DEA IN ESTIMATING MACEDONIAN POWER DISTRICT'S PRODUCTIVITY AND EFFICIENCY FOR THE PERIOD 1993-1998

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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 Data Envelopment Analyses (DEA)[2] non-parametric method on 6 models. 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 DEA Computer Program Version 2.1 developed by Tim Coelli in 1996.

1. THE METHODOLOGY

1.1. Efficiency Measures

As efficiency measurement we will use frontiers[3] or more precisely the mathematical programming frontier. The mathematical programming frontier i.e. the non-parametric method is the Data Envelopment Analysis **(DEA)** method[4]. We'll only look at some concepts that are of substantial value for understanding the mechanism of the estimations provided in this paper.

Farrell (1957) proposed that the efficiency of a firm consist of two components, the technical and the allocative efficiency. These two measures combined will provide the measure of the economic (total) efficiency. See next Figure 1.

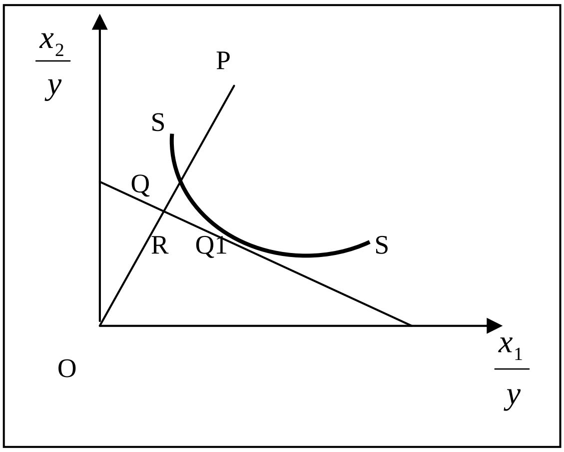

Figure 1

What we can see from Figure 1 is a firm that uses two inputs x_1, x_2 and produces one output-y. The isoquant S-S in Figure 1 is of a fully efficient firm. There is a production frontier that corresponds with this isoquant and is for fully efficient firms only. But, in practice we don't know the production frontier and it must be estimated from observations on a sample of firms. The estimation can be by parametric or non-parametric methods[5]. So, if the firm is operating inefficiently, say in the point-P from Figure 1, the measure of technical inefficiency could be represented by the distance-QP. This distance is representing the amount by which the inputs can be reduced without reducing the output. The percentage term by which all inputs need to be reduced to achieve technical efficient production is represented by QP/OP ratio. The technical efficiency from Figure 1 is thus:

$$TE = OQ/OP = 1 - QP/OP \quad (1)$$

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[3] A production function is a frontier as well. The difference is that the assumption of efficient firms in the production function method operating on frontier is relaxed with the DEA method.
[4] For more in depth rationale of the method see [1], [2], [3], [4].
[5] The parametric method is the Stochastic Frontier and/or the Econometric Method.

It is obvious that-TE will take value between 0 and 1 and can be indicator for the degree of technical inefficiency of a firm. For example a firm that operates at point-Q is fully efficient and the proper TE takes value 1. The allocative efficiency of a firm that operates at point-P is:

$$AE = OR / OQ \quad (2)$$

What we can see from Figure 1 also and from Equation 2 as well is that the point Q is technically efficient but allocatively inefficient. It takes the firm to reduce its production costs to be operational at the totally efficient point-Q_1. Thus, the allocative efficiency is:

$$AE = OR / OQ \quad (3)$$

The distance-RQ represents the reduction in the production costs that would occur if the production were performing at the technically and allocatively efficient point Q_1 instead at the technically efficient but allocatively inefficient point Q. Thus, the total economic efficiency will be:

$$EE = OR / OP = TE \cdot AE = OQ / OP \cdot OR / OQ \quad (4)$$

1.2. Data Envelopment Analysis

As we said previously the production function and the proper isoquant should be estimated, because we don't know them in practice. Farell (1957) suggested an estimation of linear convex isoquant such that no point from the observed data lies to the left or below it. As an illustration for a linear convex isoquant see the next Figure 2. Later, in 1978, Charnes Cooper and Rhodes used the Farell method and the term DEA was first used by them. A mathematical programming model was used to estimate the linear convex isoquant as in Figure 2[6].

