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Quaderno N. 02-03

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Using Stochastic Frontier Analysis for the Access Price Regulation of Electricity Networks

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March 22, 2002

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Abstract

The deregulation of the electricity industry is currently on the political agenda in many countries. In most countries, the deregulation of the sector is combined with a (re-) regulation of the electricity networks in most of the countries. In many countries incentive-based regulation – e.g. price-cap regulation, yardstick regulation – was introduced to promote efficiency improvements in electricity networks. However, with information asymmetry between regulator and network owners, companies who are subject to an incentive-based regulation will be able to obtain an information rent. Benchmarking can help to address this regulator's concern that it does not have good information about the scope for a company to make cost efficiencies (an asymmetry of information). In this paper, we analyze the costs structure of Swiss electricity distribution network operators with respect to cost and scale efficiency of the industry. A stochastic frontier model is applied to estimate the average costs of efficient network operators as a benchmark for the industry.

Keywords: stochastic frontier analysis; electricity distribution; efficiency measurement; network, access price regulation; benchmarking

JEL classification: L94; R32; L43

1. Introduction

For more than ten years, the deregulation of the electricity industry is on the political agenda in many countries. Since electricity networks are viewed as natural monopolies, the deregulation of the sector is typically accompanied by the regulation of the network access prices. In many countries incentive-based regulation – e.g. price-cap regulation, yardstick regulation – was introduced to promote efficiency improvements in electricity networks. However, with information asymmetry between regulator and network owners, companies who are subject to an incentive-based regulation will be able to obtain an information rent.[1] Benchmarking can help to address the regulator's concern that he does not have good information about the scope for a company to make cost efficiencies (an asymmetry of information). Essentially, any benchmarking technique is a system whereby the ratios of a firm's inputs to outputs, the production costs or the quality are compared to external references. For instance, by comparing the costs of similar companies the regulator can establish a set of "yardsticks" of performance from which he could infer any one firm's attainable cost efficiency level. In doing so the dependence of the price that any company received on its own cost level would be broken. Therefore, benchmarking analysis can be used to set the informational basis for a more effective regulation because it reduces the informational asymmetries between firms and regulator regarding costs.

In the application of many incentive-based regulation models regulators, generally, make use of some form of benchmarking analysis of utilities. For instance, the definition in a price-cap regulation model of the X-factor, which varies between companies and reflects the level of inefficiency of the company, can be based on the results of a benchmarking analysis. Moreover, the yardstick regulation model proposed by Shleifer (1985), is based on a benchmarking analysis of the costs. In this model, the regulated price for the individual firms depends on the average costs of identical firms.

In recent years, benchmarking was introduced in many countries such as Chile, England and Wales, Japan, Norway, Australia (New South Wales, Queensland, Victoria) and the Netherlands.[2]

Regulators can use a range of techniques when benchmarking companies, from very basic single-factor measures to econometric techniques – e.g. Corrected Ordinary Least Squares (COLS) and Stocastic Frontier Analysis (SFA)- or mathematical programming approaches – e.g. Data Envelopment Analysis (DEA).[3]

In this paper, we adopt the stochastic frontier analysis (SFA) to study 59 Swiss electricity distribution network operators with respect to cost and scale efficiency. The average cost model specification suggested by Filippini and Wild (2001) is utilized to calculate individual efficiency scores. These authors estimated an average cost function

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[1] Cf. Laffont and Tirole (1993).

[2] For a comprehensive list of countries adopting benchmarking cf. Jamasb and Pollitt (2001).

[3] For a presentation and discussion of these methods see Kumbhakar and Lowell (2000) and Coelli et. al. (1998).

for the Swiss electricity distribution sector using a GLS estimation technique.[4] In their studies, these authors considered only the cost of network operation. [5] In the current paper, the average cost model used by these authors is estimated using stochastic frontier analysis.

Swiss electricity distribution industry

The Swiss electricity industry is composed of about 1,200 utilities, with about 90 percent of them publicly owned distributors that provide power to their communities exclusively. About 140 of them also generate power, but generally, the amount of generated power is small and is determined by the ability to exploit favorable hydroelectric power generation possibilities. Several different types of actors are operating in the transmission and distribution of electricity:[6]

- Fully vertically integrated utilities (T, R, L, G): BKW, CKW, EWZ
- Pure transmission (and generation) companies (T, G): ATEL, EGL, EOS, NOK
- Regional network operator and resellers (R, [G]): They buy electricity from the transmission (extra high voltage) network companies and sell it to local distributors. They mainly operate the high voltage network and some of them have their own generation.
- Regional distributors (R, L, [G]): They buy electricity from the transmission (extra high voltage) network companies and sell it to customers who are connected to the medium and low voltage grid. They operate the high, medium and low voltage grid and some of them have their own generation.
- Local distributors (L, [G]): They buy electricity from the regional (high voltage) network operators (resellers) and sell it to customers who are connected to the medium and low voltage grid. They operate the medium and low voltage grid and some of them have their own generation.

