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REGULATING TRANSMISSION SYSTEM OPERATORS: AN INCENTIVE SCHEME FOR THE NORDIC ELECTRICITY MARKET

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Abstract

The transmission system operators (TSOs) of the Nordic countries play a crucial role in the development of an integrated regional electricity market in Scandinavia. They provide the transmission networks that enable trade of electricity between the countries. The TSOs are currently operating under rate of return or revenue-cap regulation as decided by the national regulators. These regimes may to differing extents provide incentives for cost-efficiency, but they do not explicitly give incentives for integration between national markets. The purpose of this paper is to design an incentive scheme that gives incentives TSOs to act in ways that increase the trading capacities between countries, thereby promoting market integration. The scheme is based on the output-oriented technical efficiency ($TE_o$) of the TSOs. This is related to integration by constructing an output measure for TSOs that includes the market expanding effects of trade. A benchmark model is used to estimate $TE_o$ for six TSOs using a panel data set. The model is estimated by two methods, COLS and SFA (REM), using a Cobb-Douglas log-linear function. The preferred model is shown to be the REM. Estimated efficiency scores are in the range 56-100 percent, with an average of 75 percent.

1. Introduction

The political vision of an integrated electricity market in Europe has been formed both at a regional level in the Nordic countries [1] and at a European level by the EC [2]. Integration is thought to bring benefits arising from a more efficient use of resources, such as higher utilization of cost-efficient generation and complementary supply and demand structures in the different countries. The development of an integrated regional electricity market in Scandinavia is an ongoing process that involves several aspects of the electricity market. Wholesale markets have been integrated through a common power exchange and integration of retail markets is in progress through harmonization of differing market conditions. An essential part of this process is the development of electricity transmission infrastructure that interconnects geographically separate markets and enables the physical exchange of electricity between countries. A key actor in this area is the Transmission System Operator (TSO) who owns, operates, maintains and develops the high-voltage transmission grid. The TSO is a natural monopoly utility that grants non-discriminatory access to the grid for market actors. Through this responsibility the TSO has a part in market facilitation, meaning that it provides the physical market place that enables producer and consumers to meet and trade both nationally and across borders. This market place can be expanded through investments in new cross-border interconnections, national grid expansions and other congestion management measures that increase the trade capacity of existing connections. The direction of the TSO’s grid development and congestion management is thus of great interest from an integration perspective.

As natural monopolies the TSOs are subject to regulation. In the Nordic countries the TSOs operate under rate of return and/or revenue-cap regulation [3]. These are economic regulations
that focus on the economic aspects of the TSO-operation, such as reasonable tariff levels and cost-efficiency. Regulations of grid development and congestion management are less developed. Directions for this have been given by the European Union (EU) in directives and legislations [2], [4], [5]. Nordic energy regulators (NordREG) are working on indicators that can be used to monitor the TSOs compliance of the EU congestion management guidelines [6]. Work is also in progress on how to transform directives and guidelines into incentive regulation that incentivises TSOs to enhance their performance of grid development and congestion management [7], [8]. The purpose of this paper is to contribute to this work by proposing an incentive scheme based upon the output oriented technical efficiency of the TSOs.

2. Incentive regulation

2.1 Background to incentive regulation theory

Regulation is commonly characterized as a principal-agent relationship between the regulator and the (monopoly) firm. A typical attribute of this relationship is the information asymmetry between the two parts. The regulator wants the firm to achieve specified objectives in an efficient manner, but it does not know all the circumstances applying to the realisation of the objectives. Such circumstances include the cost structure of the firm and the characteristics of its technology. The firm on the other hand is likely to have more detailed knowledge of these things and of what is required to achieve different objectives. This asymmetry gives the firm a strategic advantage against the regulator and could lead to the firm operating less efficiently than it would in a competitive environment, where its existence would not be protected by a monopoly status. The traditional economic regulations “cost of service” and “rate of return” regulation has been criticised for causing moral hazard problems since the firm has little incentive to reduce its costs when prices are allowed to follow costs [9]. There is therefore a need for regulation that gives firms economic incentives to achieve objectives in an efficient way.

