ESTIMATION OF THE MACEDONIAN POWER DISTRICT'S PRODUCTION FUNCTION

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ABSTRACT

Efficiency and productivity analyses can provide an important insights and information about the electricity sector in the light of the deregulation reform going on in Macedonia. The question of economies of scale, optimal networking, investment and other are of importance for the transmission and distribution power districts.

In this paper subject of analyze are the 28 Macedonian power districts. We will use the Stochastic Frontier (SF)[2] parametric method on 2 models with total of 4 versions. It was shown that the operational efficiency (low voltage system) is higher than the strategic one (high voltage system). As well, it was shown that the plant layout influences the district economies of scale and technical change. Also, the labor productivity is sensitive to the number of consumers.

This paper is organized as follows: part one describes the method of DEA, its efficiency measures and the mechanism of it. Part two is about the data and the models in use. Last part is the conclusion. The references are in the end.

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[2] I am using the Stochastic Frontier Computer Program Version 4.1 developed by Tim Coelli in 1996.

1. THE ANALYSIS

1.1. The rationale for the analyses

Soon the liberalized market for electricity should start in Macedonia. Decision makers must take into account that the aim of the deregulation is to promote a long run efficiency gains through competition and to stimulate a technical innovation and efficient investment through viable electricity market design. Special focus should be on the transmission and distribution fraction of this industry. This is understandable because the transmission raises problems of network externalities and large sunk costs or economies of scale where competitive market prices may not recover the investment. While, the distribution districts must appreciate more the importance of serving the customer choice and provide product diversity in achieving long run efficiency gains. Independently of what competition promotion will be designed, the portfolio manager model or the customer choice model, the distribution districts must know what are their economies of scale, how do they perform in technical efficiency by utilizing the inputs, should they invest in high voltage or low voltage level equipment, what are the elasticities of output with respect to the relevant inputs, what are the technical changes etc. On some of the questions above answers can be given out from the results of the analyses in this paper.

1.2. The data

The electricity transmission and distribution in the Republic of Macedonia is accomplished through 28 districts. We will estimate the production function under different criteria for the distribution districts and analyze their technical efficiency and productivity over the period under observation from 1993 to 1998. The summary statistics for the data are illustrated in the following Table 1[3].

	Number of consumers (high and low voltage)	Electric energy sold (MWh) (high and low voltage)	Power lines (km) (high and low voltage)	Transformer capacity (MVA)	Employees
1993	560564	3379351	19066	2079	3482
1994	576500	3419882	19269	2020	3380
1995	594930	3599177	19553	2097	3463
1996	606431	3964681	19825	2143	3182
1997	618506	3866852	20078	2218	3168
1998	634432	3866908	20295	2225	3227
Growth (%)	2.5	2.8	1.3	1.4	-1.4
mean:	598560.5	3682809	19681	2130.333	3317

Overall, from Table 1 we can see that the number of consumers is increasing while the electricity sold has reached its peak in 1996 and then it stabilizes. However, the electricity consumption is growing more than the number of consumers. The number of employees in the distribution districts is declining by 1.4 % in the period.

2. THE METHODOLOGY

2.1. Production Function

In this paper the technical efficiency of the distribution districts is analyzed through estimation of the production functions. The data on input prices were not available thus; the cost function and the allocative efficiency could not be parametrically estimated. The estimation of the production function will give answer on the technical efficiency i.e. how do the distribution districts perform given its inputs. The best situation for them is to be fully efficient and to give the maximum output given its inputs. However, this is rarely the case and we are expecting variations among their performances. The production function is the Cobb-Douglas type on log of the data. Two outputs will be defined, electricity sold in MWh at high and low voltage level and number of consumers at high and low voltage level.

2.2. Stochastic frontier theory

The deterministic estimate of a production function (frontier) was proposed by Aigner and Chu (1968) by considering Cobb-Douglas production function as in the following model:

$$\ln(Y_i) = x_i\beta - U_i \quad (1)$$

[3] The data were kindly provided by the Macedonian Chamber of Commerce (the Energy and Industry Department).