Moreover, there are combinations of these types of distributors, e.g. mixed regional network operator and regional distributors who are resellers in parts of their territory and directly deliver power to final consumers in other areas.

There is great divergence in size and activity among these utilities: The smallest ones sell not more than 0.1 GWh and the largest ones sell over 10,000 GWh, which still is

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[4] The estimation of cost functions in the electricity distribution industry are well documented in empirical research cf. Neuberg (1977) and Pollitt (1995) for the estimation of average cost functions and Nelson and Primeaux (1988), Salvanes and Tjøtta (1994), Burns and Weyman-Jones (1996), Filippini (1996), Hayashi, Goo, and Chamberlain (1997) and Filippini (1998) for the estimation of total cost functions.

[5] In the empirical literature on electricity distribution, most studies estimate cost functions, which also include the expenditure for purchasing electricity. However, since the regulator is only interested in network costs, it is important to separate costs of network operation and costs for purchasing electricity and only consider the former.

[6]
T: Transmission (extra high voltage, 220/380 kV);
R: Regional distribution (high voltage, 150-50 kV);
L: Local distribution (medium and low voltage, 30 kV – 220 V);
G: Generation

only about one fifth of the sales of the average regional electricity company in the UK. Moreover, in Switzerland, the average number of persons served by an electric utility is approximately 6,000, whereas in the UK it is about 1.8 million. However, the largest 100 utilities in Switzerland account for 75 percent of total electricity sales to end-users whereas the smallest 980 or so utilities for the remaining 25 percent.

The regional and local electric utilities purchase power mainly from seven so-called “Ueberlandwerke” – the vertically integrated utilities and transmission companies mentioned above –, which form the backbone of the industry. These larger companies provide most of the generated electricity. Moreover, these dominant companies own and control the national grid that is planned and used in close cooperation.

Deregulation of electricity distribution

With the planned introduction of the new Electricity Market Law (EML) in 2003, the electricity sector of Switzerland will be reformed by moving from regulation to liberalization of some parts of this industry. All customers will have the free choice of energy supplier, hence introducing competition in energy generation and sale activities. The EML stipulates gradual market liberalization over six years. During an initial phase of three years, about 100 electricity consumers with a demand of over 20 GWh per annum can buy electricity from the producer of their choice. Additionally, distributors are allowed to procure from the market 20 percent of their electricity sales to non-eligible customers. This results in a 30 percent market opening. During the second phase, about 250 consumers with a demand of over 10 GWh per year have market access, and distributors may buy 40 percent of their sales from the competitive market, which corresponds to a market opening of 50 percent. After six years, the electricity market will be fully open to competition, which goes beyond the requirements of the EU electricity market directive.

The access to the transmission and distribution network will be organized subject to a regulated third party access (TPA) model with point-of-connection (“postage stamp”) network prices. All transmission and distribution network owners will have the obligation to provide non-discriminatory access to the network. The transmission grid will be operated by one independent grid company, which will be privately-owned with the condition that the majority of capital be held by Swiss parties. At the same time, the distribution grid operators will only be required to keep separate accounting for distribution activities on the one hand and sales or production activities on the other hand.

The EML will regulate the transmission and distribution prices with an approach that is principally based on rate-of-return (ROR) regulation. The ROR regulation allows the utility to set prices that cover its operating and capital costs as well as a return on capital. Moreover, Article 6 of the law states that transmission and distribution prices should reflect costs of an “efficiently operated network company”. Therefore, this article of the new EML will give the regulator the possibility to apply benchmarking or yardstick competition to regulate network access prices.

The paper is structured as follows: in the next section, a cost frontier model for the electricity distribution industry is developed. In section 3 a data set of 59 Swiss electricity distributors, which will be used in the empirical analysis, is presented. Section 4 summarizes the estimation results and gives some insights on scale and cost efficiency of the electricity distribution industry in Switzerland. In section 5, results are summarized and some conclusions are drawn.

2. Cost frontier model for electricity distribution

The stochastic cost frontier model

A frontier cost function defines minimum costs given output level, input prices and the existing production technology. It is unlikely that all firms will operate at the frontier. Failure to attain the cost frontier implies the existence of technical and allocative inefficiency.

