

**THE ESTIMATION OF AN AVERAGE COST  
FRONTIER TO CALCULATE BENCHMARK TARIFFS  
FOR ELECTRICITY DISTRIBUTION**

**AEA International Conference on Modelling Energy Markets  
Technical University of Berlin, September 10-11, 1998**

**by**

**Massimo FILIPPINI**

*Department of Economics - Università della Svizzera Italiana  
Via Ospedale 13  
6900 Lugano, Switzerland  
E-mail: massimo.filippini@lu.unisi.ch*

**and**

**Jörg WILD**

*Socioeconomic Center - University of Zurich  
Blumlisalpstrasse 10  
8006 Zurich, Switzerland  
E-mail: jwild@sozoec.unizh.ch*

**September, 1998**

# **THE ESTIMATION OF AN AVERAGE COST FRONTIER TO CALCULATE BENCHMARK TARIFFS FOR ELECTRICITY DISTRIBUTION**

**by**

**Massimo FILIPPINI and Jörg WILD**

## **ABSTRACT**

In this paper we have examined the scale and cost inefficiency of a sample of Swiss electricity distribution utilities. To do so, we have considered estimation of a stochastic frontier average cost model using the approach suggested by Schmidt and Sickles (1984) for panel data. A translog cost function was estimated using panel data for a sample of 30 municipal utilities over the period 1992-1996. The results indicate the existence of economies of output and customer density and economies of scale. Moreover, the findings on cost inefficiency show that a majority of the distribution utilities is not producing at the minimum level of the cost and that a possible application of the frontier methodology employed in this paper relates to the regulation and benchmarking of the delivery rates.

## **Introduction**

The privatization and the deregulation of the electric power sector were introduced in many countries, including England, Norway, Chile and New Zealand. In Switzerland, as in other European countries, several proposals exist to institute changes in the electricity market and therefore move to competition. All these proposals contain as a central element of the reform the introduction of Third Party Access (TPA). With the introduction of TPA, the electricity distribution utilities are obliged to allow nondiscriminatory access to all companies that wish to send electricity over the utility's transmission and distribution lines for sale at the final consumer level. This open access must be accompanied by clear and specific tariffs for the transmission and distribution services, which implies a functional unbundling. As a result, the distribution utilities at the local level, which are the object of our study, must separate their different functions: the delivery of electricity and the retail sale of electricity. With the introduction of TPA, an unbundled distribution utility should charge itself the same rate for distribution that it charges other electric utilities that want to utilize its distribution lines. Because the electricity distribution utilities will still have a monopoly franchise to deliver electricity within their services territories, a rate regulation by the regulatory commission is necessary. Otherwise, the distribution utilities could raise the rates above what they would be in a competitive market. This raises the problem of determining proper rates for the delivery of electricity at the local level.

In Switzerland there exists a proposal that suggests setting the rates for the delivery of electricity so that they equal the average distribution cost measured in Swiss francs per kWh. According this proposal, therefore, each distribution utility should set the delivery rate at the level of the own average cost.

The purpose of this paper is to make a contribution to the debate on transmission and distribution pricing through the econometric estimation of a translog average cost frontier for a sample of Swiss electricity distribution utilities. The estimated average cost frontier could be employed by the regulatory commission to benchmark rates at the distribution level.

This article is organized as follows. Section 2 presents the frontier average cost model for the electric distribution utilities. In section 3, the data for 30 Swiss public electricity distributors from our sample are presented. Parameter estimates of the average frontier cost function are presented in section 4. In section 5 we present the results in term of economies of density and scale and in term of cost inefficiency. Section 6 reports the conclusions.

### **Specification of the Frontier Average Cost Function**

Cost functions in the electricity distribution industry are well documented in empirical research<sup>1</sup>. All these studies estimated a cost function which also includes the expenditure on purchasing electricity in the total costs. Thus, these studies do not separate the sale function of a utility from the delivery function and, therefore, are not ideal for benchmarking delivery rates.

The costs of operating a distribution system are the costs of building and maintaining the system of service lines, mains and transformers. These costs may depend upon:

- the total number of customers served;
- the maximum demand on the system, which determines the capacity of the system;
- the size of the distribution area;
- the capacity of the transformers;
- the length of distribution line;
- the total kWh sold, which affects wear and tear on the transformers;
- the price of labor; and
- the price of capital.

