currency exchange rates. There are really only two practical alternatives; the average rates of

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[2] An alternative is to use hypothetical units based on engineering information, as mentioned already in Farrell (1957). In Chile and Spain hypothetical model best practice units are used for benchmarking, see Jamasb and Pollitt, 2001.

exchange and the Purchasing Power Parity (PPP) as measured by OECD. The latter approach is chosen here. Relative differences in input prices like wage rates and rates of return on capital may also create problems as to distinguish between substitution effects and inefficiency.

According to the findings in Jamasb and Pollitt (2001) international comparisons are often restricted to comparison of operating costs because of the heterogeneity of capital. They formulate as a precondition for international comparisons to focus on improving the quality of the data collection process, auditing, and standardisation within and across countries. Cross section data for the present study has been collected uniquely for the effort by national regulating agencies, and special attention has been paid to standardise the capital input as a replacement cost concept.

Regarding the extent of international studies Jamasb and Pollitt (2001) found that 10 of the countries covered in the survey (OECD- and some non-OECD countries) have used some form of benchmarking and about half of these use the frontier-oriented methods DEA, Corrected Least Squares (COLS) and Stochastic Frontier Approach (SFA). They predict that benchmarking is likely to become more common as more countries implement power sector reforms.

The paper is organised in the following way: In Section 2 a brief discussion of the methods of DEA and Malmquist productivity index calculations is offered. Some new indices are developed to capture the cross-country pattern of the nationality of peers and the nationality of units in their inefficient unit sets. In Section 3 the theory of distribution of electricity as production is reviewed as to the choice of variable specification. The data is presented in the form of partial diagrams developed to reveal the structure of the data and the occurrence of outliers. A trial run is performed in Section 4 to check any outlier problem. The results on efficiency distributions and inter-country productivity differences using Malmquist indexes are presented in Section 5. Conclusions and further research options are offered in Section 6.

2. The methodological approach

The DEA model

As a basis for benchmarking we will employ a piecewise linear frontier production function exhibiting the transformations between a set of outputs, y_m $(m = 1,..,M)$ and the substitutions between a set of inputs, x_s $(s=1,..,S)$. We will assume constant returns to scale. One reason for this choice is that we are going to study productivity, and this specification is in accordance with a total factor productivity interpretation. Another reason is specific to our dataset: the units are all among the larger units within each country, and thus the basis for specifying a variable returns technology is not there[3]. The frontier is enveloping the data as tight as possible and the observed best practice utilities will span the benchmarking technology. The Farrell technical efficiency measures are calculated simultaneously with determining the nature of the envelopment subject to basic properties of the general transformation of inputs into outputs (see e.g. Färe and Primont, 1995). The efficiency scores for the input- and output oriented DEA models, E_{1i} and E_{2i} respectively for utility no i $(i = 1,..,n)$, are found by solving the following two linear programmes:

$$
\begin{aligned}
& E_{1i} = \text{Min}\, q_i \\
& \text{s.t.} \\
& \sum_{j=1}^{n} l_{ij} y_{mj} - y_{mi} \geq 0 \ , m = 1,..,M \qquad (1) \\
& q_i x_{si} - \sum_{j=1}^{n} l_{ij} x_{sj} \geq 0 \ , s = 1,..,S \\
& l_{ij} \geq 0 \ , j = 1,..,n
\end{aligned}
$$

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[3] However, it could be argued that a non-increasing (NIRS) scale specification would be relevant.

$$\begin{aligned}
&\frac{1}{E_{2i}} = \operatorname{Max}\phi_i \\
&\text{s.t.} \\
&\sum_{j=1}^{n} \lambda_{ij} y_{mj} - \phi_i y_{mi} \geq 0\ ,\ m = 1,\ldots,M \qquad (2)\\
&x_{si} - \sum_{j=1}^{n} \lambda_{ij} x_{sj} \geq 0\ ,\ s = 1,\ldots,S \\
&\lambda_{ij} \geq 0\ ,\ j = 1,\ldots,J
\end{aligned}$$

(For notational ease we use the same symbol, λ, for the weights in both models.) In the general case the measures E_{1i} and E_{2i} are identical since we have specified constant returns to scale. However, we may need to keep some variables fixed when calculating the efficiency scores. In the case of e.g. one output as fixed, the input-oriented model will be the same as (1), but the output-oriented model will be different since the constraint in (2) involving this variable will be reformulated to hold without the efficiency correction of this output variable. The numerical results for efficiency scores may then be different.

The Peers

The efficient units identified by solving the problems (1) or (2) above are the basis for studying possible causes for inefficiency. Each inefficient unit will have one or more benchmark or peer units. We want to measure the influence of the peers. Let P be the set of peers and I the set of inefficient units; $P \cup I = N$ (N=set of all units). The importance of the fully efficient units as peers can be shown by an index termed the Peer index[4]. In the case of input orientation the index for each peer is based on the relative saving potential of the inefficient units that have the peer in their reference sets. The reference set is defined as:

$$P_i = \{ p : \lambda_{ip} > 0 \forall p \in P \}\ , i \in I \qquad (3)$$

Each inefficient unit, i, has a positive weight, λ_{ip}, associated with each of its peers, p, from the solution of the DEA model (1). The weights, λ_{ip}, are zero for inefficient units not having unit p as a peer. The absolute saving potential (based on the radial Farrell measure, i.e. disregarding slacks) for each inefficient unit is expressed by the difference

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[4] See Torgersen et al. (1996) for the introduction and demonstration of the concept of Peer index for both the radial efficiency measure and efficiency measures including slacks.

between the observed input quantity and the amount on the frontier sufficient to support the observed output levels for each type of input, s:

$$\sum_{r\in I_p}(x_{rs}-E_{1r}x_{rs})=\sum_{r\in I_p}x_{rs}(1-E_{1r}),\ r\in I_p\ ,s=1,..,S \qquad (4)$$

where I_p is the inefficient unit set referenced by the peer, p:

$$I_p=\{i:l_{ip}>0\ \forall i\in I\},p\in P \qquad (5)$$

One measure of the importance of a peer would be the ratio of potential savings of an input of inefficient units in the peer's inefficient unit set, I_p, to total savings of all inefficient units. However, an inefficient unit may have several peers, in the CRS case up to the number of input- plus output dimensions minus one (since all facets go through the origin), in our case maximal five peers. To discriminate between peers the weights, l_{ip}, can be utilized. To measure the importance of a peer we will calculate the savings potential for each type of input of all inefficient units in the peer's inefficient unit set weighted with the weight, l_{ip}, for the peer when forming the reference point for unit i on the frontier, relative to the total potential saving of the input in question for all inefficient units (the set I). The saving potential calculated above in (4) is therefore corrected by weighing each inefficient unit's potential with this weight (see the appendix for the weights). The (input oriented) Peer index, $r_p{}^s$, for each peer and each type, s, of input, is the ratio of the total weighted saving potential of the inefficient units in the reference set of the peer and the total saving potential in the complete dataset[5]:

$$r_p{}^s=\frac{\sum\limits_{i\in I_p}\dfrac{l_{ip}}{\sum\limits_{p\in P}l_{ip}}x_{is}(1-E_{1i})}{\sum\limits_{i\in I}x_{is}(1-E_{1i})}\quad \forall p\in P,s=1,..,S \qquad (6)$$

In the VRS case the sum of weights, l_{ip}, over peers, p, is equal to one, but in the CRS case there is no restriction on the sum (but each l_{ip} is restricted to be non-negative). Therefore, the weight l_{ip} has to be normalized by division with the total sum of weight for each inefficient unit. Summing also over all the peers (index p) in the numerator, we get the index value of one for each type of input.

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[5] An output-oriented peer index can be constructed in an analogous way, see Torgersen et al. (1996).

Another measure of the importance of peers is provided by calculating the super efficiency score (SE) (Andersen and Petersen, 1993). This score is obtained by removing the peer in question from the full data set used when calculating the efficiency scores according to the program (1), and then calculating the efficiency score of the peer against this new frontier. The efficiency score must necessarily be greater than (or equal to) one. A third measure of the importance of a peer that has been used in the literature is a pure count of the number of times a peer is a referencing unit for inefficient units, i.e. the number of sets P_i defined in (3) where the peer appears. The measures give us different information. The Peer index shows the importance of a peer as role model for best practice in terms of potential improvement of performance, the pure count shows number of appearances, but without discriminating between differing peer influence on the reference point of the inefficient units, while the Super efficiency score tells us about the influence on the shape of the production frontier.

Cross group influence of peers

Since we have countries as sub-groups it is of interest to so investigate the cross-country relationships by focussing on the importance for inefficient units in a country of peers from each of the other countries. Such a cross-country index of peer importance has been used in Schaffnit et al. (1997). Units must now be identified by country. Using the notation in (3) we first form the set, I^i, of inefficient units, k_i, of a country, i, appearing in the peer referencing sets, P^j, of another country, j:

$$N_{ij} = \left\{ k_i : l_{k_i l_j} > 0 \text{ for } k_i \in I^i, l_j \in P^j \right\}, \forall i, j \qquad (7)$$

Let us denote the number of inefficient units in a country, i, for n^i $(i=1,\ldots,n)$. Dividing the numbers of inefficient units in country i having peers from country j with the total number of inefficient units in each country we get a relative measure, r_{ij}, for cross country peer importance[6]:

$$r_{ij} = \frac{N_{ij}}{n^i}, \forall i, j \qquad (8)$$

The index r_{ij} is based on whether the l -coefficients are zero or positive. A more instructive representation of importance as peers may be obtained by developing the peer index (6) to serve a study of links between countries. A Cross country peer pattern

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[6] Schaffnit et al. (1997) also include the number of peers in the set in the denominator.

index, r_{ij}^{s}, can be established by weighing the saving potential of an input, s, for a country, i, with the $\lambda_{k_i l_j}$ - weights, and then looking at the potential associated with the peers from another country, j:

$$r_{ij}^{s}=\frac{\sum\limits_{l_j\in P^j}\sum\limits_{k_i\in I^i}\dfrac{\lambda_{k_i l_j}}{\sum\limits_{p\in P}\lambda_{k_i l_j}}x_{k_i s}(1-E_{1k_i})}{\sum\limits_{k_i\in I^i}x_{k_i s}(1-E_{1k_i})}\ ,s=1,..,S,\forall i,j \qquad (9)$$

This index will be variable specific, as is the case for the peer index (6).