In this paper we consider the estimation of a stochastic frontier cost function using panel data.[7] To illustrate this econometric approach consider the cost function:

$$C_{it} = X_{it} b + u_i + v_{it} \qquad u_i \geq 0 \qquad i = 1, 2, ..., N \;\; and \;\; t = 1, 2, ..., T \tag{1}$$

In this specification the error term is composed of two parts: the first, u_i, is a one-sided non negative disturbance reflecting the effect of cost; the second, v_{it} , is a two-sided disturbance capturing the effect of noise. The statistical noise is assumed to follow a normal distribution, and the inefficiency term u_i is generally assumed to follow either a half normal or truncated normal distribution.[8]

In a stochastic frontier setting the efficiency is measured as the ratio of actual costs to least cost level:

$$EFF_i = \frac{E(AC_i \mid u_i, X_i)}{E(AC_i \mid u_i = 0, X_i)} \tag{2}$$

Therefore, predictions of cost efficiency (EFF_i) are calculated according to the following expression:

$$EFF_i = \frac{X_{it} b + u_i}{X_{it} b} \geq 1 \tag{3}$$

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[7] Different approaches can be used to estimate a frontier cost function with panel data. A good overview is given by Battese (1992), Simar (1992) and Fabbri, Fazioli and Filippini (1996). For applications of the stochastic frontier methodology with panel data in Switzerland cf. Filippini and Prioni (1994) on the regional bus industry and Filippini (1999) and Crivelli, Filippini and Lunati (2001) on nursing homes.

[8] The inefficiency term u_i might also have a time trend (cf. Battese and Coelli, 1992).

These predictions are made using the procedure suggested by Jondrow et al. (1982).

Specification of the frontier cost function

The costs of operating a distribution system are the costs of building and maintaining the system of service lines, mains and transformers, and of measuring and billing electricity. Burns and Weyman-Jones (1996) draw up a comprehensive list of the factors these costs may depend upon:

(a) the maximum demand on the system;

(b) the total number of customers served;

(c) the type of consumer;

(d) the dispersion of the consumers;

(e) the size of the distribution area;

(f) the total kWh sold;

(g) system security;

(h) the length of distribution line and

(i) the transformer capacity.

However, the last two factors, the length of the distribution line and the transformer capacity, are inputs rather than output characteristics and therefore should not be included in the model. Moreover, Shleifer emphasized that only “observable characteristics that cannot be altered by the firm” should be used to model the heterogeneity of output. To overcome serious multicollinearity problems, we are incorporating the different effects suggested by Burns and Weyman-Jones mostly in terms of relative rather than absolute variables.

In our model we distinguish three different network levels (high, medium, and low voltage). The main output is kWh transported on the medium-voltage grid. Additional variables for the high- and low-voltage grid are included. Maximum demand is embodied in form of the load factor (LF), which is the relation between average and maximum demand. To account for the heterogeneity of consumers we differentiate between two customer groups (medium- and low-voltage customers) with their respective average consumption levels. The dispersion of consumers and the structure of the service area are modeled by the incorporation of a customer-density variable and variables indicating the area shares of different ground categories. System security should also be used as an output indicator. Unfortunately, we are not able to include system security variables in our specification because no data are available.

The inputs to the operation of the distribution system consist primarily of labor and capital. Assuming that output and input prices are exogenous, and that (for a given technology) firms adjust input levels so as to minimize costs of distribution, the firm's total average cost of operating the electricity distribution system can be represented by the average cost function

$$AC = C / Y = AC(Y, PL, PC, HGRID, LVSH, AVGL, LF, CD, AGSH, FOSH, UPSH, OTSH) \quad (4)$$

where C represents total cost, AC represents average cost per kWh and Y is the output represented by the total number of kWh transported on the medium-voltage grid. PL and PC are the prices of labor and capital, respectively.[9] HGRID is a dummy variable to separate distribution utilities that are also operating a high-voltage grid. LVSH represents the share of electricity that is delivered on the low-voltage network. This variable considers the differences among the utilities in terms of customer structure. AVGL is the average consumption per low voltage customer. LF is the load factor and CD is the customer density measured in customers per hectare of settlement land. AGSH represents the share of agricultural land, FOSH represents the share of forestland and UPSH indicates the share of unproductive land with respect to the total size of the service area, respectively. OTSH is a variable used to control for outputs other than the distribution of electricity that are included in the accounting data of electric utilities. We use the share of “other revenues” on total revenues as output indicator for these activities.