Price-cap regulation and the associated X-factor efficiency targets were introduced to give firms a “bonus” in the form of larger profits if they could beat the target. This solves the moral hazard problem by giving incentives for higher managerial effort, but gives rise to the problem of adverse selection [9]. Due to the asymmetric information problem, the regulator is uncertain about what the regulated firms’ inherent cost structures are and what potential efficiency gains could be made. This leads to the risk of setting the price-caps either too high or too low in relation to actual costs. A remedy to the information problem is the application of yardstick competition [10] or competitive benchmarking [11]. These methods work by deriving some benchmark or reference performance against which a firm’s actual performance can be compared. The benchmarks can be derived through parametric or non-parametric methods that estimates or calculates a production or cost frontier that defines the maximum production or minimum cost levels attainable in the industry [12]. This increases the regulators information about what the efficient levels of cost and/or production are and informs the decision of suitable price-caps. An important part of this methodology is the recognition of the heterogeneity of firms operating environments. This can be accounted for by normalizing the benchmarks with regards to observable heterogeneity of the firms. Unobservable heterogeneity poses a larger problem, but can be handled through stochastic frontier methods [13], [14]. Well designed incentive regulation can hence be an effective way to provide regulated firms with incentives to exert managerial effort to reach the uncovered efficiency potential in their operation.
2.2 An incentive scheme

As discussed in section 2.1, an incentive scheme is based on some performance measure that can be used as an indicator of a firm’s performance in one or several aspects, at different points in time. Connecting the firm’s performance over time with financial rewards and penalties will result in an incentive for the firm to align its performance with that associated with a reward, rather than a penalty. The difficulty in designing an incentive scheme is to define a performance indicator that both reflect the aspect of operation that is subject to improvement and that can be accurately measured. Likewise important is that the regulated firm can affect the level of the indicator. If these points can be fulfilled, an incentive scheme could be formulated as in (1).

\[ I = \frac{E_{t_1} - E_{t_0}^*}{E_{t_0}} \]  

\( I \) = Reward or penalty  
\( E_{t_0} \) = Firm’s performance in time \( t_0 \)  
\( E_{t_1} \) = Firm’s performance in time \( t_1 \)  
\( E_{t_1}^* \) = Target performance in time \( t_1 \)

The model (1) relates the percentage development of a firm’s performance indicator between time-points \( t_0 \) and \( t_1 \) with a target development for time \( t_1 \). The time-range from \( t_0 \) to \( t_1 \) is the regulatory period for which measurement of the indicator is done at the beginning and end. If the firm’s performance improvement between \( t_0 \) and \( t_1 \) is larger than the target, the value of \( I \) will be positive and the firm will receive a reward. If not, \( I \) will be negative and the firm will receive a penalty. The size of the reward or penalty is not specified by the model (1), it only defines by how many percent the firm exceeds or fails the target. To define a financial reward or penalty, the percentage \( I \) needs to be transformed into monetary terms. There are plenty of ways that this could be done. The simplest example would be to use \( I \) directly as a percentage change in allowed revenue or tariff-level under revenue- or price-cap regimes, or in the regulated rate of return. Alternatively, if the level of \( I \) is unreasonable to use directly, it could be transformed into a more suitable magnitude by defining the reward or penalty as a function of \( I \), see [7] for an example of this. Another consideration is to put a cap on the size of the potential reward or penalty, so as to limit the risk exposure of the firm.

2.3 Efficiency analysis and benchmarking

The study of productive efficiency can be divided into technical efficiency (TE) and economic efficiency [13]. TE is a purely physical notion relating to the maximum technically feasible output producible by a given input bundle, referred to as output oriented TE, or the minimum input bundle necessary for producing a given output, referred to as input oriented TE. Economic efficiency most commonly refers to cost efficiency (CE), which is an input oriented measure describing the minimum cost achievable for a given output. Regulation theory is for the most part concerned with the economic efficiency of firms, since it is the potential for cost-savings that is interesting to regulators [15]. The concepts are of course related since an increased TE will allow for higher CE.

To derive a “best practice” benchmark against which the technical efficiency of individual firms can be measured, a representation of the technological possibilities of the firms is necessary. Such a representation can be obtained from observations of different input and output combinations of firms in the same industry. Non-parametric techniques such as DEA [12] achieves this by enveloping all observations in a linear “hull”, where the best
observations define the shape of the hull. Parametric techniques on the other hand begins with defining a functional relationship between outputs and inputs and estimates the parameters of this function using statistical methods. This results in the traditional production function reflecting the average performance of the observed firms. However, for the purpose of efficiency studies it is more appropriate to define a function that reflects the best performance of firms. This is referred to as a production frontier and can be estimated by the methods of Corrected Ordinary Least Squares (COLS) and Stochastic Frontier Analysis (SFA). These methods are described in the following sections.