The Malmquist productivity index

The Malmquist productivity index, introduced in Caves et al. (1982a), is a binary comparison of the productivity of two entities, usually the same unit at different points in time, but we may also compare different units at the same point in time. Let the set of units in country j be N_j, and consider two utilities, k_i and l_j, from country i and j, respectively. The output- and input vectors of a unit are written y_{ki}, x_{ki}, etc. The Malmquist productivity index, M, for these two units is then:

$$M_{k_i,l_j}^{i}(y_{k_i},x_{k_i},y_{l_j},x_{l_j})=\frac{E^{i}(y_{l_j},x_{l_j})}{E^{i}(y_{k_i},x_{k_i})}\ ,k_i\in N_i,l_j\in N_j \qquad (10)$$

The Malmquist index is the ratio of the Farrell technical efficiency measures for the two units, as calculated by solving the programmes (1) or (2)[7]. The superscript on the indexes shows the reference technology base (i.e. i means that the efficiency measures are calculated with respect to the frontier for country i). We follow the convention of having the first unit in the subscript in the denominator and the second in the numerator, thus unit l_j is more productive than unit k_i if $M_{k_i,l_j}^{i} > 1$, and vice versa. If it is relevant to operate with different reference technologies for the units, following Färe et al. (1994), the Malmquist index can be decomposed multiplicatively into a term reflecting each

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[7] We have used Farrell (1957) efficiency measures, E, instead of distance functions as in Caves et al. (1982a) because the definition (3) is then symmetrical whether we assume an input- or output oriented measure. However, we adopt the assumption of constant returns to scale. The input- and output oriented measures are then identical. We still stick to the efficiency measure notation.

unit catching up with its reference technology, and a term reflecting the distance between the two reference technologies.

It may be of interest to involve a comparison of several units. According to Caves et al. (1982b) multi-country comparisons are the problems to which multilateral comparative techniques most often have been applied. We may want to both compare productivity levels between countries, and to compare utility productivity levels. The crucial point concerning the choice of comparisons is the assumption about production technologies. There are two basic possibilities:

i) A common frontier technology may be assumed, allowing utilities from different countries to support the DEA envelope.

ii) The technologies are national, i.e. only own country firms may be best practice firms.

Caves et al. (1982b) operated with country-specific technologies and countries as units, and developed a multilateral country productivity index for a comparison of two countries. The calculation involved the geometric mean of the bilateral productivity comparison between each of the two countries and all other countries in order to obtain transitivity. Another way to obtain transitivity proposed in Caves et al. (1982b) was to introduce a representative country to be compared with the two countries involved in the bilateral comparison. The approach in Berg et al. (1993) of using a fixed base technology can be interpreted as use of a representative country (see Førsund, 2002). In a setting similar to ours Nordic banks are studied by assuming separate technologies for each country, and then by using the frontier for one country as a common reference, productivity between countries are compared by comparing the efficiency scores of the largest banks in each country, as well as the average banks. A common Nordic technology was also tried. We will in our study assume a common frontier technology.

Common inter country technology

As pointed out in in Caves et al. (1982) it is an advantage to use a transitive index when comparing productivities of two countries (units). Berg et al. (1992), (1993), and Førsund (1993) (see also the general discussion in Førsund, 2002) demonstrate that the

Malmquist index (10) is not transitive. However, in the case of the same frontier technology being valid for all countries, corresponding to assumption i) above, the Malmquist productivity index is greatly simplified, since the benchmark technology will be common for all productivity calculations. The index is then transitive.

A useful characterisation of the productivity of a unit, k_i, in a country, i, may be obtained by comparing the efficiency score for this unit with the geometric mean of all the other scores, following up Caves et al. (1982b), (p. 81, Eq. (34)), measuring the productivity of one country against the geometric mean of the productivities of all countries:

$$\overline{M}^{C}_{k_i}(y_{k_i},x_{k_i}) = \frac{E^{C}(y_{k_i},x_{k_i})}{\left[\Pi_{l\in N} E^{C}(y_l,x_l)\right]^{1/n}}, k_i \in N_i, l \in N \quad , C = \text{common technology} \qquad (11)$$

where n is the total number of all utilities and N represents the set. To focus on bilateral productivity comparisons between countries as units one way of formulating a bilateral country comparison is to compare the geometric means of efficiencies over units for each country, i and j:

$$\overline{M}^{C}_{l_j,k_i}(y_{l_j},x_{l_j},y_{k_i},x_{k_i}) = \frac{\left[\Pi_{k_i\in N_i} E^{C}(y_{k_i},x_{k_i})\right]^{1/n_i}}{\left[\Pi_{l_j\in N_j} E^{C}(y_{l_j},x_{l_j})\right]^{1/n_j}}, k_i \in N_i, l_j \in N_j, \qquad (12)$$

where n_i and n_j are the total number of utilities within each country i and j. This index may be termed the bilateral country productivity index, and is also transitive, in the sense that the index is invariant with respect to which third country efficiency score average we may wish to compare with countries i and j.

If we want to express how the units within a country, i, are doing compared with the average over all units, the country j specific index in the denominator of (12) can be substituted with the geometric average of the efficiency scores of all the utilities like the denominator in (11).

We could also study structural differences by calculating relative productivities for the average units for each country. Farrell (1957) introduced the notion of how the average unit kept up with the best practice units as a measure of structural efficiency within an industry. In Førsund and Hjalmarsson (1979) structural efficiency is measured as the average unit's efficiency score. If we denote variables with bars on top for arithmetic averages, the following Malmquist productivity index may serve as a measure of overall productivity:

$$\overline{M}^{C}_{ij}(\bar{y}_i,\bar{x}_i,\bar{y}_j,\bar{x}_j)=\frac{E^{C}(\bar{y}_j,\bar{x}_j)}{E^{C}(\bar{y}_i,\bar{x}_i)}\ ,i,j=1,..,n,\ C = \text{common technology} \qquad (13)$$

3. Model specification and data

Distribution as production

In the review of transmission and distribution efficiency studies Jamasb and Pollitt (2001) point to the variety of variables that have been used as an indication that there is no firm consensus on how the basic functions of electric utilities are to be modelled as production activities. However, they mention that the variety of the variables used may, to some extent, be explained by the lack of data.

Modelling the production activity of transportation of electricity has old traditions within engineering economics (see e.g. Førsund (1999) for a review). According to Smith (1961) the problem of the most economical way of setting up transmission of electricity between a point of production and a point of consumption was first analysed by Lord Kelvin in 1881. Before a power line is constructed there are substitution possibilities between the weight of the conductor and energy generated at the point of production due to a larger conductor (in mass) implying less loss of power, all other aspects being held constant. Applying the various laws of electricity, like Ohm's law, a production function can be derived with electricity delivered as output and weight of conductor and energy generated as inputs. As parameters we have length of conductor, specific resistance, specific weight of conductor, and voltage at consumer point. As to scale properties this function exhibits constant returns to scale.

Moving from the stylised transmission problem of Lord Kelvin to modelling a distribution utility we may start by noting some basic activities of distribution, following Neuberg (1977). Distribution was there divided into four related but distinguishable activities. Distribution proper consists of load dispatching, customer installations, and equipment maintenance. Customers account activity includes meter reading and billing. Sales activity encompasses demonstrating, selling, and advertising. Lastly there is general administration, including office supplying and renting. On the input side these activties will be captured by properly specified labour, capital and materials inputs. However, deregulation usually unbundled supply of electricity and distribution by the local utility, thus sales of electricity, customer accounts, etc. are then not included in distribution.

As to the physical production activity electricity is delivered through a network to a number of customers. The basic picture is the same as in Lord Kelvin's transmission problem above. In addition to lines (consisting of overhead-, under ground-, and under water cables) transformers are important to physical distribution. However, we will not model the optimal configurations of lines and transformers. We assume that the utilities take the existing lines, transformer capacity and number and geographical distribution of customers as given. But, at pointed out in Neuberg (1977), this is not the same as saying that these variables must be regarded as constants in our analysis. Past decisions reflected in configurations of lines and transformers may give rise to current differences in efficiency. These variables that are exogenous for the firm, may be seen as endogenous from the point of view of society. Even distribution jurisdictions can be rearranged, making number of customers endogenous.

On a general abstract level the outputs of distribution utilities are energy delivered to each node (customer), and inputs are the energy received by the utility and real capital in the form of lines and transformers, in addition to inputs used for the distribution activity mentioned above. Due to the high number of customers for a standard utility it is impossible to implement the conceptualisation of a multi-output production function to the full extent. The usual approximation is to operate with total energy delivered and number of customers separately as outputs (see e.g. Salvanes and Tjøtta, 1994). The latter variable is also often used in engineering studies as the key dimensioning output variable, and taken as the absolute size of a utility (Weiss, 1975). The role of lines varies. It can be regarded as a capital input, but it is also used as a proxy for the geographical extent of the service area. For fixed geographical distribution of customers the miles of distribution line would be approximately set (but note the possibilities of inefficient configurations), thus line length may serve as a proxy for service area. Due to probability of wire-outage and cost of servicing the extent of customer area will influence distribution costs. Non-traditional variables such as size of service area may be used to specify differences in the production system or technology from firm to firm.

The energy received by a utility is usually not represented as an input, but the loss in the network system can be used as an input, although it is conceptually a by-product of the transportation activity.

In engineering studies the load density may be a characterisation of capital. Load density is the product of customer density and coincident peak load per customer (kWh per square mile). The maximum peak load may also describe capital, or also be used as an output indicator as a quality attribute.

According to the extensive review in Jamasb and Pollitt (2001) the most frequently used inputs are operating costs, number of employees, transformer capacity, and network length. The most widely used outputs are units of energy delivered, number of customers, and size of service area.

Choice of model specification

Considerations of costs, time and feasibility of establishing variables with common definitions by the national regulators have restricted the choice of variables for this study. As regards input variables it has not been possible to use a volume measure of labour due to the lack of this information for one country (Denmark). Instead a cost measure has been adapted. Labour cost and maintenance have been added to total operating expenses (TOM). We then face the problem mentioned in the introduction about national differences in wages for labour. It has been chosen to measure total operating and maintenance costs in Swedish prices.

A measure for real capital volume has been established for 1997 by the involved regulators by first creating for the sample utilities a physical inventory of existing real capital in the form of length of types of lines (air, underground and sea) distributed on three classes according to voltage, categories of transformers according to type (distribution, main) and capacity in kV, transformer kiosks for distribution, and transformer stations for main transformers. The number of capital items has been in the range of 60-100. As a measure of real capital the replacement value (RV) is the theoretical correct measure (see Johansen and Sørsveen, 1967). To obtain such a measure aggregation over the categories has been necessary due to the high number of items. It is then necessary to use the same weights, i.e. national prices will not yield a correct picture if prices differ. It has been chosen to use Norwegian prices for all countries. A more preferred set of weights may be average prices for all countries, but it has not been feasible to establish such a database so far. Although lines and transformers have been used separately as inputs in the literature (see e.g. Hjalmarsson and Veiderpass (1992a), (1992b) and Jamasb and Pollitt, 2001), the groups have been aggregated into a single aggregated capital volume measure in this study.

The energy fed into the distribution system is the physical input, and electricity taken out and losses in lines and transformers are the physical outputs. We will measure as input the loss in MWh in the system. This variable will capture a quality component of the distribution system. A problem is that data are usually more unreliable than for energy delivered due to measuring routines not coinciding with the calendar year. In some countries an average loss for the last three years is used, while loss for the last year or its estimate is used for other countries.