The ratio of the actual over the potential output, defined by the frontier, is used to define the technical efficiency as:

$$TE_i = \frac{Y_i}{\exp(x_i\beta)} = \exp(U_i) \quad (2)$$

The above model is bounded above by the non-stochastic, i.e. deterministic, term $\exp(x_i\beta)$ and other noise and/or measurement errors upon the frontier were not taken into account. Because of that this frontier is known as deterministic frontier (see more in [1]). Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977) independently proposed the SF production function where an additional random error, V_i is added to the random variable U_i. This additional variable will account for other random factors that will affect the output. The model on panel data has the following form:

$$Y_i = x_i\beta + (V_i - U_i) \quad (3)$$

Where: $Y_i -$ is the output in the production function of the i-th firm;

x_i -is a (k x 1) vector of transformations of the input quantities of the i-th firm;

β -is a vector of unknown parameters;

U_i -are random variables (non-negative) which are assumed to account for technical inefficiency in production and are often assumed to be iid;

V_i -are iid N (0, $\sigma^2{}_v$) random variables and are independent of the U_i.

The model in the equation (3) is a stochastic frontier because it is bounded above by the stochastic variable $x_i\beta + V_i$ and the stochastic frontier can vary about the deterministic part $x_i\beta$. After the model in the equation (3) was suggested, where the efficiency effects were time invariant, a model by Battese and Coelli (1992) was proposed that allow efficiency to vary over time such as:

$$U_i = U_i \exp(-\eta(t-T)) \quad (4)$$

U_i -are assumed iid as truncation at μ of the N (μ, $\sigma^2{}_u$) distribution and η -is the parameter to be estimated. This means that the non-negative firm effects U_i -decrease, remain constant or increase as t-increases if $\eta > 0$, $\eta = 0$ or $\eta < 0$ respectively.

In order to provide a good starting value for the iterative maximization process, and with the calculation of the Maximum Likelihood Estimation (**MLE**) in mind, there is a new variable γ -defined as (see [2] and [3]):

$$\gamma = \frac{\sigma_U^2}{(\sigma_V^2 + \sigma_U^2)} \quad (5)$$

It is worth to note that if γ=0 - there are no firm effects, then we should consider a traditional response function; if μ=0 - then the (in)efficiencies of the decision making units are following the half normal distribution; if $\eta = 0$ - the (in)efficiency is time invariant.

2.3. The SF models and the assumptions

For production-function maximum-likelihood estimation of the electricity distribution districts of Macedonia we will use the Cobb-Douglas functional form on log of the data. The following models will be considered by following the equation 3 from above:

1) Model 1a) and Model 1b) where output is the MWh electricity sold to high and low voltage consumers respectively.

a) $\log(MWh_{high}) = \beta_0 + \beta_1 \log(km_{high}) + \beta_2 \log(MVA) + \beta_3 \log(L) + (V_i - U_i)$

b) $\log(MWh_{low}) = \beta_0 + \beta_1 \log(km_{low}) + \beta_2 \log(MVA) + \beta_3 \log(L) + (V_i - U_i)$

2) Model 2c) and Model 2d) where output is the number of consumers on high and low voltage level respectively.

c) $$\log(cons_{high}) = \beta_0 + \beta_1 \log(km_{high}) + \beta_2 \log(MVA) + \beta_3 \log(L) + (V_i - U_i)$$

d) $$\log(cons_{low}) = \beta_0 + \beta_1 \log(km_{low}) + \beta_2 \log(MVA) + \beta_3 \log(L) + (V_i - U_i)$$

For each of the models above we will try to find the right specification by testing and estimating the following assumptions on the γ, μ, η :

Assumption 1 γ, μ, η	**Assumption 2** $\mu = 0$	**Assumption 3** $\eta = 0$	**Assumption 4** $\mu = \eta = 0$

In assumption 1 all the parameters γ, μ, η are estimated. Here if η is subject to estimation that means the distribution district's effects are time varying and U_i is non-negative truncation of the N (μ , $\sigma^2{}_u$) distribution. The parameter γ is the variance parameter and has value from the interval [0, 1]. If γ is statistically significantly closer to 1 the SF presentation is appropriate for the model. If γ is statistically significantly closer to 0 then the usual response function is appropriate presentation for the model. The assumption of the latter is that all of the districts are efficient.
Assumption 2 is the same as the assumption 1 but the N (μ , $\sigma^2{}_u$) distribution is half-normal (μ =0) i.e. it becomes N (0, $\sigma^2{}_u$).
Assumption 3 suggests time invariant (in)efficiencies i.e. the distribution districts do not change their (in)efficiency through the time period under observation.
Assumption 4 is time invariant model where the power plants effects U_i have half-normal N (0, $\sigma^2{}_u$) distribution; (μ =0).