2.4 COLS
Equation (2) describes a deterministic production frontier written in the log-linear Cobb-Douglas form [13].

\[
\ln y_i = \beta_0 + \sum_{n} \beta_n \ln x_{ni} - u_i \quad u_i \geq 0 \tag{2}
\]

The disturbance term \( u_i \) in (2) is non-negative to ensure that no observations lie above the frontier. \( Y_i \) is the output of firm \( i \) and \( x_{ni} \) are inputs used by \( i \). Ordinary Least Squares (OLS) estimation of (2) will give a biased estimation of the intercept \( \beta_0 \) since the restriction \( u_i \geq 0 \) is not satisfied by OLS. A way to obtain an unbiased estimate of \( \beta_0 \) is the Corrected Ordinary Least Squares (COLS) approach. The description of the COLS-method below is based on that given in [13]. COLS estimates (2) with OLS and then corrects the intercept as in (3).

\[
\hat{\beta}_0^{\text{COLS}} = \hat{\beta}_0 + \max_i \left\{ \hat{u}_i \right\} \tag{3}
\]

Equation (3) obtains an unbiased estimate of the intercept \( \beta_0 \) by adding the largest OLS residual to the estimated OLS intercept. With this correction (2) will bound the data from above. An estimation of the individual efficiencies of firms can be based on the residuals of the OLS-regression, after they have been corrected in a similar manner as the intercept with the difference that the largest residual is now subtracted (instead of added) from each residual, as shown in (4).

\[
\hat{u}_i^{\text{COLS}} = \hat{u}_i - \max_i \left\{ \hat{u}_i \right\} \tag{4}
\]

Finally, using cross-sectional data, the technical efficiencies of the individual firms can be obtained from (5).

\[
TE_i = \exp \left\{ -\hat{u}_i^{\text{COLS}} \right\} \tag{5}
\]

If using panel data, the efficiency of a firm is derived as the average of its efficiency scores. The COLS-method can be described graphically as in figure 1.
In figure 1 the OLS estimation of the production function $Y_{OLS}$ with intercept $\beta_0$, is parallel shifted up to the level of the largest positive residual. The corrected function $Y_{COLS}$ now lies on or above all the residuals.

Estimation of (2) with the COLS-method means that at least one firm observation will be defined as 100 percent efficient. Since the COLS-method uses the residuals as basis for measurement of efficiency, it interprets all deviation from the frontier $Y_{COLS}$ as inefficiency. Any occurrences of random shocks, measurement errors and unobserved heterogeneity will therefore be interpreted as inefficiency. However, the same problem occurs in the non-parametric method DEA [12].

2.5 SFA

An alternative way to derive a parametric estimation of the frontier is to use a stochastic frontier model (6).

$$\ln y_u = \beta_0 + \sum \beta_n \ln x_{ui} + v + u_i \quad u_i \geq 0 \quad (6)$$

Model (6), which is presented in a panel data formulation, contains both a symmetrically distributed error term $v_i$ and a one-sided time-invariant inefficiency term $u_i$. The term $v_i$ represents the traditional random error term familiar in conventional OLS-regression, explaining deviations from the frontier that is due to the effects of random shocks and measurement errors. The term $u_i$ is a negatively skewed error term that explains deviations from the frontier that can be interpreted as inefficiency. Separation of the respective effects of the two terms can be accomplished either by fixed- or random-effects panel data models (FEM and REM), or by maximum likelihood estimation (MLE) with distributional assumptions on the two error terms [13]. In FEM and REM estimation the most efficient firm (or firms) will be regarded as 100 percent efficient and the efficiency of the others will be measured in relation to that/those firm(s).
FEM estimation uses the fixed effects as an estimation of inefficiency. This is problematic in an efficiency context because the fixed effect includes all time-invariant characteristics of firms and can therefore not distinguish heterogeneity from inefficiency (regardless of whether the time-invariant heterogeneity is observed and included as regressors in the model). This leads to an overestimation of inefficiency [16]. REM does not suffer from this drawback and provides an interesting alternative if the assumption of no correlation between regressors and error terms can be made. Another conceptual difference between FEM and REM is that of whether the observed firms can be thought of as a sample taken from a single population of similar firms (REM), or whether they are so different from each other that they can not be considered as a population with similar characteristics (FEM). A test for which of the two specifications that is most appropriate for a given data-set is the Hausman-test [17], which is based on the difference between the two estimates. Another test to consider when choosing between different model specifications is the Lagrange-Multiplier test for panel data specification vs. a conventional OLS specification [17]. This distinguishes whether the heterogeneity in the data is significant enough to warrant a panel data treatment instead of OLS.