On the output side energy delivered and number of customers are used as outputs. The countries have information on low and high voltage, but since the classification of high and low voltage differs we have used the aggregate figures. Some measure of geographical configuration of the distribution networks should also be included for a relevant analysis of efficiency. The service area can be measured in different ways (see e.g. Kittelsen (1993) and Langset og Kittelsen, 1997). Our option in this study is to use the total length of lines.

Table 1a. Summary statistics 1997

	Average	Median	Standard Deviation	Minimum	Maximum
TOM (kSEK)	152388	97026	182923	11274	981538
LossMWh	91449	52318	104777	7020	615281
RV (kSEK)	2826609	1907286	3288382	211789	22035846
NumCust	109260	55980	163422	20035	1052096
TotLines	7640	4948	8824	450	54166
MWhDelivered	2110064	1003472	2815025	166015	178054730

Table 1b. Summary statistics, average country values 1997

Countries	No. of units	TOM	Loss MWh	RV	No. of Cust	Total Lines	MWh Delivered
Denmark	24	101285	43537	2397853	98459	4943	1039806
Finland	25	89942	91663	2564553	82242	9390	1274032
Netherlands	15	283806	164080	6003522	299139	11923	4054312
Norway	18	153533	149430	3099260	72871	6923	4510329
Sweden	42	164933	63921	1852481	75170	6608	26848

The data structure

An overview of key characteristics of the data is presented in Tables 1a,b. The difference in size between utilities is large, as revealed by the last two columns in Table 1a. A summary of the structure of the data of the individual countries shown in Table 1b is also shown in the radar diagram in Figure 1, where country averages relative to the total sample averages are portrayed. The absolute size of the Netherlands is obvious in all dimensions except for energy delivered. It is evident that the Netherlands is especially large in number of customers, but also in replacement value. It is relatively small in length of lines. Norway is largest with respect to energy delivered and also correspondingly large in energy loss, although with a smaller value than the Netherlands. Sweden stands out with relatively high operating and maintenance costs (TOM), while Finland stands out with a high number for length of lines. Denmark has the smallest number for length of lines and energy loss, and have a relatively high number of customers.

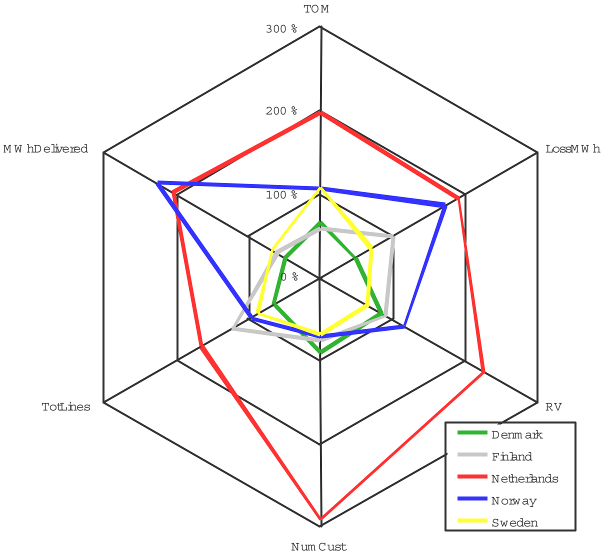
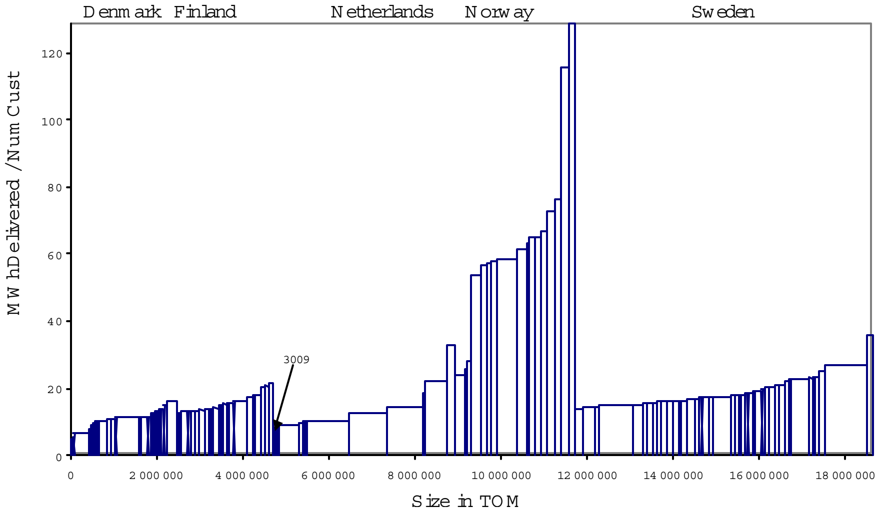


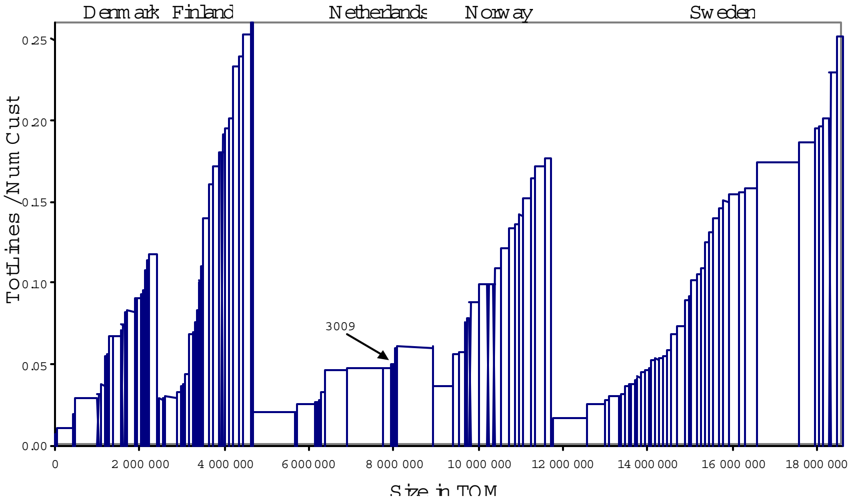
Figure 1. The average structure of the countries

In order to see more details of the structure of the data we will use diagrams to portray ratios of variables. There are three types of combinations of the variables that shed light on different structures. Forming ratios of output variables will show the distribution of output mixes, forming ratios of inputs will show the distribution of input mixes, and forming ratios of output on input (or inverse) will show us partial productivity ratios. With three outputs and three inputs the number of output mix ratios is three, and the same for input mix ratios, while the number of partial productivity ratios is nine. Due to space considerations we will only show some of these. Using a bar diagram with the width of the bars proportional to a measure of size (e.g. one of the inputs or outputs), total operating and maintenance cost (TOM) is used here, and sorting the units according to ascending values, we have what has been termed Salter diagrams. To see the structure within each country, and to compare country data we have sorted within each country in the same diagrams. Such a data study is also a way to detect outliers that seem extreme. We can then proceed to investigate in particular the data quality of such observations.

In Figure 2 distributions of output mixes are shown. Panel a shows the energy delivered per customer. Norway is here in a special position with about three times as high ratio as the other countries. The distributions for the other countries are similar as to range. There is no clear size pattern. As to outlier detection two Norwegian units have quite high values for energy per customer. This may be due to deliveries to energy intensive industries.

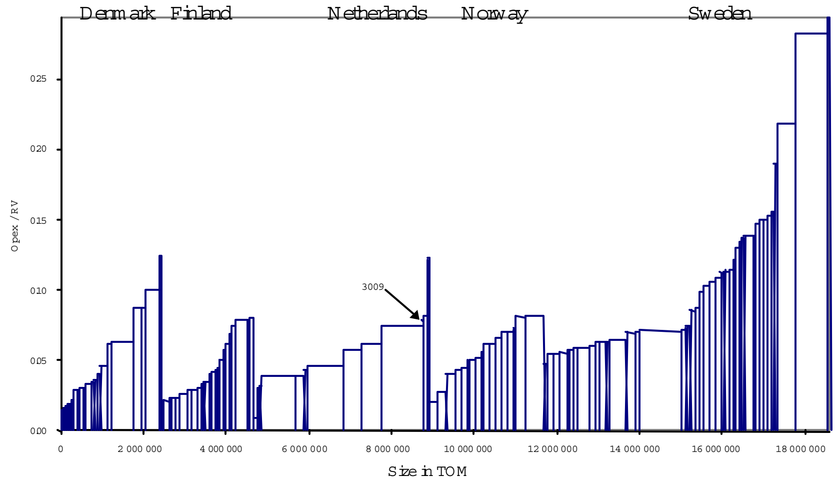


Panel a. Energy delivered per customer

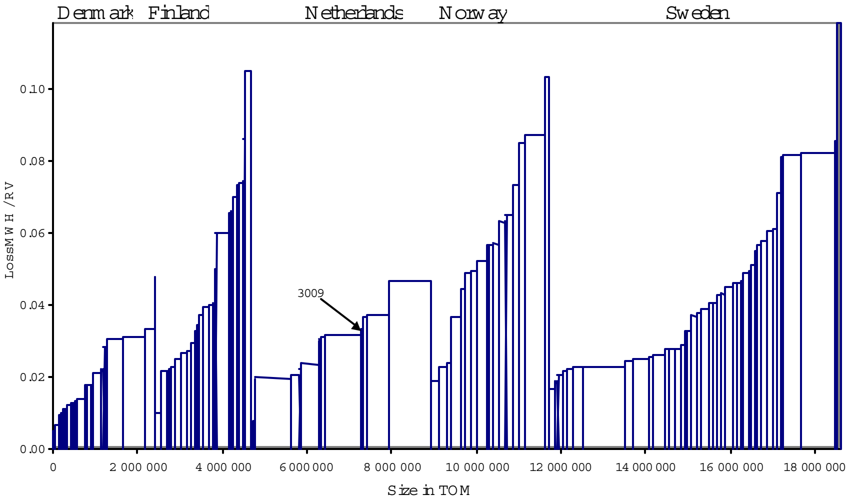


Panel b. Lines per customer

Figure 2. Output mix distributions



Panel a. Total operating costs on replacement value of capital



Panel b. Loss in MWh on replacement value of capital

Figure 3. Input mix distributions

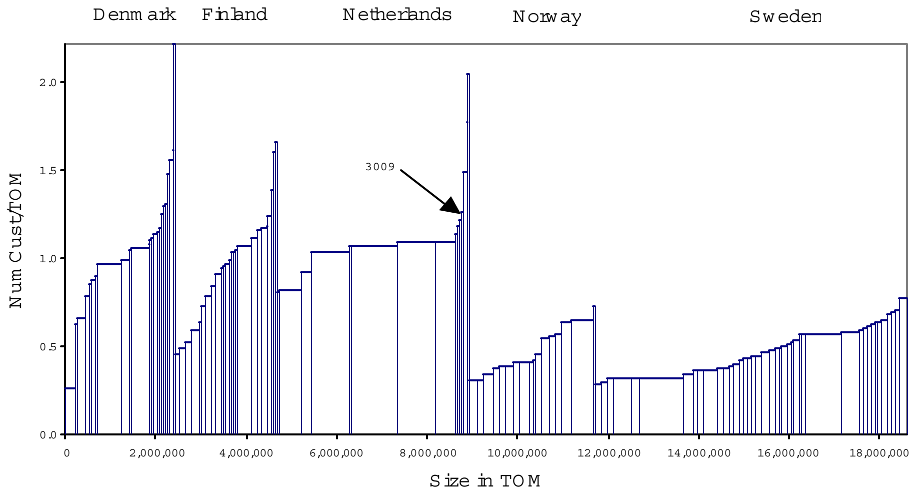
Total length of lines on number of customers is shown in Panel b. The distributions within each country are very skew for all countries except the Netherlands, with large units having the smallest ratios for Denmark, Finland and Norway, and some large units having small ratios also in Sweden, but then some large units also having high ratios. The Netherlands is a special case with the units in two distinct size classes and the distribution of lines on number of customers being quite more even than for the other countries. The distributions of Finland and Sweden have the same maximal ranges, while Norway, Denmark and the Netherlands then follow. As to outlier detection there are no extreme ones.