The maximum demand on the system and the total kWh sold can be interpreted as output indicators, whereas the total number of customers, the size of the distribution area, the length of distribution line and the capacity of the transformers can be classified as network characteristic variables. Therefore, given that the electricity distribution utilities provides services via a network, the network characteristics should be incorporated in the cost model. Following Salvanes and Tjøtta (1994), Burns and Weymann-Jones (1996) and Filippini (1996, 1997, 1998), in the average cost model specification we take into account a number of network characteristic variables, which should capture the heterogeneity dimension of the distribution system.

For the purpose of our analysis we specify two models. In the first model the output is measured by the total number of kilowatt hours (kWh) delivered, whereas in the second model the output is measured by the maximum demand. These two model specifications allow us to estimate the two types of average costs relevant for the actual discussion about

---

<sup>1</sup> See Weiss (1975), Henderson (1985), Roberts (1986), Nelson and Primaux (1988), Callan (1991), Salvanes and Tjøtta (1994), Filippini (1996, 1997, 1998) and Thompson (1997) for empirical evidence of the existence of scale economies in the transmission and distribution of electricity.

tariff regulation at the distribution level: the average distribution costs per kWh and the average distribution costs per kilowatt (kW).

Inputs to the operating 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<sup>2</sup>

$$AC = \frac{C}{y} = AC(y, w_l, w_c, CU, AS) \quad (1)$$

where  $C$  represents total cost,  $AC$  represents total average cost per kWh or, alternatively, total average cost per kW, and  $y$  is the output represented by the total number of kWh delivered or, alternatively, by the maximum demand in kW.  $w_c$ , and  $w_l$  are the prices of capital and labor, respectively.  $AS$  is the size of the service territory of the distribution utility measured in squares kilometres and  $CU$  the number of customers. These variables are introduced in the model as output characteristics. Initially, we considered others output characteristic variables such as the kilometres of mains lines and the transformer capacity. However, these variables were discarded because of a very high correlation between these variables and  $y$ ,  $CU$  and  $AS$ , leading to insignificant parameter estimates because of multicollinearity.

Using a translog function, (1) can be approximated by the following average cost function:<sup>3</sup>

$$\begin{aligned} \ln \frac{AC_i}{P_{Ki}} = & \mathbf{b}_o + \mathbf{b}_y \ln Y_i + \mathbf{b}_{CU} \ln CU_i + \mathbf{b}_l \ln \frac{P_{L_i}}{P_{K_i}} + \mathbf{b}_{AS} \ln AS_i + \frac{1}{2} \mathbf{b}_{yy} (\ln Y_i)^2 + \frac{1}{2} \mathbf{b}_{CUCU} (\ln CU_i)^2 \\ & + \frac{1}{2} \mathbf{b}_{ll} \left( \ln \frac{P_{L_i}}{P_{K_i}} \right)^2 + \frac{1}{2} \mathbf{b}_{ASAS} (AS_i)^2 + \mathbf{b}_{yCU} \ln Y_i \ln CU_i + \mathbf{b}_{yl} \ln Y_i \ln \frac{P_{L_i}}{P_{K_i}} + \mathbf{b}_{yAS} \ln Y_i \ln AS_i \\ & + \mathbf{b}_{Cul} \ln CU_i \ln \frac{P_{L_i}}{P_{K_i}} + \mathbf{b}_{CUAS} \ln CU_i \ln AS_i + \mathbf{b}_{ASl} \ln AS_i \ln \frac{P_{L_i}}{P_{K_i}} + \mathbf{v}_{it} \end{aligned} \quad (2)$$

Since linear homogeneity in factor prices is imposed, the price of capital will act as a numeraire.

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

Different approaches can be used to estimate a frontier cost function with panel data. A good overview is given by Bauer (1990), Battese (1992) and Simar (1992).

<sup>2</sup> See Neuberger (1977) for the estimation of an average cost function for electric distribution utilities and Hubbard and Dawson (1987) for a general discussion on the estimation of average cost functions.

<sup>3</sup> A translog function requires the approximation of the underlying cost function to be made at a local point, which in our case, is taken at the median point of all variables. Thus, all independent variables are normalized at their median points.