Using a linear function, equation (2) can be approximated by the following average cost function:

$$\begin{aligned} AC = {} & b_0 + b_Y Y + b_{YY} Y^2 + b_{PL} PL + b_{PC} PC + b_{HG} HGRID + b_{LS} LVSH \\ & + b_{AL}\, AVGL + b_{LF}\, LF + b_{CD}\, CD + b_{CDCD}\, CD^2 + b_{AG}\, AGSH \\ & + b_{FO} FOSH + b_{UP} UPSH + b_{OT} OTSH + u_i + v_{it} \quad u_i \geq 0 \end{aligned} \quad (5)$$

The output Y and the customer density CD are included in linear and quadratic form to allow nonlinear variations of the average-cost function.

3. Data

This study is based on the panel data set of Swiss electricity distribution utilities that was previously used by Filippini and Wild (2001). The primary data sources were the (unpublished) Swiss Federal Office of Energy’s financial statistics of electricity utilities; additional data on customers, output and technical characteristics were collected using a mail questionnaire sent to the utilities. Service area characteristics are taken from the Swiss Federal Office of Statistic’s area statistics (“Arealstatistik”). The data set consists of an unbalanced panel of 59 electricity distribution utilities over the

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[9] In this study we adopted a simple unbundling of costs between the network activities and the purchasing activities: only the costs of electricity purchasing belong to the supply, all the other costs belong to the network. This seems a reasonable approach because the supply activities in comparison to the network operation need only a limited amount of resources in terms of labor and capital. In addition, this simple unbundling mechanism considers the fact that the regulator is subject to asymmetric information and normally cannot observe subcosts.

period 1988-1996 (380 observations). All input prices and costs were deflated to 1996 constant Swiss francs using the Swiss Consumer Price Index. Descriptive statistics of the variables are presented in Table 1.

Table 1 Descriptive statistics

Variable	Description	Dimension	1. Quartile	Median	3. Quartile
AC	Average cost	Swiss cents / kWh	5.86	7.95	10.03
Y	Output	GWh	67.6	104.6	198.7
PL	Price labor	1000 CHF / employee	82.6	97.0	113.5
PK	Price capital	CHF / kVA	62.6	88.1	123.5
HGRID	High voltage grid	Dummy	0	0	1
LVSH	Low voltage sales	Share	0.59	0.74	0.90
LF	Load factor		0.52	0.56	0.59
AVGL	Average consumption low voltage	kWh / customer	5'995	6'689	7'424
CD	Customer density	Customer / ha	14.92	19.51	22.92
AGSH	Agricultural land	Share	0.22	0.34	0.42
FOSH	Forest land	Share	0.22	0.30	0.40
UPSH	Unproductive land	Share	0.01	0.02	0.06
OTSH	Other activities	Share	0.03	0.07	0.13

4. Empirical analysis

Estimation results

The results of the estimation are listed in Table 2. The OLS-coefficients are estimated using an Ordinary Least Squares technique. These coefficients are just an estimate of a linear cost function and don't allow any inefficiency predictions. They are listed only for comparison with the coefficients of the stochastic frontier models (Model 1 and 2). Model 1 uses a half-normal distribution of the inefficiency term and in Model 2, the inefficiency term is specified as a more general truncated normal distribution in which μ can be non-zero. In both models, the firm specific inefficiency term u_i is assumed to be constant over time.[10] Model 1 and 2 are estimated with a program named Frontier 4.1 by Tim Coelli (1996), which uses a three-step estimation method.[11]

Table 2 Parameter estimates

	OLS		**Model 1** (half normal)		**Model 2** (truncated normal)	
	Coefficient(a)	t-Value	Coefficient(a)	t-Value	Coefficient(a)	t-Value
Constant	9.198599***	7.73	8.856186***	6.52	5.894395***	4.57
Y	-0.006340***	-8.63	-0.007455***	-4.81	-0.005434***	-3.74
Y^2	0.000003***	7.62	0.000003***	3.66	0.000002***	3.08
PL	0.008076***	3.49	0.0073**	2.54	0.006942*	2.13
PK	0.040815***	18.33	0.028496***	14.89	0.029167***	15.70
HGRID	1.604792***	7.59	2.369328***	3.58	1.678294***	3.32
LVSH	4.460230***	7.73	6.120588***	5.94	6.297858***	6.53
AVGL	-0.000471***	-7.43	-0.000665***	-7.33	-0.00073***	-8.27
LF	-11.152949***	-9.65	-7.590265***	-7.97	-7.79334***	-8.68
AGSH	5.088802***	6.52	2.625975	1.75	5.978271***	4.65
FOSH	7.476540***	10.11	6.097725***	3.95	6.956755***	4.99
UPSH	2.051194**	2.53	-0.589187	-0.38	2.181759	1.49
CD	-0.377348***	-7.44	-0.462682***	-4.96	-0.390504***	-4.62
CD^2	0.007631***	8.05	0.00859***	4.34	0.007577***	4.38
OTSH	0.098326***	9.25	0.133963***	13.15	0.134725***	13.52
μ					2.759906***	5.19