Distribution of input mix is shown in Figure 3. Comparison of total operating and maintenance cost on replacement value of capital in Panel a reveals that Sweden has a special distribution compared with the other countries, having about twice as high costs per volume of capital. The range of the distributions for the other countries is about the same. For Denmark, Finland, and Norway large units have high ratios, while for the Netherlands it is two small units with the highest ratios, and for Sweden large units are located at both ends of the distribution. As to outlier detection one small Danish unit and two small Dutch units have exceptional high values within their national distributions and may deserve a closer inspection.

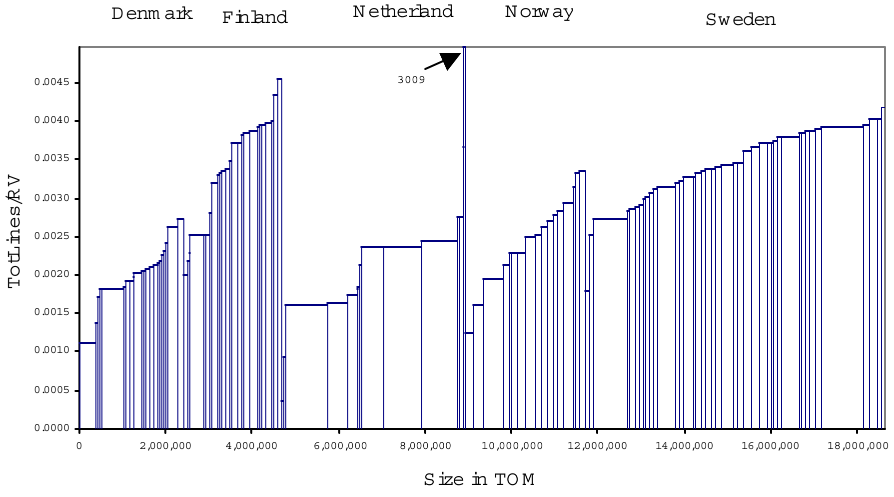
Energy loss on replacement value of capital is shown in panel b. Denmark and the Netherlands have about the same range and considerably narrower than the other three countries. For Denmark small units have the lowest value of this input mix, while large units have high mix values. For Finland, the Netherlands and Norway there are no clear size pattern, while Sweden has large and small units at both ends of the input mix. As to outlier detection there are one unit from each of the countries Denmark, Finland and Sweden that stand out with high mix, and one from Finland and two from the Netherlands that stand out with low mix value within national distributions.

Some productivity ratios are shown in Figure 4. High productivity outliers may be important for the solution of the DEA model, so special attention should be paid to them. In Panel a number of customers on operating and maintenance costs are shown. The distribution for the countries varies both with regards to range and minimum – maximum values. Denmark has the most extreme range, and then Finland and the Netherlands. For these three countries there are small units with the highest productivities. The distributions for Norway and Sweden are similar and the range much more limited. The maximum values are considerably lower than for the other countries. There is no distinct size pattern as for the other countries. As to outlier detection one

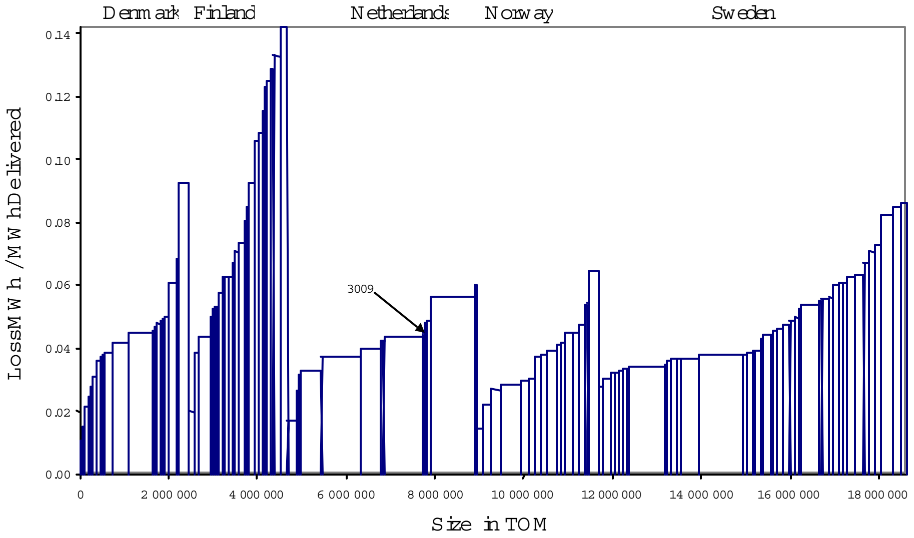
Danish unit is quite extreme, as well as two Finnish ones and two Dutch ones. We will expect these to show up as best practice units, and their data should be investigated carefully.



Panel a. Number of customers on total operating costs



Panel b. Lines on replacement value of capital



Panel c. Loss in MWh on MWh delivered

Figure 4. Partial productivities

Panel b portrays length of line on replacement value. The distributions are different for each country. Denmark and Norway are most similar, with about the same range and no extreme observations. Finland's distribution is shifted almost completely to a higher level than the Danish, with the low values in the range of the Danish high values. The Swedish distribution is more similar to the Finnish one. Large units dominate the lower tail of the Danish, Finnish and Norwegian distribution. The Dutch distribution is most extreme with a few small units having extremely high productivities. These units are candidates for closer scrutiny as outliers.

Panel c shows the energy loss on energy delivered. This is the inverse of productivity, but is the standard form of presenting such information. The Finnish distribution stands out with the maximal range. A large unit has a small loss ratio, while two medium sized units have maximal loss ratio. For Denmark the small units have smallest loss ratios, i.e. they are most productive in this partial dimension. The distributions for the Netherlands, Norway and Sweden are somewhat more even and no clear pattern as to location of units according to size. Regarding outliers Finland has an outlier with a low ratio internally, but not compared with other countries.

Looking at the tails of the Salter distributions shown above some potential outliers may be identified [8]. The output-mix not shown, energy delivered on lines, is dominated at the high end-range by Finnish utilities, while the input-mix not shown, energy loss on operating costs, is not dominated by utilities from a particular country. The six partial productivities not shown confirm Norwegian dominance of ratios with energy delivered in the numerator, and Finnish dominance as to lines on operating costs. The participating regulators have all investigated these units (including the ones not shown in the figures) and controlled the data for faulty reporting on preliminary analyses. The dataset described above is to the best knowledge of the parties the most reliable data that can be obtained at this stage. Some uncertainties exist, especially with respect to data for energy losses.

4. Trial runs

Technical performance of the model

The choice of variables to be used has also been based on the results of the step-wise testing procedure for inclusion of relevant variables performed in Kittelsen (1993), starting with the most aggregate model regarded as relevant, and then disaggregating the variables. But it may be of interest to check the significance of the variables by looking at significant differences in the efficiency scores by excluding variables. This can be done by testing H_o: that all variables should be included against H_1: that each variable in turn is taken out. The results of such a test is shown in Table 2. The difference in

Table 2. Test of significance of variables by change in efficiency scores, E

H_0	H_1	Diff. E H_0-H_1	D+	T
Critical level 0.9			0.14	1.29
Critical level 0.95			0.16	1.65
Critical level 0.99			0.19	2.34
Loss	All-Loss	-0.03	0.11	1.74
RV	All-RV	-0.32	0.73	16.35
TOM	All-TOM	-0.05	0.19	3.25
Totlines	All-Totlines	-0.21	0.57	9.68
NumCust	All-NumCust	-0.08	0.25	4.63
Mwh	All-Mwh	-0.05	0.19	3.15

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[8] One unit, no. 3009, is pointed out in the figures for use in Section 4 below.

average values of the E-scores is highest for RV, then Totlines, while both NumCust and Mwh have more modest differences. The smallest difference is for the input variable Loss. We have used the Kolgomorov-Smirnov one-sided test (D^+) for the equality of two distributions, and a T-test for comparison of means. H_1 is rejected for all variables on a 10%-level. The variable Loss has the weakest performance, failing the D^+ test on the levels 5% and 1%, and the T-test on level 1%. For all the other variables H_1 is rejected on a 1%-level. On the basis of these results we find it reasonable to proceed with our model specification.

Unduly outlier influence

In order to detect unduly influence from the outliers that by definition will form the set of best practice units we will first conduct a trial run. We will base our analysis on the three measures for the influence of peers introduced in Section 2. The measures are set out in Table 3. The peers split into three groups. One peer, unit 3009, stands out with especially high Peer index values, with an average of 44% that is over four times higher values on average than the next group of four units with average values in the range 10-8%. The third group of nine units has index values in the range 4-0%, with one self-evaluator. We note that the index values may vary considerably according to type of inputs for some of the peers, like unit 1023 with high value for Replacement Value, and unit 4192 with high value for loss in MWh. Unit 3009 has the highest count value almost double of the next two units that belong to the second group as to the value of the Peer index. Thus the two ways of measuring peer importance coincide.