In this paper we consider the estimation of a stochastic frontier average cost function using the approach suggested by Schmidt and Sickles (1984) for panel data. In this approach the overall residual  $v_{it}$  is composed of two terms ( $w_{it} = a_i + e_{it}$ ): a symmetric component of the disturbance ( $e_{it}$ ) that allows for noise, distributed  $N(0, s_v^2)$  and a one-sided component ( $a_i$ ) that represents cost inefficiency.<sup>4</sup> There are  $N$  firms and  $T$  observations for each firm. The attractiveness of this approach is that no assumptions need be made about the distributions of  $a_i$ . There is, however, a limitation, namely that one has to be prepared to assume that inefficiency remains constant over time.

The fact that the average cost function (1) includes a variable, the size of the service territory, that remains constant over time excludes the possibility to treat inefficiency as a fixed effect. Therefore, inefficiency has to be treated as a random effect and the coefficients of equation (2) estimated by GLS.<sup>5</sup>

## The Data

This study is based on a combined time series and cross-sectional data set for 30 Swiss electricity distribution utilities over the period 1992-1996.<sup>6</sup> The model is estimated for cross-sectional samples of publicly-owned electricity distribution utilities operating in Swiss cities.<sup>7</sup> In Switzerland, there are approximately 130 companies that could be included in a study of city electricity distribution utilities. The Swiss Federal Energy Office collects financial data only for a sample of about 100 utilities serving cities. Part of the companies listed in this sample, however, are not appropriate for the purpose of our analysis because the amount of self-generated electricity is high. Since the aim of this study is to analyze the cost structure of distribution, companies which had an amount of self-generated electricity higher than 20% of the total sales were excluded.<sup>8</sup>

For estimation, panel data for five years, 1992, 1993, 1994, 1995 and 1996, has been used. The primary sources were the Swiss Federal Office of Energy's *Finanzstatistik*; additional data were collected using a mail questionnaire sent to the utilities.

The restrictions on data described above and completed questionnaires result in a sample of 30 electricity distribution utilities for which appropriate data are available. The necessary data include the total distribution cost, the prices of capital and labor, the quantity of kWh

---

<sup>4</sup> For a presentation of this method see Schmidt and Sickles (1984) and Simar (1992).

<sup>5</sup> See Hsiao (1986) for a presentation of this econometric approach.

<sup>6</sup> Filippini (1996, 1997, 1998) estimated a total cost function for the Swiss electricity distribution utilities using a different dataset (39 Swiss electricity distribution utilities over the period 1988-1991).

<sup>7</sup> The Swiss electric power industry is composed of about 1200 firms, public and private, that are engaged in the generation, transmission and/or distribution of electric power. There is a great divergence both in terms of size and activities of these companies. In particular, approximately 900 utilities, or 74% of the total, are merely distributors of electric power. The majority of these companies are municipal and provide power service exclusively for their community. In addition they are surrounded by 300 electric utilities which operate within an urban or regional area. This group of firms operates in all three stages of provision listed above, but generally the amount of generated power is small. The municipals and the regional electric utilities purchase most of their power from 10 utilities which form the backbone of the industry.

<sup>8</sup> This group of firms is involved in generation, transmission and distribution, but the amount of generated power is small and is determined by the ability to exploit favorable hydroelectric power generation possibilities.

delivered, the maximum demand, as well as the number of customers and the size of the service territory. All input prices, total cost and variable cost were deflated to 1996 constant Swiss francs using the Consumer Price Index.

For simplicity, total distribution cost is equated to total expenditure as reported by the companies excluded the expenditure for purchased electricity. Average yearly wage rates are estimated as the labor expenditure divided by the number of employees. Following Friedlander and Wang Chang (1983) and Filippini and Maggi (1993), the capital price is calculated from the residual capital costs divided by the capital stock. Residual cost is total distribution cost minus labor cost. According to Callan (1992), the capital stock is approximated by the total installed transformer capacity, measured in kVA.<sup>9</sup> Some details of these variables are presented in Table 1.