(a) ***, **, *: significant at 0.1%, 1%, 5%

Most of the parameter estimates of all three models show the expected sign and are highly significant. Generally, the frontier models show the same influence of exogenous

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[10] Models that allowed u_i to have a time trend were estimated; but no significant time trend was found in any specification of the cost model.

[11] For further information, please refer to the mentioned working paper.

variables on average costs as the OLS model. Although there are some differences in the size of the coefficients, they are all pretty similar except the constant. The constant in Model 2 is smaller than the one in Model 1, but this can be explained by the estimation of μ. In model 1, μ is restricted to zero and so, the constant has to absorb a potential divergence from zero. Another indicator for this fact is that the constant in the OLS estimation is quite as high as in Model 1.

The coefficient of the load factor (LF) of the OLS model is higher than the ones of the two efficiency models. This can be interpreted as a potential source of inefficiency, because if the load factor increases, than the average costs would fall more in the OLS model than in the others. This means that when corrected by inefficiency, the load factor looses part of its effect and thus, the average costs would be lower.

Returns to scale and density

According to Roberts (1986), the inclusion of the number of customers and the size of the service territory in the cost function of network industries allows for the distinction of returns to output density, returns to customer density and returns to scale. Returns to scale (RS) measure the reaction of costs to an equal proportional increase in output, number of customers and size of the service area. In terms of our model specification this is equal to an expansion of output, holding output density and customer density constant. It can be shown that returns to scale – the effect of an expansion of Y, holding AVGL and CD constant on total costs - can be derived from the average cost elasticity with respect to Y, as follows[12]

$$RS = \frac{1}{1 + \frac{\partial AC}{\partial Y}\frac{Y}{AC}} \tag{6}$$

Returns to customer density (RCD) measure the reaction of costs to an equal proportional increase of output and the number of customers, holding the size of the service area fixed. In terms of our model specification, this corresponds to an equal proportional expansion of output and customer density, holding output density constant. Returns to customer density can be derived from the average cost elasticity with respect to Y and CD, as follows:

$$RCD = \frac{1}{1 + \frac{\partial AC}{\partial Y}\frac{Y}{AC} + \frac{\partial AC}{\partial CD}\frac{CD}{AC}} \tag{7}$$

Finally, returns to output density (ROD) measure the reaction of costs to an increase in output holding the size of the service area and the number of customers fixed. In terms of our model specification, this corresponds to a proportional expansion of output and

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[12] The definitions for RS, RCD and ROD for the average cost function used in this study are derived in Wild (2001, p. 198ff.).

average consumption per customer, holding customer density constant. Returns to output density can be derived from the average cost elasticity with respect to Y and AVGL, as follows

$$ROD = \frac{1}{1 + \frac{\partial AC}{\partial Y}\frac{Y}{AC} + \frac{\partial AC}{\partial AVGL}\frac{AVGL}{AC}} \quad (8)$$

Returns to scale or density are said to be increasing, constant or decreasing, when RS, RCD or ROD are greater than unity, equal to unity, or less than unity, respectively. Although these definitions are based on the average cost specification, they correspond to – and can be compared with – those suggested by Roberts (1986) for the total cost function. The resulting returns to scale and density at the median values of the sample are summarized in Table 3.

Table 3 Returns to scale and density (evaluated at median values of variables)

	OLS	Model 1 (half normal)	Model 2 (truncated normal)
Returns to scale (RS)	1.082	1.098	1.070
Returns to customer density (RCD)	1.372	1.674	1.425
Returns to output density (ROD)	1.894	2.848	3.118

We find increasing returns to scale for the electricity distribution utilities in our sample. In Figure 1 the scale expansion paths of the average costs are shown for the OLS estimates and for the two frontier specifications.

Our results suggest that returns to scale evaluated for the frontier average cost functions (Model 1 and 2) are similar to the returns to scale of the OLS function. Most of the utilities in our sample therefore are too small and do not reach the minimum efficient scale (the median utility delivers about 110 GWh). The problem of scale inefficiency might be solved by mergers between the small utilities.