The superefficiency index varies from 1.01 for the self-evaluator to 1.88. The maximal number means that the reference point on the frontier established without the peer in question in the data set on which the frontier is based, implies a use of inputs that is 88% higher than for the peer. But we see that this unit has quite low Peer index values, indicating that if the input data for this unit is increased it will not matter much for the overall results. It also has a moderate count value. The Superefficiency index is 1.21 for the most influential peer, implying that the "over consumption" of inputs at the frontier excluding this peer is 21%. Given that the units supporting the full frontier by definition are outliers this figure in itself dos not give rise to too much concern. We conclude that it

Table 3. The Peer index in %, Super efficiency score and count

Units	Total operating + maintenance costs	Loss in MWh	RV Replacement value	Average Peer index	Super-Efficiency	Count
1009	10.1	10	8.1	9.4	1.33	23
1023	6.4	6.2	19.3	10.6	1.83	37
2014	7.6	9.4	7	8	1.05	49
2016	0.8	1.4	2.4	1.5	1.88	15
2026	3	5.8	3.7	4.2	1.16	21
2124	2.9	0.9	2.2	2	1.29	25
3005	2.5	2.5	3	2.7	1.17	15
3009	47.9	44.5	38.6	43.6	1.21	88
3010	4.8	1.2	1.3	2.4	1.07	12
3017	2.4	0.8	1.7	1.6	1.1	9
4192	5.9	15.1	11.5	10.8	1.69	49
4462	0	0	0	0	1.01	0
5022	0.8	0.8	0.4	0.7	1.02	7
5047	4.9	1.3	0.8	2.3	1.41	18

is one unit, 3009, the one with the outstanding high value of the peer- and the count index that should be investigated further with respect to the overall results.

One consideration is how the peers influence inefficient units in other countries. Of the 14 peers we observe four truly multinational peers in the sense that they are referencing inefficient units from all five countries. The units are 1009, 1023, 2014, and 3009. The two units 2014 and 3009 stand out as referencing considerably more inefficient units than the other two multinational peers. The Dutch peer 3009 is especially important for Sweden in the sense that all but two of the Swedish inefficient units have this unit as their peer.

Due to the special influence of unit 3009 and its special character as a small utility in an urban area we have chosen to remove it from the data set. However, in the figures 2-4 we see that except for a very high maximal ratio of lines to replacement values the unit is not extreme. One reason for the high peer index value is its central location on the frontier.

5. The results

Efficiency scores

The distribution of efficiency scores for the CRS model (1) is shown in Figure 5. The distribution is sorted from the most inefficient unit to fully efficient ones. Each bar represents a unit; an electric utility company. The size of each unit, measured as total operating and maintenance costs (TOM) (including labour costs), is proportional to the width of each bar. The efficiency score is measured on the vertical axis and the TOM values measured in SEK are accumulated on the horizontal axis. Since an input is used as size measure, the share of the area between the step contour of the efficiency distribution and the upper limiting line at the ordinate value of 1 of the total area of the rectangle is approximately (the exact potential is input specific) equal to the total input saving potential (given the observed output structure). A rough visual estimation gives a total potential of about 20%. The exact numbers are 18% for total operating –and maintenance costs, 18% for energy loss and 19% for replacement value of capital. The

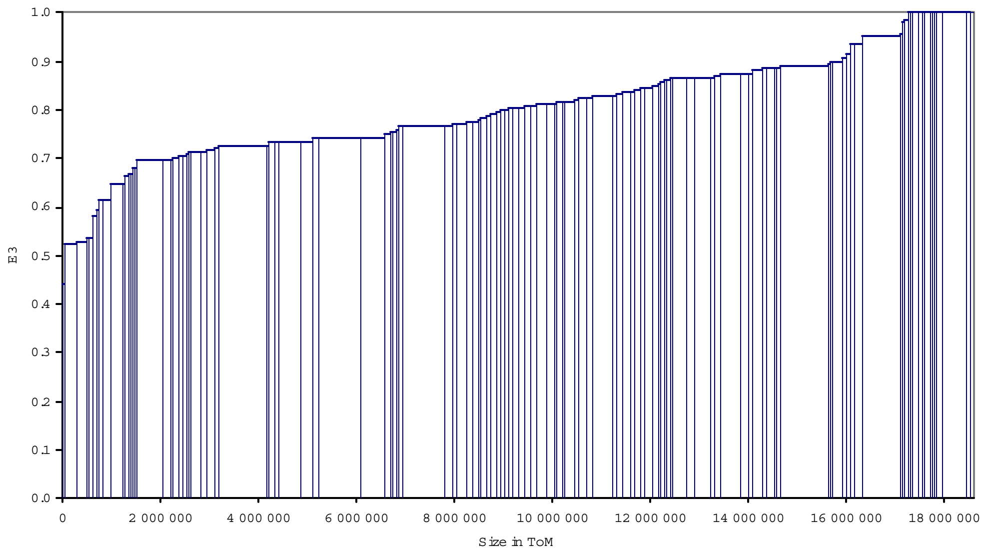

Figure 5. Efficiency distribution with common frontier

units are distributed in the interval from 0.44 to 1, and the share of TOM of fully efficient units is rather small, representing about 5% of accumulated TOM costs. There are 13 fully efficient units (one is a self evaluator) of the total number of 122 units. As to the size of the efficient units they are small and under medium, except for one large unit, but this is a self-evaluator. The largest units are all inefficient and located towards either end of the distribution.

Structural features of best- and worst practice units

From the efficiency distribution shown in Figure 5 we have calculated the average input- and output values of the 12 active peers (excluding the self-evaluator) and for the12 worst practice units. Since we have 122 units this number represents the upper and lower deciles of the distribution. The comparison is shown in Figure 6. It is the relative position in the radar diagram that reveals the structure. We see that best practice units (BP) on the average have higher values for all outputs, and relatively less in front regarding number of customers compared with worst practice units (WP). Concerning inputs the WP units have a significant over-use of capital (measured by the replacement value) leading to a much higher use of this input than for BP units, and also higher for

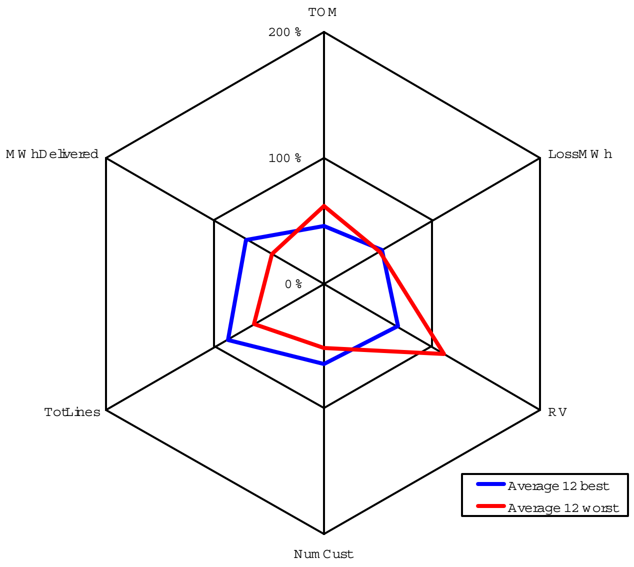

Figure 6. Structural comparison of best- and worst practice units

total operating and maintenance costs (TOM), while energy loss is actually a little lower than for BP units.

Country results

Since one common technology is assumed an inspection of where each country's units are located will be of interest. In Figure 7 the units for each country are put together and sorted according to ascending value of the efficiency score. It is remarkable that all countries have fully efficient units. This supports the use of a common technology, in the sense that no country is completely dominated by another. There are two aspects that the figure sheds light on: the size of the efficient units and how the efficient units stand out in the country specific distributions. For the three countries Denmark, the Netherlands and Sweden, the efficient units are quite small compared to average size within each country. This is especially striking for the Netherlands with the most pronounced dichotomy in size with one group of large units and the other with considerably smaller ones. The units within the group of large units have about equal efficiency levels, while the group with small units has units both at the least efficient part and the most efficient part of the distribution. The least efficient units have only half the value of the efficiency score than the average. For Finland and Norway the efficient units are closer to the medium size (disregarding the large Norwegian self

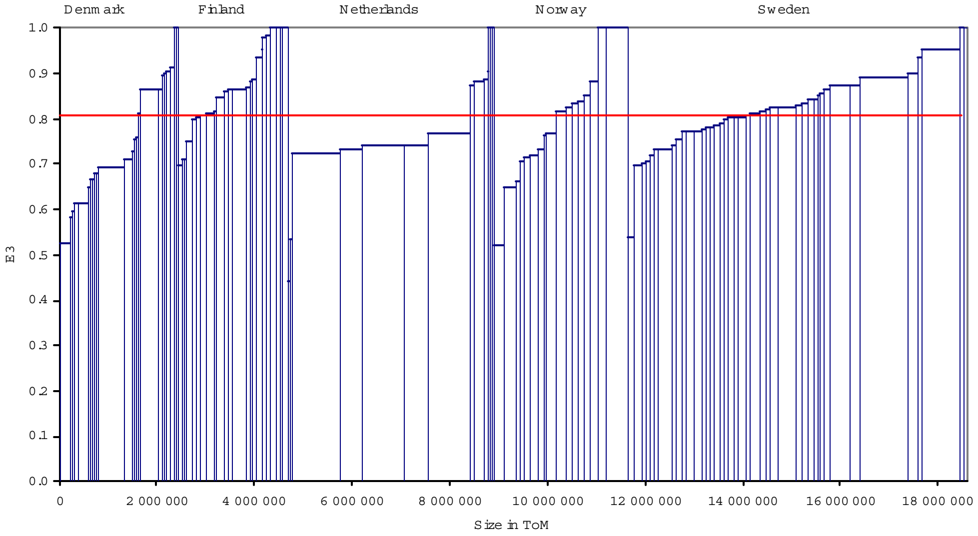

Figure 7. Country distribution of efficiency scores

evaluator). The inefficient units with the highest efficiency scores are quite below 1 for Denmark, the Netherlands and Norway, while they are much closer to the fully efficient ones in Finland and Sweden. This may indicate that we should pay attention to the influence of these former units when performing sensitivity tests. We will return to ways of measuring influence of efficient units below. The Swedish distribution is characterised by the large units being at the upper end of the inefficiency distribution, while medium- and small sized units are evenly located over the entire distribution. The Norwegian distribution has no marked size pattern, but has a much more narrow range of the efficiency scores for the inefficient units than Sweden. The range of the distribution for Finland is the most narrow without one or two extremely inefficient units like the case for the Netherlands, Norway and Sweden. Both for Finland and Denmark the largest units are located centrally in the distributions.

A summary expression for the different shapes of the efficiency distributions and different absolute size between units and location of size classes within country distributions the country share of the savings potential for the three inputs are set out in Table 4. Due to the large inefficient Dutch units that we see in Figure 7 the Netherlands has a higher savings potential than the other countries, especially for replacement value of capital. Sweden has a high potential for total operating- and maintenance costs, and Norway for energy loss. Denmark comes second to the Netherlands as regards saving potential for replacement value of capital, and has the smallest share for energy loss on the level with Finland. Finland has significantly lower savings potential for total operating- and maintenance costs and replacement value of capital than the other countries.