Variables	Unit of measurement	1. Quartile	Median	3. Quartile
Total average distribution cost	SwF. / kW	266.8	375.8	486.10
Total average distribution cost	SwF. / kWh	0.05	0.07	0.10
Maximum demand	kW	16,250	21,920	36,785
Distributed electricity	million kWh	84.95	108.30	159.50
Number of customers		7,762	10,538	17,217
Size of the service territory	hectares	1,130	2,290	5,995
Labor price	SwF. per worker	77,109	96,304	114,680
Capital price	SwF. per unit of capital	66.3	90.4	122

**Table 1 - Descriptive statistics**

## Estimation Results

Table 2 presents the GLS estimates of the translog frontier average cost function (2) under two cases. In Model 1 the dependent variable is average cost per kWh and the output is measured in kWh, whereas in Model 2 the dependent variable is average cost per kW and the output is measured in kW. The GLS estimates in Table 2 can be used to recover estimates of inefficiency for each distribution utility.

The estimated functions are well behaved. Most of the parameter estimates are statistically significant and carry the expected sign. Moreover, the coefficients of both models are similar. This results is not surprising because the two output variables, kWh and kW, have a correlation coefficient of 0.95.

Since average total cost as well as the dependent variables are in natural logarithms and have been normalized, the first order coefficients are interpretable as average cost elasticities evaluated at the sample median.

<sup>9</sup> Unfortunately no data are available which would allow the calculation of the capital stock using the perpetual inventory method.

Coefficient	<i>Model 1</i> average cost per kWh	<i>Model 2</i> average cost per kW
$b_0$	-2.582 *** (0.067)	5.926 *** (0.068)
$b_y$	-1.016 *** (0.075)	-0.913 *** (0.063)
$b_l$	0.302 *** (0.015)	0.301 *** (0.015)
$b_{CU}$	0.452 *** (0.086)	0.396 *** (0.077)
$b_{AS}$	0.226 *** (0.044)	0.208 *** (0.046)
$b_{yy}$	0.657 * (0.356)	0.997 *** (0.241)
$b_{ll}$	0.081 ** (0.031)	0.067 ** (0.030)
$b_{CUCU}$	0.975 ** (0.415)	1.144 *** (0.275)
$b_{ASAS}$	-0.059 (0.048)	-0.039 (0.042)
$b_{yl}$	-0.063 (0.050)	-0.013 (0.046)
$b_{yCU}$	-0.612 * (0.352)	-0.850 ** (0.234)
$b_{yAS}$	0.011 (0.069)	-0.017 (0.047)
$b_{CUI}$	0.105 ** (0.048)	0.045 (0.046)
$b_{ASl}$	-0.019 (0.012)	-0.017 (0.012)
$b_{CUAS}$	-0.028 (0.067)	-0.053 (0.053)

\*, \*\*, \*\*\*: significantly different from zero at the 90%, 95%, 99% confidence level.

**Table 2 - Total-cost parameter estimates (standard errors in parentheses)**

The output elasticity is negative and implies that an increase in the production of output will decrease average total cost. A 1% increase in the delivery of power will decrease the average total cost by approximately 1% in model 1 and by approximately 1.10% in model 2.

The average cost elasticity with respect to area size is positive in all versions of the average cost model, indicating that a 1% increase in area size will increase average cost by approximately 0.22% in model 1 and by approximately 0.39% in model 2.

The average cost elasticities with respect to the number of customers are positive and imply that an increase in the number of customers will increase average total cost.

To test whether individual effects are present we ran a Lagrange Multiplier test for the random effects model. The result of this test favors the random effects model over the OLS model.

### **Scale and Cost Efficiency**

#### *Economies of Scale and Density*

The inclusion in the average cost function of the number of customers and the size of the service territory allows for the distinction of economies of output density, economies of customer density and economies of scale. We define economies of output density (EOD) as the proportional decrease in total average cost brought about by a proportional increase in output, holding all input prices, the number of customers and the size of the service territory fixed. This is equivalent to the elasticity of total average cost with respect to output,

$$EOD = \frac{d \ln AC}{d \ln y} \quad (3)$$

We will talk of economies of output density if EOD is negative, and accordingly, we will talk of diseconomies of output density if EOD is positive. In the case of  $EOD = 0$  no economies or diseconomies of output density exist. Economies of output density exist if the average costs of an electricity distribution utility decrease as the volume of electricity sold to a fixed number of customers in a service territory of a given size increases.