REM estimation assumes that the population of firms share a common intercept term and that firm specific heterogeneity can be represented by a time-invariant random variable \( u_i \). The REM can be estimated by modifying the stochastic frontier model (6) to model (7) [13].

\[
\ln y_{it} = \left[ \beta_0 - E(u_i) + \sum_n \beta_n \ln x_{nit} + v_{it} - \left[ u_i - E(u_i) \right] \right] \\
= \beta_0^* + \sum_n \beta_n \ln x_{nit} + v_{it} - u_i^* 
\]

This model is estimated by a two-step GLS procedure. The \( u_i^* \) is estimated from the residuals of (7) as the average residual for each firm \( i \). Estimates of \( u_i \) can then be made from (8).

\[
u_i^{REM} = \max \left\{ \left\{ \nu_i^* \right\} - \nu_i^{REM} \right\}
\]

Firm-specific efficiency is estimated by inserting \( u_i^{REM} \) into (5).

3. An integration incentive scheme for TSOs
An application of incentive regulation as described in part 2 requires a specification of the output produced by TSOs and the inputs used in this production. Part 3 will discuss these issues.

3.1 A measure of TSO output
The TSO-operation includes several tasks. Nordel and NordREG [18] (see also [19] for a definition of core functions of TSOs) has summoned the core tasks of the Nordic TSO as; Ensuring the operational security of the power system; Maintain the momentary balance between supply and demand; Ensure and maintain adequacy of the transmission system in the long term; Enhance efficient functioning of the electricity market. The last two tasks relates to the TSO’s role as market facilitator, meaning its function in making electricity trade possible in- and between countries. This involves planning the expansion of the electricity grid from both national and Nordic perspectives. The extent to which the TSOs perform this role will
affect the physical integration of the Nordic electricity grids and thereby the expansion of national markets to a Nordic market. Physical integration has an economic impact through the price-effects that result when supply resource with different production costs becomes available for a larger demand base with different willingness to pay. The effect on prices and electricity consumption in a two-country example is depicted in figure 2.

Figure 2. Effect of electricity trade on supply and demand in two separate areas.

Supply $S_A$ in area A of figure 2 represents a production technology with lower costs relative to supply in area B. Price will therefore be lower in area A compared to B. The utilization of transmission capacity between A and B results in a price increase in A and a price decrease in B. Consequently, the quantity consumed will decrease in A and increase in B. However, the sum of electricity consumed and produced in each area has increased in both A and B. This quantity can be reformulated as consumption plus export for each area. Using this as a definition of electricity output means that output will continue to grow as cross-border transmission capacity is expanded, as long as a price difference remains between the two areas. Transmission capacity can be expanded in a number of ways: By investing in new cross-border interconnections; By increasing the capacity available on existing interconnections through removal of internal transmission constraints; By using counter-trade to simulate a larger capacity than the physically available.

The reasoning above highlights the importance of the TSOs role in market integration. It can also be used to argue that a TSO can affect the size of the electricity output, defined as consumption plus export, by integrating its grid with those of neighbouring countries. A condition for this to hold is that the production and demand structures in the countries are different enough to give rise to inherent price-differences, so that there are complementary benefits from integration. The Nordic power system shows these complementary differences through hydro- and thermal power dominated parts, as well as differences in demand due to seasonal temperature differences. In this study, the TSO output will therefore be measured as in (10)

$$\text{Output} = \text{National electricity consumption including imports + exports} \quad (10)$$

The use of (10) as an output measure is likely to capture the results of the TSO’s tasks of expanding the transmission grid and enhancing the efficient function of the market. This is
because the output measure should be expected to increase if these tasks are successfully performed by the TSO, given that exogenous factors that also affect output is controlled for. More uncertain is to what extent the task of maintaining the operational security of the power system is captured by the output measure. These and other tasks that are not accounted for could be supervised through complementary methods such as quality regulations [9].