Table 4. Country distribution of savings potential shares

	TOM	Loss	RV
Denmark	0.19	0.14	0.22
Finland	0.08	0.14	0.10
Netherlands	0.29	0.28	0.33
Norway	0.16	0.25	0.18
Sweden	0.28	0.19	0.17

As explained in Section 2 a transitive Malmquist index may be obtained by comparing units with a representative standard. When we have a pooled technology the use of the total sample geometric average efficiency score may be interpreted as using such a standard (Equation (11)). The line of the geometric mean is inserted in Figure 7. We can then compare each unit within a country with this mean (efficiency scores are given in the Appendix). The figure gives a visual impression of such comparisons. As overall characterisations we may note that the median efficiency score of Denmark and Norway is below the total mean, while the median value of Finland, the Netherlands and Sweden are higher. The Netherlands is a special case since all the large units are less productive than the sample average.

The Peers

The definition of the Peer index is given in Section 4. The results (without unit 3009) are set out in Table 5. The peers split into three groups. Two peers, unit 3010 and 2014, stand out with especially high Peer index values, with over two times higher values on average than the next group of three units with average values in the range 12-8%. The third group of eight units has index values in the range 5-0%, with one self-evaluator. We note that the index values may vary considerably according to type of inputs for some of the peers, like unit 2014 with a high value for operating and maintenance costs, unit 1023 with high value for replacement value (RV), and unit 4192 with high value for loss in MWh.

The superefficiency index varies from 1.01 for the self-evaluator to 1.88. The maximal number means that the reference point on the frontier established without the peer in question in the data set on which the frontier is based, implies a use of inputs that is 88% higher than for the peer. But we see that this unit has quite low Peer index values, indicating that if the input data for this unit is increased it will not matter much for the overall results. The Super-efficiency index is 1.18 for the most influential peer, 3010, implying that the "over-consumption" of inputs at the frontier excluding this peer is 18%. Given that the units supporting the full frontier by definitions are outliers this figure in itself dos not give rise to too much concern. The count number is the third highest. The second most influential unit, 2014, has the highest count number, but a low super-

Table 5. The peer index for each input, super-efficiency and count

Units	TOM	LossMWh	RV	AVERAGE	SE	COUNT
1009	7.7%	7.5%	7.9%	7.7%	1.33	27
1023	5.5%	6.7%	20.4%	10.9%	1.83	39
2014	29.4%	19.9%	15.7%	21.7%	1.06	79
2016	0.7%	1.5%	2.4%	1.5%	1.88	11
2026	3.6%	7.0%	5.0%	5.2%	1.17	27
2124	4.0%	0.9%	2.3%	2.4%	1.29	19
3005	0.2%	0.4%	0.6%	0.4%	1.17	9
3010	25.4%	27.8%	25.2%	26.2%	1.18	63
3017	1.7%	0.7%	1.3%	1.3%	1.10	7
4192	7.7%	15.8%	12.3%	12.0%	1.69	71
4462	0.0%	0.0%	0.0%	0.0%	1.01	0
5022	11.5%	11.3%	6.6%	9.8%	1.10	41
5047	2.6%	0.4%	0.2%	1.1%	1.41	6

efficiency index of only 1.06, implying 6% over-consumption without this unit. The unit 4192 in the second most influential group in the range 12-8% has the second highest count number, and a high Super-efficiency value of 1.69, implying 69% over-consumption. The most notable changes of dropping unit 3009 are that units 2014 and 3010 have taken over its role. They have both increased their Peer index values. This is also notable for unit 5022, while unit 3005 has had a decrease.

Cross country peer pattern

We have already seen (in Figure 7 for Efficiency distribution on countries) that each country has peers. The pattern of country origin of peer and associated inefficient units can tell us whether the common technology assumption makes empirical sense overall, and about the nature of the peers: are they multinational or pure national peers? Table 6 is constructed on the basis of the solution for the weights, l_{ij}, (see the appendix) of the CRS model (1). It shows the number of inefficient units in each peer's referencing set. An inefficient unit may appear in on or more of the peer columns (the maximal number for each is five; the number of corners of a full facet in the CRS model with six variables). The country of origin of each peer is also shown. All the peers are referencing one or more inefficient unit from own country. Of the 13 peers we observe

Table 6. The national distribution of inefficient units on peers

	Denmark		Finland				The Netherlands			Norway		Sweden	
	1009	1023	2014	2016	2026	2124	3005	3010	3017	4192	4462	5022	5047
Denmark	10	21	13	4	4	8	5	12	4	6	0	1	0
Finland	8	3	15	3	13	2	2	12	0	9	0	2	0
Netherlands	6	11	6	0	7	0	2	6	1	7	0	0	0
Norway	2	3	12	4	3	1	0	5	0	15	0	8	0
Sweden	1	1	33	0	0	8	0	28	2	34	0	30	6
Total	27	39	79	11	27	19	9	63	7	71	0	41	6
Home index	0.37	0.54	0.19	0.27	0.48	0.11	0.22	0.10	0.14	0.21	-	0.73	1.00

five truly multinational peers in the sense that they are referencing inefficient units from all five countries. The units are 1009, 1023, 2014, 3010, and 4192. Of these the three units 2014, 3010, and 4192 stand out as referencing considerably more inefficient units than the other two multinational peers. On the next levels three peers are referencing units from four countries, three peers are referencing units from three countries, and one peer is referencing units from two countries. Only one peer is truly national and only referencing inefficient units from own country, Swedish unit 5047. Only one peer is a self-evaluator (Norwegian peer 4462). If we compare the number of inefficient units from the same country as the peer with the total number of times inefficient units appear in a peer's referencing unit set this number can vary between zero and 1. If we use as criterion for national peers that 50% or more of the inefficient units in a peer's set of referenced units is from own country, we have from the last row of Table 5 that three peers are national; units 1023, 5022, and 5047[9]. Both the Swedish units have a national role as peers. Unit 2026 is close with an index value of 0.48. We note that of the three units with the most inefficient units in their referencing unit sets unit 3010 has the most "international" profile with a national index value of 0.1, unit 2014 has 0.19 and unit 4192, has 0.21. Both the last two units are behind unit 3017 with "home index" value of 0.14.

Based on the pattern of country origin of peers and referenced units, Sweden has the most national peers with only one of its two peers referencing a few inefficient units

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[9] The second to last row in Table 5 for "Total" is also shown in Table 4 as the "Count" column.

from Norway, Finland and Denmark. The “home index” values are the highest of all peers, 1.00 and 0.73. Denmark and Sweden seem to be most apart with reference to the common technology frontier, since two of Denmark’s peers have only a single Swedish inefficient unit in their set of referenced units, and only one Danish inefficient unit has a Swedish peer. Two of the four Finnish peers have no Swedish units in their sets of referenced units. Three peers, one each from Finland, the Netherlands and Norway, have the maximal number of inefficient Swedish firms in their sets of referenced units; actually the Finnish and Norwegian ones refer more units than the Swedish peers themselves, and the Dutch one just a few less than the Swedish one with the highest number of Swedish inefficient units in its referencing unit set.

We can also investigate the cross-country relationships by focussing on the importance for inefficient units in a country of peers from each of the other countries, as explained in Section 2. The distribution of the index of cross country peer importance is set out in Table 7. The numbers are relative, i.e. 95 in the first cell mean that 95% of the inefficient Danish units have Danish peers, etc. We see that Finland and Norway are the only countries for which all the inefficient units have national peers. It is remarkable that all the inefficient units in the Netherlands have Danish peers. Inspecting the column for Sweden the rather special position is shown by the fact that none of the inefficient units from Netherlands have Swedish peers, and that the index values for Denmark and Finland are quite low, 5 and 10%. Norway’s role is special with 53% of Norwegian inefficient units having a Swedish peer. As for Table 5 of individual peer patterns the country index values for Sweden as regards Finland, Netherlands and Norway is on the same level as for Sweden itself, higher index for Finland and Norway and lower for the Netherlands. The disassociation with Denmark is shown by the low index value of 5% for the share of Swedish inefficient units having Danish peers.

Table 7. Cross country peer importance index (unweighted) in %

	Denmark	Finland	Netherlands	Norway	Sweden
Denmark	95	82	91	27	5
Finland	43	100	67	43	10
Netherlands	100	73	82	64	0
Norway	33	100	33	100	53
Sweden	5	85	73	83	78

Regarding the role as benchmarks it has been customary for Norway to look to Sweden (see Jamasb and Pollitt (2001) concerning benchmarking the national grid), but according to Table 6, following the rows, Norway should look to its own best practice distribution utilities, and also to Finland, since all the Norwegian utilities have both Norwegian and Finnish peers. Denmark should also first look to its own peers, and then to peers from the Netherlands. Finland should look first to its own peers, and then to the Netherlands, while the Netherlands should first look to Denmark and then to itself. Sweden should look to Finland and then to Norway. Looking at the columns Finland seems to be crucial as a benchmarking country for all other countries. However, it should be remembered that few units are involved in establishing these patterns, so Table 6 should only be taken as an indication of relationships to be studied further.

The cross-country pattern established in Table 7 is based on whether the l -coefficients are zero or positive. As argued in Section 2 a better representation of importance of peers may be obtained by developing the peer index to serve a study of links between countries. The results for the Cross country peer pattern index, r_{ij}^{s}, are set out in Table 8a-c. The picture we get has more nuances than the message from Table 7. For two of the three inputs Dutch peers are more important than Danish ones for inefficient units in Denmark. The unweighted peer pattern index was the same for Denmark and Norway, while we now see that the weighted cross-country peer index higher for Danish peers for two of the inputs. Dutch peers are in another league as being important for Finnish inefficient units than the other countries. It is remarkable that Swedish peers with a much lower unweighted index than Denmark and Norway have a much higher value of the weighted index. Denmark seemed to be most important for inefficient Dutch units with the unweighted index, but we now see that for

Table 8. Cross country peer pattern index in %.

Panel a. Replacement value of capital

	Denmark	Finland	Netherlands	Norway	Sweden
Denmark	39.8	17.5	37.8	0.3	4.7
Finland	2.1	72.4	20.3	0.7	4.5
Netherlands	45.4	10.9	40.6	3.1	0.0
Norway	15.5	23.7	5.7	43.1	12.0
Sweden	0.2	46.5	26.1	4.9	22.3

Panel b. Total operating and maintenance costs

	Denmark	Finland	Netherlands	Norway	Sweden
Denmark	34.6	15.2	40.1	0.4	9.8
Finland	3.6	57.5	32.2	1.2	5.4
Netherlands	38.4	14.0	45.2	2.4	0.0
Norway	10.2	22.9	8.1	40.6	18.2
Sweden	0.6	36.7	33.0	4.5	25.3

Panel c. Energy loss

	Denmark	Finland	Netherlands	Norway	Sweden
Denmark	36.7	16.1	38.4	0.3	8.4
Finland	3.1	60.1	31.3	1.2	4.3
Netherlands	38.3	14.9	44.4	2.5	0.0
Norway	9.1	22.6	8.7	44.0	15.5
Sweden	0.4	35.4	30.3	4.4	29.5

two of the three inputs Dutch peers are more important. Norwegian peers are most important for inefficient Norwegian units, while Finnish peers that seemed to be of equal importance looking at the unweighted measure now appear much less important, only half of the index value for Norwegian peers. The link to Dutch peers is not so strong, while a Swedish peer is much more important. For Sweden the role of Finnish peers is most dominant, while it is noticeable that Dutch peers are now more important than Swedish ones. A most remarkable result is the low impact of Norwegian peers, the weighted index values are all between 4 and 5%, while the unweigthed index showed the second highest value. The connection between Sweden and Denmark is still very weak, although for one input the Swedish peer has an index value of almost 10% for inefficient Danish units. The link from Swedish inefficient units to Danish peers is much weaker.