Economies of customer density (ECD) are defined as the proportional decrease in total average cost brought about by a proportional increase in output and the number of customers, holding all input prices and the size of the service territory fixed. Economies of customer density (ECD) can thus be defined as

$$ECD = \frac{d \ln AC}{d \ln y} + \frac{d \ln AC}{d \ln CU} \quad (4)$$

We will talk of economies of customer density if ECD is negative, and accordingly, we will talk of diseconomies of customer density if ECD is greater than 0. This measure is relevant for analyzing the cost of distributing more electricity to a fixed service territory as it becomes more densely populated.

Economies of scale (ES) are defined as the proportional decrease in total average cost brought about by a proportional increase in output, the number of customers and the size of the service territory, holding all input prices fixed. ES can thus be defined as

$$ES = \frac{d \ln AC}{d \ln y} + \frac{d \ln AC}{d \ln CU} + \frac{d \ln AC}{d \ln AS} \quad (5)$$

We will talk of economies of scale if ES is smaller than 0, and accordingly, we will talk of diseconomies of scale if ES is greater than 0. In the case of  $ES = 0$  no economies or diseconomies of scale exist. This measure is relevant for analyzing the impact on cost of merging two adjacent electricity distribution utilities.

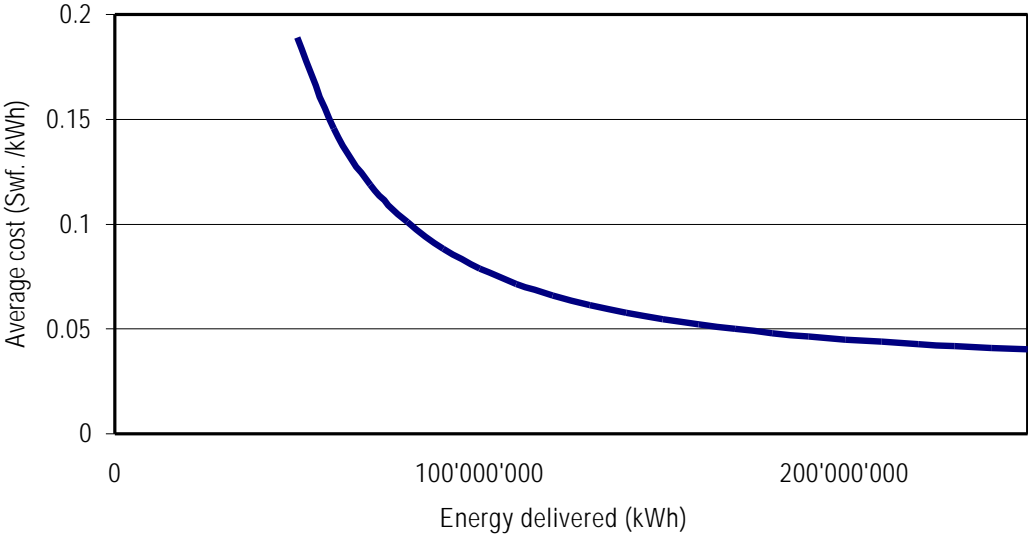
Table 3 presents the estimates of economies of output density, customer density and economies of scale evaluated using the estimation results from Schmidt-Sickles frontier models.<sup>10</sup>

	Model 1 (kWh)	Model 2 (kW)
Economies of output density	-1.01	-0.91
Economies of customer density	-0.79	-0.52
Economies of scale	-0.34	-0.32

**Table 3 - Economies of scale and density**

We note that all indicators for economies of scale and economies of output and customer density are greater than 1, which means that the majority of the Swiss electricity distribution utilities operate at an inappropriately low scale and density level.<sup>11</sup>