The output measure presented here assumes that the TSO can affect the amount of output produced. This represents a different view than that traditionally taken in studies of transmission and distribution utilities [11]. Because the demand for transmission services is a derived demand originating from the derived demand for electricity, it has been assumed that the TSO meets a given demand that it can not affect. A natural output measure then becomes the amount of electricity transferred by the TSO. The reasoning in this section on the contrary argues that the TSO can affect the demand by enlarging the market and increasing the possibilities for international electricity trade.

3.2 TSO inputs
The output measure (10) can be used as the dependent variable $y$ in the benchmark models of section 2.3. Remaining is a specification of the inputs $x_n$ that are used in the production of $y$. The applications in the literature on production functions for TSOs are sparse. For the most part it is cost functions that are specified and used in benchmarking, see [11] and [19] for examples. Pollitt [20] provides an example of a production function for the transmission service with three inputs and three outputs. The inputs suggested, based on the traditional production inputs of labor, capital and energy, are: Number of employees; Circuit km*Capacity (kV); and Electric energy losses. The following three outputs are suggested: Electric energy entered; Maximum system demand; and Circuit km. This specification of labor and capital inputs have been used in studies of distribution system operators (DSOs) as well [21].

Publicly published data by TSOs often include specification of number of employees and line lengths categorized by voltage level. However, electric energy losses are more sparsely published. Therefore, this study will use the inputs labor and capital specified as: Number of full-time equivalent employees and Line length*Voltage level.

3.3 A production function for TSOs
Because the output measures (10) will be used as the output of the TSO production function, other variables that affect this output needs to be controlled for. For this reason, the Gross Domestic Product (GDP) and the industries share of total electricity consumption will be included as non-discretionary (exogenous) inputs in production. The GDP will capture differences in the relative sizes of electricity demand between countries, as well as demand variations over time due to business cycles. Industry’s share of total electricity consumption is meant to capture differences in output that can be explained by different demand compositions. A larger share of industry consumption is likely to give a higher output-level, all things equal. The resulting TSO production function is given in (11).

\[ Y = f (FTE, \text{Network}, \text{GDP}, \text{Industry}) \]  

\[ Y = \text{Total national electricity consumption} + \text{electricity export} \]  

\[ \text{FTE} = \text{Full time equivalent employees/year} \]  

\[ \text{Network} = \text{Line length} * \text{MV capacity} \]  

\[ \text{GDP} = \text{Gross domestic product} \]
Industry = Industry’s share of total consumption

The inclusion of non-discretionary inputs in (11) means that these inputs will affect the shape of the production function. These types of inputs are commonly referred to in the literature as non-stochastic environmental variables that are observable to the firms when making production decisions [12].

3.4 Empirical estimation

The function (11) will be estimated using both the COLS and the SFA approach. The functional specification used is a Cobb-Douglas log-linear production function, specified as in (12).

\[ \ln y = \beta_0 + \beta_1 \ln FTE + \beta_2 \ln Network + \beta_3 \ln GDP + \beta_4 \ln Industry + u \]  

This simplicity of the Cobb-Douglas form is an advantage in small samples, compared with more sophisticated representations such as the translog function which requires larger degrees of freedom in estimation. The data used is an unbalanced panel data set for six TSOs spanning the years 2000-2008. The included TSOs are the four Nordic TSOs and those of the Netherlands and Poland. They are the following with the observed years and country in parenthesis: Energinet.dk (Denmark, 2005-2008), Statnett (Norway, 2004-2008), Svenska kraftnat (Sweden, 2000-2008), Fingrid (Finland, 2000-2008), TenneT (the Netherlands, 2002-2008) and PSE operator SA (Poland, 2006-2008). This sums to a total of 37 observations. The data has been collected from publicly published information including annual reports, Eurostat, OECD and Nordel annual statistics.