Productivity comparisons

In Section 2 ways of performing productivity comparisons depending on the technology assumptions were discussed. In the case of a common technology for all countries Table 9 shows the ratios of the geometric average of the efficiency scores for each country relative to all other countries and also to the total geometric mean (cf. (12)). Finland

Table 9. Relative country productivity measured by ratios of geometric means. Common technology

	Denmark	Finland	Netherlands	Norway	Sweden
Denmark	1.00	1.16	1.06	1.04	1.12
Finland	0.86	1.00	0.91	0.90	0.97
Netherlands	0.95	1.10	1.00	0.99	1.06
Norway	0.96	1.11	1.01	1.00	1.08
Sweden	0.89	1.04	0.94	0.93	1.00
Total average	0.92	1.07	0.97	0.96	1.03

seems to be the most productive country within the pooled technology, having higher mean value than all the other countries. Sweden comes most close, while Norway and the Netherlands are on about the same level, and Denmark is the least productive country. Starting with the latter country Finland and Sweden are the most productive countries relative to Denmark, while the Netherlands and Norway is in front with 4-6 percentage points. Norway's performance is closest to the Netherlands, lacking behind with about 1 percentage point. It is interesting to note, in view of the special situation of Sweden revealed earlier, that Sweden on the average is in front of all countries with the exception of Finland. We can use the performance against the total sample average as a final ranking. The last row shows that the ranking is Finland, Sweden, the Netherlands, Norway and Denmark, the two first countries being in front of the total (geometric) average and the other three behind.

Another approach to measuring overall efficiency is to focus on the (arithmetic) average unit within each country. Farrell (1957) introduced the notion of how the average unit kept up with the best practice units as a measure of structural efficiency within an industry. In Førsund and Hjalmarsson (1979) structural efficiency is measured as the average unit's efficiency score. In our setting of a common frontier we can use the efficiency score of the average units for each country against this frontier as a measure of structural efficiency. The numbers are set out in Table 10. We see that the ranking from the most efficient country to the least is Finland, Sweden, the Netherlands, Norway and Denmark, confirming the picture given by Table 9.

Table 10. Structural efficiency. Efficiency score of average unit.
Common frontier

	E-score average unit
Denmark	0.696
Finland	0.845
Netherlands	0.746
Norway	0.704
Sweden	0.842

We could also study structural differences by calculating relative productivities for the average units based on the efficiency scores in Table 10. The total picture is more or less the same as revealed by Table 9. Differences are due to differences in location of small and large units in the country efficiency distributions portrayed in Figure 7.

We have investigated the possibility of operating with individual country technology by running the DEA model for the three output- and three input variables. However, we may have a problem of dimensionality with Denmark, Finland, the Netherlands and Norway, since this sample includes 24, 25, 14 and 17 units respectively. The ad hoc rule

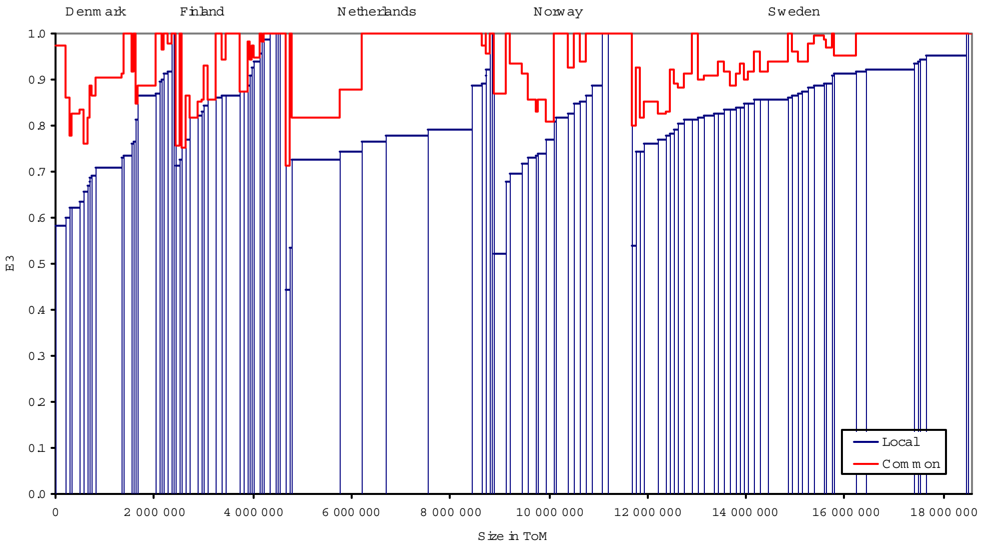

Figure 8. Local versus common frontier

that there are dimensionality problems if the number of dimensions multiplied with 3 is higher than the number of observations, apply to the Netherlands and Norway. A trial run of country specific technologies is presented together with the common frontier in Figure 8. As expected the number of efficient units in the Netherlands and Norway increase drastically, and also for Denmark. The individual changes for the units can be large. The distribution for Sweden with 42 observations is much more stable and we see a more or less parallel shift upwards of the whole distribution.

6. Conclusions

When doing international benchmarking for the same type of production activity in several countries, applying a common frontier technology seems to be yielding the most satisfactory environment for identifying peers. In our exercise for a sample of large electricity distribution utilities from Denmark, Finland Norway, Sweden and the Netherlands it is remarkable that peers come from all countries. Some new indices have been developed to capture the cross-country pattern of the nationality of peers and the nationality of units in their inefficient unit sets. Bilateral Malmquist productivity comparisons can be performed between units of particular interest, e.g. according to size, or location of utility (urban-rural), etc. We have focused on the average unit within each country. Our results point to Finland as the most productive country within the common technology.

The advantage of working with the DEA model is the rich details of the results and the concrete connections to actual units. However, this may also be a problem because it is not always so easy to find explanations for specific features. We would like to point out some issues of interest for further development:

i) Improve the comparability of data between countries by harmonizing definitions of variables and extending collection to cover environmental variables
ii) Define financial variables and collect data for cost efficiency exercises
iii) Investigation of scale properties by specifying variable returns to scale technology

iv) Increasing (where possible) the number of cross section observations enabling us to study country specific technologies

v) Establishing time series of cross sections enabling productivity developments to be studied

vi) In the latter two cases a more general transitive Malmquist index should be developed.

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Appendix

Appendix A: Efficiency Scores and dataset

	E3_ex3009	Opex	LossMWh	RV	NumCust	TotLines	MWhDelivered
1001	0.676734	22483.54	13339	991472.03	24377	2105.24	232688
1002	0.687793	41874.93	25400	1912762.9	45948	4185	523050
1003	0.66649	48059.15	36434	2931045.02	60158	5611	802616
1004	0.758842	45380.41	16177	1309396.04	47535	2676	657793
1005	0.727624	32375.18	17999	1861718.7	37259	4023	471385
1006	0.657099	42492.6	20330	2214205.9	49487	4052	540322
1007	0.916829	76215.32	16985	2563419.99	86466	5813	1097128
1008	0.812311	21796.45	7020	1364007.22	35234	2678.5	166015
1009	1	40655.85	15570	325498.92	59925	450	331845
1010	0.762892	53010.4	48734	2732238.56	69170	6624	713470
1011	0.865205	364461	111112	3622274.05	384388	4014	2642278
1012	0.691292	58687.26	20740	1901808.73	52719	3908	735879
1013	0.63218	83634.79	34035	2881461.51	65608	5980	709658
1014	0.707979	529844.28	258000	8350585.64	513460	15182.5	5746024
1015	0.913616	88721.74	53031	2432479.87	138114	5147	1461126
1016	0.622759	176880.98	52213	3855713.72	116476	7852	1350991
1017	0.896387	63349.39	20500	725323.55	70237	1398.4	654766
1018	0.898915	24718.9	9158	325870.61	31982	591.77	251087
1019	0.600395	62098.04	22297	2061775.1	38278	4365.8	446211
1020	0.734747	173601.21	108533	5223067.45	171487	14198	1789351
1021	0.583886	203411.89	77605	2336584.06	51544	6103	839511
1022	0.867427	76631.62	21850	1234181.31	67225	2121	1001450
1023	1	44364.26	13971	3021076.31	98220	6951	1310486
1024	0.619665	56091.1	23849	1370505.56	47718	2613	480210
2011	0.954618	28084.79	41567	556848.34	44878	1275.9	515100
2013	0.88559	31487.24	26885	782959.79	37168	2580.1	507500
2014	1	117635.87	111511	4967079	131352	22537	1772000
2016	1	61904.41	122431	5591432.09	85764	22316.1	1063000
2017	0.865689	293538.89	223035	3726767.33	311836	9369.1	5100700
2019	0.767227	63907.43	68439	926690.4	40436	3074.2	530700
2023	0.726788	42602.33	26626	535928.99	39975	1168.6	503600
2026	1	41467.65	60705	923739.13	68804	2599.6	1214300
2029	0.936644	131712.15	152733	6168021.04	152816	24545.4	2071800
2030	0.855195	151031.57	135114	5112500.91	78532	19837.8	1016900
2033	0.823428	97493.81	67366	2296659.62	43745	8516.2	953300
2049	0.907632	47200.91	44824	1363078.21	48775	5367.3	665000
2053	0.712084	65120.9	74238	1129027.32	61911	2253.8	1281700
2067	0.831881	39719.94	48205	1202150.43	41389	4182.9	567000
2072	0.98179	53958.53	50586	2351726	53354	10204	804000
2073	0.985205	98307	91561	1312772.54	115532	3306	2350000
2074	0.859157	126295.65	165898	1581392.34	115137	5037.8	1794000
2085	0.752136	104968.49	78408	3646622.82	51432	12300.8	723700
2094	0.871337	89267.42	103726	3849875.15	75194	15148.4	977800
2098	0.923922	41390.43	80864	941331.66	42810	3591	658800
2107	0.844706	73993.43	57754	1455898.48	71179	4885.5	1089000
2109	0.816422	165716.16	245009	6191209.5	98413	22934.3	1726300
2115	0.865243	67284.66	79297	1079420.74	82925	2718.1	1263000
2117	0.871577	78743.31	96076	2583052.64	56644	10214.9	769000
2124	1	135721.34	38729	3837631.88	106058	14790.1	1932600
3002	0.892797	77772.73	54971.06	1775177.33	116197	3779	1125723.15
3003	0.884367	204942.6	105799.65	5215163.13	188350	9008.6	6142004.02
3004	0.44042	57875.75	51272	6590767.14	46535	2358	855265.29
3005	1	41329.16	38323.01	1273187.03	84733	2311	868205.68