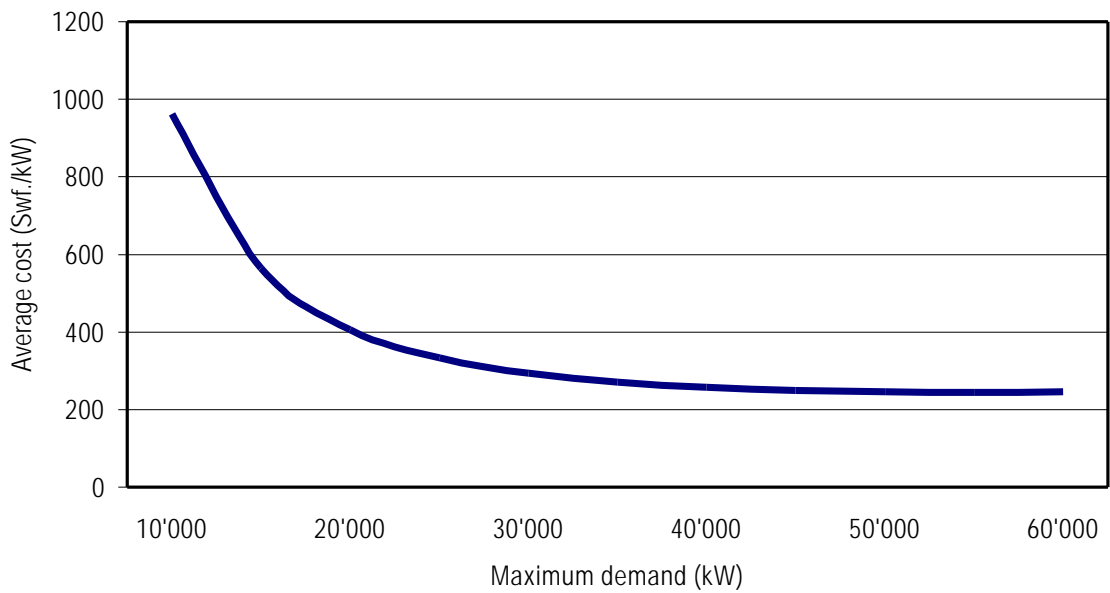
The average cost (AC) curves implied by our estimated translog models appear in Figure 1 and 2, evaluated with all variables other than output (measured in kWh or kW alternatively) set to their sample median. These curves are “L” shaped and indicate the presence of economies of density.



**Figure 1 - Estimated AC curve using kWh as output indicator (Model 1)**

<sup>10</sup> Equations (3), (4) and (5) have been evaluated at the input prices of the median company.

<sup>11</sup> These results confirm the results obtained by Filippini (1997, 1998) estimating a translog total cost function for another sample of Swiss electricity distribution utilities.

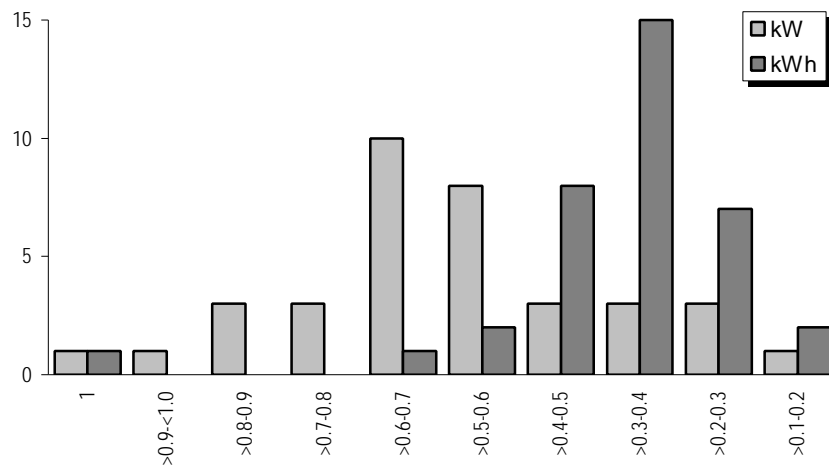


**Figure 2 - Estimated AC curve using kW as output indicator (Model 2)**

*Cost inefficiency*

The estimation results reported in Table 2 can be used to recover estimates of the level of cost inefficiency of each distribution utilities along the line suggested by Schmidt and Sickles (1984). This amounts to counting the most efficient distribution utility in the sample as 100% efficient and measuring the degree of cost inefficiency of the other utilities relative to the most efficient distribution utility.

The level of cost efficiency ranges from 10 to 100%. Complete summary statistics of the various efficiency measures for both models appear in Figure 3. These relatively low scores indicate a high dispersion of cost inefficiencies across distribution utilities, and could be due to the relative inhomogeneity of the activities of the firms considered in the sample.



**Figure 3 - Distribution of cost efficiency**

## Conclusions

In this paper we have examined the scale and cost inefficiency of a sample of Swiss electricity distribution utilities. For this purpose, we have estimated a stochastic frontier cost model function using the approach suggested by Schmidt and Sickles (1984) for panel data. A translog cost function was estimated using panel data for a sample of 30 municipal utilities over the period 1992-1996.