2.4. Estimation and results[4]

For the maximum likelihood estimation on the models defined above we will use a SF software version 4.1 developed by Tim Coelli (see [2] and [3]). The results from the SF estimation are illustrated in the next Table 2. Different hypotheses were tested and the results are illustrated in Table 3. The hypotheses testing for the assumptions were conducted with the generalized likelihood-ratio (LR) test statistics. For illustration purposes the complete treatment for the Model 1a) is illustrated in the table 2.
From the table 3 it can be seen that statistically significant is the assumption 4 for the Model 1a). Thus, the MWh output (electricity sold) at high level voltage in Macedonia is with time invariant (in)efficiencies with half normal distribution truncated at μ =0 . What that means is that for the period under observation the distribution districts neither improved nor decreased their efficiency in operating with the defined inputs.
The economies of scale are $e = \varepsilon_{km} + \varepsilon_{MVA} + \varepsilon_L = 0.720$ thus, decreasing economies of scale. The km input factor is with negative elasticity which might suggest congestion in using this input. The traditional time factor to catch for technical change was insignificant and it was excluded from this model.
By following the same procedure we have estimated and tested assumptions for the other models as well. The results of the estimation are illustrated in the table 4. The t-statistics are shown in parenthesis for the estimated parameters in the tables. The technical change was significant only for the Model 2d).

Table 2. Illustration of the analyses and assumption tests for the model 1a).

	Assumption 1 γ, μ, η	**Assumption 2** $\mu = 0$	**Assumption 3** $\eta = 0$	**Assumption 4** $\mu = \eta = 0$
β_0 **-cons.**	7.904 (17.034)	7.960 (13.918)	7.914 (14.994)	7.950 (13.243)
β_1 **-km**	-0.442 (-2.413)	-0.429 (2.095)	-1.449 (2.693)	-0.494 (-2.472)
β_2 **-MVA**	0.328 (2.118)	0.370 (2.270)	0.264 (1.862)	0.294 (1.997)
β_2 **-L**	0.824 (3.022)	0.771 (2.605)	0.948 (3.759)	0.920 (3.537)

[4] The results for each model are readily available upon request to each interested party.

γ	0.978 (89.193)	0.928 (41.886)	0.977 (73.160)	0.920 (39.056)
μ	-3.783 (-1.862)	0	-3.662 (-1.806)	0
η	-0.016 (-1.113)	-0.017 (-1.141)	0	0
log (likelihood)	-67.115	-67.948	-67.698	-68.614

Table 3. LR tests on the assumptions for the model 1a).

Assumptions	**null -** H_0	χ^2 **- statistics**	$\chi^2_{0.95}$ **-value**	**Decision**
LR= -2($l_R - l_U$) LR = -2(1-4)	$\mu = \eta = 0$	**2.998**	**5.991**	**accept** H_0
LR= -2($l_R - l_U$) LR = -2(1-2)	$\mu = 0$	**1.666**	**3.841**	**accept** H_0
LR= -2($l_R - l_U$) LR = -2(1-3)	$\eta = 0$	**1.166**	**3.841**	**accept** H_0
($\mu = 0$) LR = -2(2-3)	$\eta = 0$	**0.500**	**3.841**	**accept** H_0

Table 4. Results from the estimation on the models.