The output variable is constructed from Eurostat statistics on total electricity consumption excluding the energy sector plus data on electricity exports presented in annual reports and Nordel annual statistics. National GDP is used in OECD base-year 2000 constant prices, adjusted to € PPP.

4. Results and discussion

The results of the estimation of model (12) and the accompanying technical efficiency scores are described in section 4.1. The use of efficiency scores in the integration incentive scheme is demonstrated in section 4.3.

4.1 Results of the estimation methods

The COLS-model ignores the panel-data aspects of the data and treats all the observations as independent from each other. Whether this is a valid treatment partly depends on the degree of heterogeneity in the data. If this is small then the data can be well approximated by a common intercept. The estimated efficiency scores of the COLS-method are presented in table 1. The estimated coefficients of model (2) are presented in table 2.

Methods to estimate the stochastic frontier in a panel data setting were discussed in section 2.5. The FEM approach is inappropriate given the time-invariant regressors included in (12). The MLE approach appeared to be difficult to apply to the given data set. This can be because a small sample with large variation in firm performance can make it difficult to separate the effects of noise and inefficiency using the distributional assumptions in MLE, as pointed out in [19]. This leads to the REM approach as the suitable choice for a panel data treatment of the sample. The estimated efficiency scores of the REM-method are presented in table 1. The estimated coefficients of model (7) are presented in table 2.
Table 1. Technical efficiency scores and rank (in parenthesis).

<table>
<thead>
<tr>
<th></th>
<th>COLS</th>
<th>REM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average efficiency (TEo)</td>
<td>0.77</td>
<td>0.75</td>
</tr>
<tr>
<td>Statnett (Norway)</td>
<td>0.86</td>
<td>1.00</td>
</tr>
<tr>
<td>Energinet.dk (Denmark)</td>
<td>0.74</td>
<td>0.56</td>
</tr>
<tr>
<td>Fingrid (Finland)</td>
<td>0.72</td>
<td>0.66</td>
</tr>
<tr>
<td>Svenska kraftnat (Sweden)</td>
<td>0.88</td>
<td>0.80</td>
</tr>
<tr>
<td>Tennet (the Netherlands)</td>
<td>0.82</td>
<td>0.87</td>
</tr>
<tr>
<td>PSE Operator SA (Poland)</td>
<td>0.58</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Table 2. Estimated coefficients of the production frontier.

<table>
<thead>
<tr>
<th></th>
<th>$\beta_0$</th>
<th>$\beta_1 \ln \text{Labor}$</th>
<th>$\beta_2 \ln \text{Network}$</th>
<th>$\beta_3 \ln \text{GDP}$</th>
<th>$\beta_4 \ln \text{Industry}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLS</td>
<td>-5.76*</td>
<td>0.34*</td>
<td>0.36*</td>
<td>0.52*</td>
<td>1.0*</td>
</tr>
<tr>
<td>REM</td>
<td>0.33</td>
<td>0.02</td>
<td>0.36*</td>
<td>0.38*</td>
<td>0.29</td>
</tr>
</tbody>
</table>

*Indicate statistical significance at the 0.1 percent level in a two-tailed t-test.

4.2 Discussion of results and choice of model

Average efficiency in table 1 is almost the same for both methods. The ranking of the firms differ somewhat between the methods, but the upper half and lower half contains the same firms in both cases. The reasons behind the differences in efficiency scores of the TSOs are of course an interesting question. A relatively efficient TSO has a larger output for a given input level compared with a relatively inefficient TSO. The model used is designed to evaluate how efficient TSOs are at facilitating cross-border electricity trade, measured under the assumption that a higher level of trade will give a higher output level for a given input level. This should mean that TSOs that use their input resources with a primarily national focus will have a relatively lower output level because they miss the output expanding effects of a trade facilitating focus. The low efficiency score for the Danish TSO seems contradictory in this sense because Denmark actually has a high trade exchange compared to the other TSOs in the sample. Their low efficiency score could however be due to deficiencies in accounting for scale effects in the model used. The Cobb-Douglas specification assumes equal returns to scale for all firms. The Danish output is half the size of the next smallest output (Fingrid). This means that it will be compared to considerably larger firms, which may operate at a different level of returns to scale. The low efficiency score for Poland could be due to that the electricity market liberalization in Poland is at an earlier stage than in the rest of the sample. This could be expected to have a negative effect on the amount of trade, based on that trade flows increased significantly in the Nordic countries after the liberalizations of the 1990-ties. Apart from inefficiency, differences in efficiency scores could also be due to unobserved heterogeneity that is not accounted for in the model. To the extent that such heterogeneity could potentially be observed, more variable could be included in the model. For example, an area variable has been tested for inclusion in the model to account for differences in capital input due to country size. This variable however showed to be correlated with the capital variable and was therefore excluded. Another aspect to consider is if effects of weather or different climate conditions should be included in some way.