The results indicate the existence of economies of output and customer density and economies of scale. Moreover, the findings on cost inefficiency show that a majority of the distribution utilities is not producing at the minimum level of the cost.

A possible application of the frontier methodology employed in this paper relates to the regulation of the delivery rates. Distribution utilities have a monopoly franchise to distribute electricity within their service territories and, therefore, are to be subject to rate regulation by the regulatory commission. Otherwise, the distribution utilities could raise the rates above what they would be in a competitive market.

The distribution rates should be set at levels reasonable and adequate to meet costs which must be incurred by efficiently operated facilities. As presented in the introduction, in Switzerland there exists a proposal that suggests setting the rates for the delivery of electricity so that they equal the average distribution cost measured in Swiss francs per kWh. We believe that the regulators could use the estimated average cost frontier model to control the level of the rates proposed and applied by the single distribution utilities. In this case the average cost frontier model would become an instrument to benchmark distribution rates.

## Bibliography

- Battese, G.E., 1992, Frontier Production Functions and Technical Efficiency: a Survey of Empirical Applications in Agricultural Economics, *Agricultural Economics*, 7, 185-208.
- Bauer, P.W., 1990, Decomposing TFP Growth in the Presence of Cost Inefficiency, Nonconstant Returns to Scale, and Technological Progress, *Journal of Productivity Analysis*, 1, 287-300.
- Burns, P. and Weymann-Jones T.G., 1996, Cost Functions and Cost Efficiency in the Electricity Distribution: a Stochastic Frontier Approach, *Bulletin of Economic Research*, 48, 42-64.
- Callan, S.J., 1991, The Sensitivity of Productivity Growth Measures to Alternative Structural and Behavioral Assumptions: An Application to Electric Utilities 1951-1984, *Journal of Business & Economics Statistics*, 9, 207-213.
- Filippini, M. and Maggi, R., 1993, Efficiency and Regulation in the case of the Swiss Private Railways, *Journal of Regulatory Economics*, 5, 199-216.
- Filippini, M., 1996, Economies of Scale and Utilization in the Swiss Electric Power Distribution Industry, *Applied Economics*, 28, 543-550.
- Filippini, M., 1997, *Elements of the Swiss Market for Electricity*, Physica-Verlag. Berlin.
- Filippini, M., 1998, Are Municipal Electricity Distribution Utilities Natural Monopolies?. *Annals of Public and Cooperative Economics*, (forthcoming).
- Friedlaender, A.F. and Shaw-Er Wang Chiang, J., 1983, Productivity Growth in the Regulated Trucking Industry, *Research in Transportation and Economics*, 1, 149-184.

- Hsiao, C., (1986), *Analysis of Panel Data*, Cambridge University Press, New York.
- Hubbard, L.J. and Dawson P.J., 1987, Ex ante and ex Post long-run average cost functions, *Applied Economics*, 19, 1411-1419.
- LIMDEP, 7.0, 1998 (Econometric Software, Inc., Belpport, NY).
- Nelson, R.A. and Primaux, W.J. Jr., 1988, The Effects of Competition on Transmission and Distribution Costs in the Municipal Electric Industry, *Land Economics*, 64, 338-346.
- Neuberg, L.G., 1977, Two issues in the municipal ownership of electric power distribution systems, *Bell Journal of Economics*, 8, 302-322.
- Salvanes, K.G. and Tjøtta, S., 1994, Productivity Differences in Multiple Output Industries: An Empirical Application to Electricity Distribution, *The Journal of Productivity Analysis*, 5, 23-43.
- Schmidt, P. and R.E. Sickles, 1984, Production Frontiers and Panel Data, *Journal of Business and Economic Statistics*, 2, 367-374.
- 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.
- Swiss Federal Office of Energy, various years, *Finanzstatistik*, Bern.
- Thompson, H.G., 1997, Cost efficiency in Power Procurement and Delivery Service in the Electric Utility Industry, *Land Economics*, 73, 287-296.
- Weiss, L.W., 1975, Antitrust in the Electric Power Industry. In: *Promoting Competition in Regulated Markets*, ed. A. Phillips. Washington, DC: Brookings Institution.