In addition, there are significant economies of customer density and economies of output density. Average distribution costs fall the more densely populated a service area is, and the higher the average consumption per customer (i.e. the output density) is. However, the returns to density can not be altered by the network operators, since they are characteristics of the service area that are determined by exogenous factors.

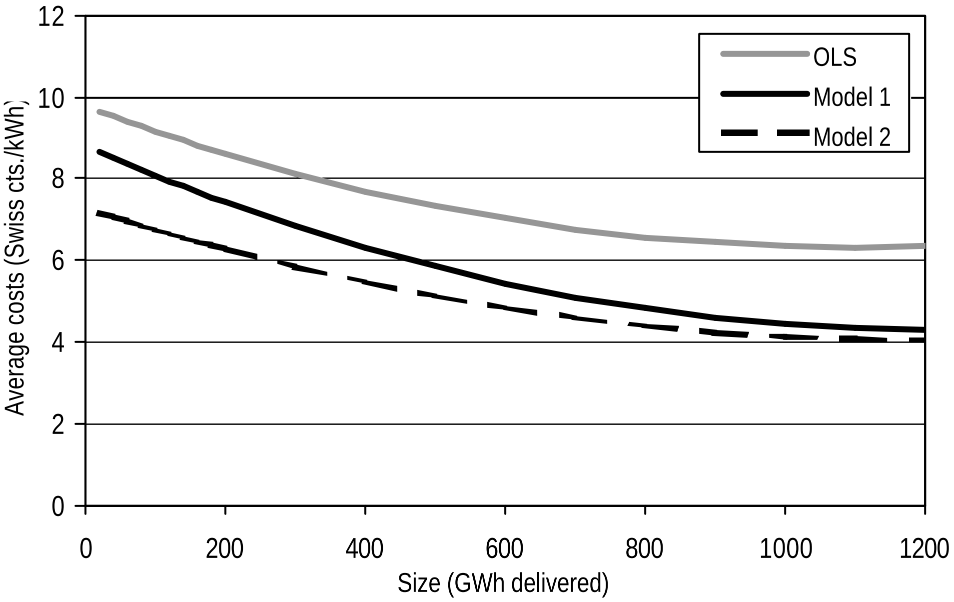

Figure 1 Scale expansion paths of the average costs (all three voltage levels)

Cost efficiency

The estimation results reported in Table 2 can be used to recover estimates of the level of cost inefficiency of each electricity utility along the line suggested by Simar (1992) and Coelli and Battese (1996). The inefficiency indicator can be interpreted as the ratio of actual costs to the efficient level of costs as presented in expression in expression (3) in section 2. Table 4 shows some summary statistics of efficiency scores (EFF) for both models calculated for the electricity utilities of our sample.[13] The estimated cost efficiency scores of each individual firm are reported in Table 5 in the Appendix. The estimated variances of *V* and *U* are listed in Table 6.

Table 4 Statistics on efficiency scores (EFF)

	1st quartile	**Median**	**3rd quartile**	**Average**
EFF Model 1	1.1553	1.3292	1.5941	1.4909
EFF Model 2	1.3137	1.5149	1.7966	1.6671

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[13] EFF is calculated as the ratio of actual costs to the efficient level of costs. The values of the inefficiency scores can be interpreted as follows: an efficiency score of 1.3292 means that the firm’s cost are 32.92% higher than the cost of an equivalent firm that is efficient.

Median cost inefficiencies in model 1 is about 33%; which is somewhat lower than the median value of 51% received in Model 2. This shows that the efficiency scores are sensitive with respect to assumptions on the distribution of the firm effect u_i (half normal and truncated normal respectively). However, there is a clear positive correlation between the efficiency scores (the Pearson correlation between efficiency scores in the two models is 0.586). Unfortunately, the efficiency scores of some firms differ substantially in the two models: Especially firm 59, which has an efficiency score of 4.39 in Model 1, is evaluated as 100% efficient in Model 2.

A likelihood ratio test favors Model 2 (truncated normal distribution of firm effects) at an 98% significance level, which – on average – postulates higher inefficiency levels.

5. Summary and conclusions

In most countries, deregulation of the electricity industry comes along with a (re-) regulation of the network access prices. To give the network operators efficiency incentives, access price regulation is often implemented with incentive oriented regulatory instruments such as price-cap regulation or yardstick competition.