	Model 1a) $\mu = \eta = 0$	**Model 1b)** $\mu = 0$	**Model 2c)** **response**	**Model 2d)** γ, μ, η
β_0 **-cons.**	7.950 (13.243)	4.901 (10.204)	-1.064 (-3.157)	5.414 (22.332)
β_1 **-km**	-0.494 (-2.472)	0.360 (3.005)	0.311 (2.799)	0.386 (7.881)
β_2 **-MVA**	0.294 (1.997)	0.172 (1.498)	0.160 (1.650)	0.251 (4.904)
β_3 **-L**	0.920 (3.537)	0.840 (4.578)	0.483 (2.825)	0.319 (4.155)
β_4 **- T**	NA	NA	NA	0.024 (3.800)
γ	0.920 (39.056)	0.887 (22.617)	NA	0.968 (94.525)
μ	0	0	NA	0.485 (5.114)
η	0	0.058 (3.317)	NA	-0.001 (-0.178)

Table 5. A summary on the estimation results presented in table 4.

Output	**Model 1a)**	**Model 1b)**	**Model 2c)**	**Model 2d**
Stochastic	Yes	Yes	No	Yes
Deterministic	No	No	Yes	No
Time invariant	Yes	No	NA	No
Economies of scale	0.720	1.372	0.954	0.959
Technical change	No	No	No	0.024

From the table 5 we can see that the (in)efficiencies are stochastically in nature for all of the distribution districts except when serving the consumers at high voltage level. That means Macedonian distribution districts differ in utilizing the factor inputs when selling electricity at low and high voltage levels. They also differ in technical efficiency when serving the consumers at low voltage level (model 2d) but are sharing the same technical efficiency when serving the consumers at high voltage level (model 2c).
For the observing period, the Macedonian distribution districts, have not changed their technical (in)efficiency for the electricity sold at high voltage level (model 1a), but do have improved in time with the electricity sold at low voltage level (model 1b) and have improved in serving the consumers at low voltage level (model 2d).
For the Macedonian distribution districts we can say that there are increasing economies of scale of 1.372 only at selling electricity at low voltage level (model 1b). Selling electricity at high voltage level (model 1a) and serving all customers (models 2c and 2d) is with decreasing economies of scale. This is very interesting finding since we

would expect increasing economies of scale at high voltage level. Maybe the situation with the last years investment in the transmission have changed the situation compare with this period from 1993 to 1998.
The only statistically significant technical change is at serving customers at low voltage level (model 2d). The improvement in serving customers at low voltage level is 2.4 % per year.
Statistically significant are all parameters except for the MVA factor input when selling electricity at low voltage level (model 1b).
The input factor elasticities are presented in the following table. The interpretation is as follows: the number shows by how many percentages the output will increase (decrease) if the corespondent input increases (decreases) by 1 %.

Table 6. The input elasticities for the estimated model's output.

Output	MWh high	MWh low	Cons high	Cons low
β_1 **-km**	**-0.494**	**0.360**	**0.311**	**0.386**
β_2 **-MVA**	**0.294**	**0.172**	**0.160**	**0.251**
β_3 **-L**	**0.920**	**0.840**	**0.483**	**0.319**

What we can see from the table 6 is that a 1 % increase in km power lines will decrease the MWh sold at high voltage level. This is to be expected because of the congestion in the transmission. The km factor input elasticity for the other outputs is around 0.3 %. That means if we increase the km factor input by 1 %, those outputs will increase by 0.3 %.
The MVA factor input was insignificant for the MWh sold at low voltage level. For the other outputs it is in the range of 0.1 % to almost 0.3 % elasticity.
The highest dispersion of the elasticity is with the number of employees. Less number of workers is required in serving consumers at high voltage level than in low voltage level in both types of production function.

CONCLUSION

The analyses of transmision and distribution of electricity is very important in the light of power market deregulation. It is the sector that links the power generation with the customers. The power company should appreciate the importance of customer's choice and product diversity in achieving the long-run efficiency gains. For example customers will value electricity at different locations and times, reliability or other ancillary services. Consumers are not interested in kWh or other technical terms, but in comfort and convenience. Because of that a comprehensive productivity and efficiency analyses is required.
In Macedonia the distribution district's performances are:

- Clear congestion in the transmission while selling MWh to high voltage level customers;
- Increasing economies of scale only at selling MWh to low voltage level customers;
- Efficiency in utilizing inputs has increased only to serving consumers at low voltage level;
- The strategic efficiency (the transmission management) time invariant for the period;
- Technical change is significant only in serving number of customers at low voltage level;
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