3006	0.765765	496853.29	295280.89	7961906.18	405119	18737	9007000
3007	0.792201	855985.33	587644.1	18742123	929079	44413	13493000
3008	0.775645	854417.47	430000	22035845.9	887370	53800	11402761.1
3010	1	25715.99	8700.51	211788.45	29160	776.38	274662.64
3011	0.535676	40998.93	20731.56	3128177.87	48623	2905.7	428336.95
3012	0.727185	981538.02	615281	13222556	1052096	21408	10836294.74
3013	0.741053	448438.52	181002.87	7723032.8	490721	12689.6	4528658.56
3016	0.907843	11273.71	8273.98	374280.42	20035	691	204510.47
3017	1	42565.72	12345.79	345590.96	45315	948	458463.66
3018	0.920098	81399.68	36243.22	993553.38	98509	2741	851054.64
4006	0.769322	172683.61	179469	2766162.57	52062	6345.43	6022192
4015	0.846969	117144.41	115530	2596728.4	52384	8616.63	3034062
4032	0.806571	48341.37	48800	864663.15	34836	2720.49	892255
4064	0.678837	90038.04	42945	1809745.63	36801	5011.25	1034089
4071	0.729231	128540.66	118962.99	2448860.54	39319	6937.37	2631234
4134	0.52227	224755.52	180984	8000838.15	74768	12825	4588150
4192	1	141482.06	100092	2022617.72	53333	5300.73	6866079
4227	0.718325	156336.1	206466	3634676.41	60440	9179.45	4601819
4301	0.733648	72121.2	102655	995363.12	30098	2267.29	1907885
4412	0.851324	129279.75	141906	1942061.99	72184	4135.29	4677916
4422	0.817323	214901.71	195997.2	5365991.47	135574	13388.86	7267680
4462	1	471899.94	505283.58	5784251.32	303734	11233.82	17805473
4503	0.86307	120463.41	109171	1933818.6	45531	6456.55	2601455
4511	0.885158	167795.64	148345	8044530.02	91435	9946.6	6672297
4536	0.826347	146958.56	175540	2065511.03	83125	4721.36	4699095
4540	0.740334	143654.33	178592	2833596.14	57410	7679.71	3740307
4549	0.69367	217205.64	139000	2677271.57	88642	7852.63	2143930
5006	0.889958	93991	35866	1251823.29	38739	4834	785788
5010	0.817186	100606	41082	681571.38	62670	1977	1113204
5017	0.822076	219827	71548	3162057.9	74745	11573	1127620
5022	1	72348	32630	380432.09	34840	1588	733419
5025	0.933988	82956	31610	1715049.68	35396	6912	576548
5028	0.865628	127184	44000	2021594.3	40033	7856	655985
5031	0.742655	67318	25640	517436.33	42306	1305	755680
5037	0.855105	179753	66447	1702379.91	83429	6163	1394750
5047	1	80273	32300	273288.51	50557	774	998733
5062	0.882891	144330	55055	1989475.99	52322	7871	916177
5069	0.811926	146065	44552	2683695.54	64959	9065	1005493
5070	0.846405	116384	55132	1123310.28	55316	3806	1402782
5075	0.744348	95426	41000	1494621.24	36364	4772	835370
5078	0.823672	69229	23164	497337.63	38790	1488.4	692703
5081	0.915577	206752	66900	1490805.39	158858	4873	2207387
5121	0.802283	98621	37617	878983.45	63956	2689.95	985086
5128	0.942434	108708	36143	955316.95	65240	3552	1093065
5135	0.781832	101172	50898	1184711.32	69444	3700	1104800
5138	0.872834	99622	52000	918120.08	39638	3532	736000
5144	0.792681	101234	69712	1723129.7	53804	5871	1243737
5146	0.777218	75721	27611	503521.04	36458	1449	705183
5148	0.824197	113219	45422	741626.86	76282	2125	1238588
5149	0.953281	789833	229380	2792562.95	448920	7639	6637400
5151	0.53718	106616	31000	1510914.54	45985	2711.6	806002
5155	0.887464	185793	80831	3348675.32	58622	13484	953900
5159	0.767746	141326	59665	1617596.16	52814	5379	1072666
5166	0.846268	61606	31900	394714.45	34600	1292	605408
5167	0.856693	391502	151000	6057432.3	123434	22998	2807043
5171	0.835255	96674	45859	645833.6	48303	2232.2	751727
5176	0.93772	66410	24680	484542.59	39101	1859	572341
5182	0.889199	68989	26206	566350.27	36218	1904	815022

5195	0.912416	420237	156400	1919833.26	241040	6051	4228600
5196	0.906006	59133	33614	1031059.39	41657	3843	960439
5199	0.811651	148871	142000	2462513.61	54590	8532	1945835
5203	0.837082	97378	39070	845779.23	49330	2733	1082023
5208	0.837725	94128	41553	1636356.04	41820	6118	680770
5214	0.83233	148327	52423	2355029.84	43304	8737	837825
5215	0.858753	73306	22123	547114.77	44420	1647	800157
5217	0.869614	88546	29327	891579.48	31934	3370	589000
5219	0.854295	128356	64895.6	2327161.63	35712	9010	754600
5235	0.922202	980700	314654	13806798.1	309693	54166	8276786
5236	0.759864	278733	121785	4672085.9	101499	16060	1474213

Appendix B: Weights. Peers in column header, referenced units in row headers.

Lambda													
	1009	1023	2014	2016	2026	2124	3005	3010	3017	4192	4462	5022	5047
1001	0.082	0.125	0.053				0.003						
1002	0.130	0.244	0.108				0.001						
1003		0.412	0.044	0.067	0.059		0.049						
1004		0.234	0.003			0.023		0.716		0.015			
1005		0.265		0.058		0.061							
1006	0.011	0.371	0.060					0.155					
1007		0.687				0.044		0.489					
1008		0.340		0.002		0.019							
1009	1.000												
1010		0.228	0.108	0.086			0.298						
1011	4.978	0.377							1.082				
1012		0.249	0.016			0.091		0.550		0.008			
1013		0.267	0.069			0.147		0.504					
1014	2.820	0.823			0.981			6.528		0.109			
1015	1.006	0.459	0.019		0.358		0.067						
1016		0.282				0.295		1.972					
1017	0.403	0.070							0.859	0.005			
1018	0.384	0.042						0.076	0.055	0.003			
1019		0.108	0.031			0.190		0.114					
1020	0.911	0.316	0.488		0.005			0.732					
1021			0.227					0.019				0.607	
1022		0.217							0.966	0.040			
1023		1.000											
1024	0.090	0.149	0.042					0.760					
2011	0.179				0.364		0.108						
2013	0.012	0.025	0.071		0.200			0.378					
2014			1.000										
2016				1.000									
2017	0.935				1.623			4.522		0.230			
2019			0.094					0.585				0.317	
2023	0.088	0.009			0.180			0.723		0.007			
2026					1.000								
2029			0.750	0.296	0.342		0.064						
2030			0.880										
2033			0.345									0.466	
2049			0.209		0.070			0.549		0.008			
2053	0.092				0.644			0.311		0.056			
2067	0.028		0.156		0.177			0.240					
2072		0.007	0.384	0.044		0.035							
2073	0.794				0.609			0.576		0.173			
2074			0.080		0.111			3.153		0.095			
2085			0.510			0.055							
2094			0.649	0.024									
2098			0.121		0.093			0.666		0.022			
2107			0.142		0.203			1.258		0.036			
2109			1.018										
2115	0.107				0.765			0.798		0.012			
2117			0.453										

2124						1.000							
3002	0.774	0.101	0.050		0.199		0.467						
3003	0.512	0.970							0.619	0.643			
3004		0.453								0.038			
3005							1.000						
3006		0.450	0.131		1.138			7.862		0.676			
3007		1.905	0.383		4.269			13.249		0.218			
3008		2.818	0.876		0.885			14.621		0.155			
3010								1.000					
3011		0.495											
3012	11.014	0.556			3.799			2.288		0.176			
3013	4.777	1.069			0.218			2.757		0.076			
3016	0.043	0.038	0.002				0.159						
3017									1.000				
3018	0.701	0.041	0.035		0.091			1.424					
4006			0.078							0.852		0.042	
4015			0.285							0.343		0.237	
4032			0.077					0.685		0.081		0.010	
4064			0.145			0.078		0.168		0.084			
4071			0.213							0.287		0.389	
4134		0.502	0.057	0.237						0.521			
4192										1.000			
4227			0.168	0.096						0.612			
4301			0.024					0.388		0.249		0.068	
4412	0.208				0.403					0.600			
4422		0.211	0.026	0.226	0.673					0.857			
4462											1.000		
4503			0.180							0.266		0.625	
4511		0.335		0.131						0.888			
4536	0.029				0.353			0.889		0.585			
4540			0.216							0.467		0.205	
4549			0.217					0.072		0.090		1.528	
5006			0.186					0.228		0.040		0.157	
5010								1.324		0.044		0.362	0.180
5017			0.477			0.035		0.248		0.021			
5022												1.000	
5025			0.218			0.136							
5028			0.329			0.028				0.003			
5031								1.175		0.047		0.057	0.071
5037			0.174					1.129		0.034		0.740	
5047													1.000
5062			0.321							0.013		0.351	
5069			0.201			0.292		0.255		0.002			
5070			0.078					0.447		0.081		0.793	
5075			0.186					0.231		0.058		0.061	
5078			0.010					1.031		0.041		0.148	
5081			0.006					4.958		0.096		0.241	
5121			0.035					1.691		0.043		0.221	
5128			0.077					1.558		0.057		0.192	
5135			0.077					1.564		0.044		0.327	
5138			0.104									0.753	
5144			0.199					0.069		0.058		0.648	
5146			0.007					0.775		0.036		0.317	

5148							1.647	0.037		0.233	0.359
5149	1.142						3.676 0.343				5.098
5151		0.016			0.121		0.655	0.037			
5155			0.598								
5159			0.180				0.179	0.035		0.636	
5166							0.576	0.013		0.489	0.002
5167			0.973					0.133		0.232	
5171			0.018				0.482			0.916	
5176			0.028				0.716	0.003		0.412	
5182			0.029				0.703	0.056		0.257	
5195							2.682	0.038		1.239	2.327
5196			0.124				0.571	0.070		0.142	
5199			0.283					0.102		1.009	
5203			0.047				0.878	0.068		0.401	
5208			0.256				0.121	0.017		0.110	
5214			0.363		0.031			0.020			
5215			0.011		0.003		1.358	0.059			
5217			0.120				0.213	0.019		0.259	
5219			0.394							0.076	
5235			1.911		0.551			0.557			
5236			0.688							0.348	
AU		0.027	0.209	0.120			2.174	0.140			