The new Swiss electricity market law states that network access prices should reflect costs of an "efficiently operated network company". One way to calculate the costs of an efficient network is to perform a benchmarking analysis and specify a best practice. In this paper we applied the stochastic frontier methodology to predict the efficient technology.

However, the main goal of the analysis did not consist in the calculation of efficiency scores for individual firms. More importance was laid on the one hand on the investigation of the characteristics of cost function in terms of returns to scale and density and on the other hand on the determination of the influences of service area characteristics on costs. Our results that are based on panel data for a sample of 59 Swiss electricity distributors (380 observations) might be of interest for the regulator. Our main findings are:

- The parameter estimates in the average cost model have the expected sign and are highly significant (most of them at the 99.9% significance level). The explanatory power of the model is rather high: with the OLS-specification, more than 80% of the variation of average costs can be explained.
- Exogenous heterogeneity variables have significant and measurable influence on distribution cost. These are the customer density, the customer structure (medium and low voltage customers), the average consumption per customer, and shares of different land categories (forest, farm and unproductive land) in the service area.
- Frontier functions were calculated for two assumptions on the distribution on the firm specific error term (half normal and truncated normal distribution). The results of the two models are similar. However, the efficiency scores for some utilities are rather sensitive with respect to the assumed distribution. A likelihood ratio test between the two models supports the truncated normal distribution.
- The truncated normal model suggests that the median utility has excess costs of about 50% compared to the cost frontier. This suggests that there exists a substantial

potential for augmentations of efficiency that might be realized by the incentive oriented regulation of access prices.

- We find increasing returns to scale (1.07 for the median utility in the truncated normal model), which says that an increase in total cost by 10% would enable an expansion of firm size (in terms of GWh, number of customers and area size) of 10.7%. Minimum efficient scale is reached with an output of about 1000 GWh per year, which corresponds to about 100’000 customers. Since the median utility in Switzerland has less than 10’000 customers, electricity distribution is characterized by notable scale inefficiency.
- Moreover, increasing returns to output and customer density are found. These results are rather typical in network industries.

It is planed to extend our analysis in two directions:

(1) we are interested in the robustness of results (different distribution assumptions on firm specific inefficiency; variation of sample; changes in theoretical model);

(2) comparison of parametric (stochastic frontier analysis) and non-parametric methods (data envelopment analysis).

References

Battese, G. E. (1992), Frontier Production Functions and Technical Efficiency: A Survey of Empirical Applications in Agricultural Economics, *Agricultural Economics*, 7, 185-208.

Battese, G.E. and Coelli, T.J. (1992), Frontier Production Functions, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India, *Journal of Productivity Analysis*, 3, 153-169.

Coelli T. , D.S.P Rao and G. Battese. (1998), An Introduction to efficiency and Productivity analysis, Boston: Kluwer Academic Publisher.

Burns, P. und Weyman-Jones, T. G. (1996), Cost Functions and Cost Efficiency in Electricity Distribution: A Stochastic Frontier Approach, *Bulletin of Economic Research*, 48 (1), 41-64.

Coelli, T. J. (1996), 'A Guide to FRONTIER Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation', Mimeo, Department of Econometrics, University of New England, Armidale.

Coelli, T.J. and Battese, G.E. (1996), Identification of Factors which Influence the Technical Efficiency of Indian Farmers, *Australian Journal of Agricultural Economics*, 40(2), 19-44.

Fabbri, D., Fazioli, R., Filippini, M.,1996, *L'intervento pubblico e l'efficienza possibile*, Il Mulino, Bologna.

Filippini, M. (1996), Economies of Scale and Utilization in the Swiss Electric Power Distribution Industry. *Applied Economics*, 28, 543-550.

Filippini, M. (1998), Are Municipal Electricity Distribution Utilities Natural Monopolies?. *Annals of Public and Cooperative Economics*, 2, 157-174.

Filippini, M. (1999), Cost and Scale efficiency in the Nursing Home Sector: evidence from Switzerland, Quaderno N. 99-01, Facoltà di scienze economiche, Università della Svizzera Italiana.

Filippini, M., Prioni, P. (1994) Is Scale and Cost Inefficiency in the Swiss Bus Industry a Regulatory Problem? Evidence from a Frontier Cost Approach, *Journal of the Economics of Business*, 1(2), 219-31.

Filippini, M. and Wild, J. (2001), Regional Differences in Electricity Distribution Costs and their Consequences for Yardstick Regulation of Access Prices, *Energy Economics*, 23 (4), 477-488.