The estimated coefficients presented in table 2 have the expected signs. The output is expected to be increasing in all included inputs, which is confirmed by the positive signs. All coefficients are significant in the COLS estimation, but only Network (the capital input) and GDP in the REM estimation. It is however expected that these are the two variables that will have the greatest effect on output, since increased transmission capacity will increase trade (as
discussed in section 3.1) and GDP will capture the demand fluctuation due to business cycle effects. It is less obvious to see how additional labor inputs could increase the output.

Part of the choice between the COLS and REM approaches is a choice of whether it is meaningful to recognize the panel data aspect of the data. This choice can be informed by a Lagrange Multiplier test with the null hypothesis that an OLS specification is preferred to a REM specification [17]. The test is based on examining if the variance of the individual effects is equal to zero \( \sigma^2_u = 0 \). If \( \sigma^2_u \neq 0 \), then a panel data specification will perform better than OLS. The LM-test statistic is \( \chi^2 \)-distributed with one degree of freedom. An LM-test for model (11) gives a test-statistic of 38.05, which exceeds the critical value of \( \chi^2 \). This rejects the null hypotheses that OLS is preferred to REM. The model of choice for the data is therefore suggested to be the REM-specification. Another advantage of REM is that it allows for both inefficiency and random noise, whereas COLS only allows for the former.

4.3 An application of the integration incentive scheme

The efficiency scores of table 1 could be used as performance indicators in the incentive scheme (1). To apply this, a regulatory period is specified. The initial performance of a firm is determined as the output technical efficiency score for a historical period, as given in table 1. A target efficiency level is determined by the regulator with support of the information provided by the benchmark model. At the end of the regulatory period, the firm’s efficiency is determined again using the initially estimated frontier. Using Svenska Kraftnat as example, assuming a target efficiency of 0.84 and a future efficiency score of 0.86, the incentive scheme is calculated as in (13).

\[
I = \frac{Et_1 - Et_1^*}{Et_0} = \frac{0.86 - 0.84}{0.80} = 0.025
\]  

(13)

In this case Svenska Kraftnat has exceeded the efficiency target by 2.5%, which means they will receive a financial reward. Since they operate under a rate of return (ROR) regulation, the value of \( I \) could be translated into an increased ROR. A simple transformation could be \( 0.5*I \), which would give an increase in ROR of 1.25% for the next regulatory period. The scheme could likewise be incorporated into revenue cap and price cap regimes. The power of the incentive scheme is that it gives the TSO a financial incentive to work for increased electricity trade, thereby facilitating the further integration of the Nordic electricity market.

5. Conclusions

The purpose of this paper has been to suggest an incentive scheme focused at integration. The scheme is based on the output-oriented technical efficiency (TEo) of the TSOs. This is related to integration by constructing an output measure for TSOs that includes the market expanding effects of trade. It is argued that TSOs can increase this output by expanding the trade capacities with neighbouring countries. The technical efficiency is estimated by two methods; COLS and SFA (REM). The production frontier is estimated as a Cobb-Douglas log-linear function with five variables including the constant term. The preferred model is shown to be the REM. Estimated efficiency scores are in the range 56-100 percent, with an average of 75 percent. A problem of the model could be that firm sizes differ a lot between largest and smallest size, which might not be properly accounted for in the simple Cobb-Douglas model used. A larger sample would allow for more sophisticated functional representations to be tested and is likely to increase the reliability of estimated efficiencies. This could also allow for a better representation of the heterogeneity of the firms operating conditions by inclusion.
of more variables. The complexity of the TSO business and the differences in firms operating environments makes comparisons of TSO efficiencies a challenging task. The functioning of the proposed incentive scheme relies on that efficiencies can be properly estimated. More research needs to be done to conclude that this is the case.

References