Hayashi, P. M., Goo, J. Y.-J. und Chamberlain, W. C. (1997), Vertical Economies: The Case of U.S. Electric Utility Industry, 1983-87, *Southern Economic Journal*, 63 (3), 710-725.

Jamasb, T., Pollitt, M. (2001), Benchmarking and Regulation: international electricity experience, *Utilities Policy*, 9 (3), 107-130.

Jondrow, J., Lowell, C.A.K., Materov, I.S., and Schmidt, P. (1982), On the Estimation of technical Inefficiency in the Stochastic Frontier Production Function Model, *Journal of Econometrics*, 19, pp. 233-238.

Kumbhakar S.C. Lowell,C.A. (2000), Stocastic frontier analysis, Cambridge: Cambridge University Press.

Laffont, J. J., Tirole, J. (1993), *A Theory of Incentives in Procurement and Regulation*, MIT Press.

Nelson, R. A. und Primeaux, W. J. Jr. (1988), The Effects of Competition on Transmission and Distribution Costs in the Municipal Electricity Industry, *Land Economics*, 64 (4), 338-346.

Neuberg, L. G. (1977), Two Issues In the Municipal Ownership of Electric Power Distribution Systems, *Bell Journal of Economics*, 8 (1), 303-323.

Pollitt, M. G. (1995), *Ownership and Performance in Electric Utilities*, Oxford University Press, Oxford.

Roberts, M. J. (1986), Economies of Density and Size in the Production and Delivery of Electricity, *Land Economics*, 62 (4), 378-387.

Salvanes, K. G. und Tjøtta, S. (1994), Productivity Differences in Multiple Output Industries: An Empirical Application to Electricity Distribution, *Journal of Productivity Analysis*, 5, 23-43.

Shleifer, A. (1985), A Theory of Yardstick Competition, *Rand Journal of Economics*, 16, 319-327.

Simar, L., (1992), Estimating Efficiencies from Frontier Models with Panel Data: A Comparison of Parametric, Non-parametric and Semi-parametric Methods with Bootstapping, *The Journal of Productivity Analysis*, 3, 171-203.

Wild, J., 2001, *Deregulierung und Regulierung der Elektrizitätsverteilung. Eine mikro-ökonomische Analyse mit empirischer Anwendung für die Schweiz.* vdf Hochschulverlag AG an der ETH Zürich, Zürich.

5. Appendix: Efficiency scores

Table 5 Efficiency scores of the individual firms

Firm	Model 1	Model 2
1	1.4787	1.5358
2	1.2746	1.6591
3	1.4746	1.9215
4	1.4933	1.6130
5	1.2619	1.3850
6	1.0617	1.3467
7	1.4253	1.3898
8	1.4591	1.6494
9	1.3907	1.5284
10	1.2918	1.3235
11	1.5941	1.8848
12	1.3806	1.3976
13	1.6599	1.7534
14	1.1658	1.3296
15	1.0310	1.0424
16	1.2527	1.3797
17	1.0789	1.2565
18	1.6619	1.8127
19	1.5377	1.5008
20	3.2436	3.1371
21	1.2820	1.2889
22	1.5136	1.6848
23	1.0582	1.2524
24	1.1160	1.4533
25	1.9734	2.9131
26	1.3050	1.5149
27	1.3826	1.7966
28	1.6388	1.6381
29	1.1961	1.7779
30	1.6472	1.6432
31	1.1553	1.2439
32	1.1298	1.2469
33	1.4932	2.0184
34	1.3163	1.5641
35	1.1818	1.9793
36	1.2881	2.6590
37	1.0403	1.1228
38	1.1192	1.3490
39	1.1416	1.1964
40	1.0218	1.0413
41	1.7019	1.6368
42	1.0332	1.1046
43	1.3292	1.4314
44	1.1960	1.4326
45	1.0143	1.0325
46	3.5066	5.1323
47	1.0667	1.2814
48	1.2109	1.3142
49	2.0364	2.5975
50	1.8484	2.4742
51	1.5402	1.7883
52	1.3382	1.5748
53	1.0943	1.1305
54	1.5354	1.4826
55	1.1583	1.3137
56	1.9556	2.2553
57	1.7203	1.8628
58	2.0712	2.2843
59	4.3900	1.0000
Average	1.4909	1.6671

Table 6 Estimated variances of *U* and *V*

Parameter	Model 1	Model 2
$\hat{s}^2 = \hat{s}_v^2 + \hat{s}_u^2$	7.6122	2.6606
$g = \frac{\hat{s}_u^2}{\hat{s}_v^2 + \hat{s}_u^2}$	0.9555	0.8740

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