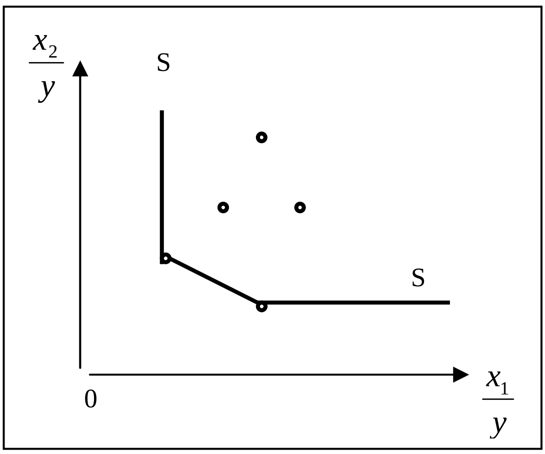


Figure 2

[6] More on the construction of the DEA models see [1], [2], [4].

The returns to scale and the input/output orientation

The returns to scale in connection to the input/output orientation are illustrated in the next Figure 3.

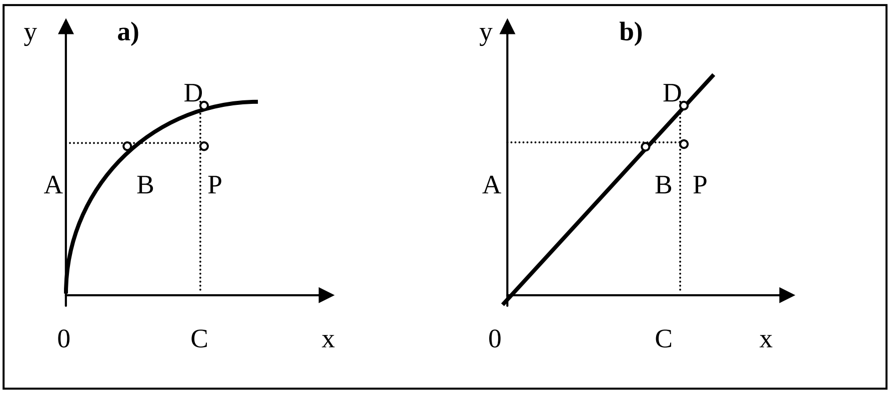


Figure 3

From Figure 3-graph a) we can see the decreasing returns to scale case and the constant returns to scale on the graph b). If we ask by how much the input quantities can be proportionally reduced so the output will be the same then this is the movement from P to B in both graphs. That is the input orientated efficiency measure. Now, if we ask by how much the output can be proportionally expanded by using the same input quantities, then this will be the movement from P to D in both graphs. What is different in both graphs is that the input/output distinction matters only in the graph a), because the BP distance is not the same as the distance PD as it is the case in the graph b). In that way we can say: when there are constant returns to scale it doesn't matter if the research is input or output orientated, but it matters when there are variable returns to scale.

This is very important because the electricity industry have in general increasing returns to scale and it is input orientated simply because it has to meet the demand for electricity by managing the inputs utilization.

When a technology is analyzed as with variable returns to scale and constant returns to scale separately, the technical efficiency can be decomposed on scale efficiency and pure technical efficiency[7]:

$$TE = SE \cdot PE \quad (5)$$

The TFP is a measure of productivity involving all factors of production. The MTFP change between two data points can be obtained by calculating the distances of each data point.

[7] See [2].

2. THE ANALYSIS

2.1. The Data

The power transmission and distribution in Macedonia is accomplished through 28 districts.

We will analyze the efficiency and productivity of those districts. This is important because, apart from the resources used on the generation side, there are different factors necessary to describe the consumption side as well, such as low/high voltage consumers (or industrial/residential consumption criteria), rural/urban networking, layout of power plants etc.

For the analyses we'll use the following variables [8]:

1. km-of lines high voltage;
2. km-of lines low voltage;
3. km-of lines (sum);
4. labor (number of blue and white shirts);
5. kVA-installed transformer capacity;
6. Consumers (sum);
7. MWh-sale high voltage;
8. MWh-sale low voltage;
9. MWh-sale (sum).

The period under observation will be 1993-1998. The summary statistics for the data are illustrated in the following Table 1.

	Number of consumers	Electric energy sold (MWh)	Power lines (km)	Transformer capacity (kVA)	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

Table 1

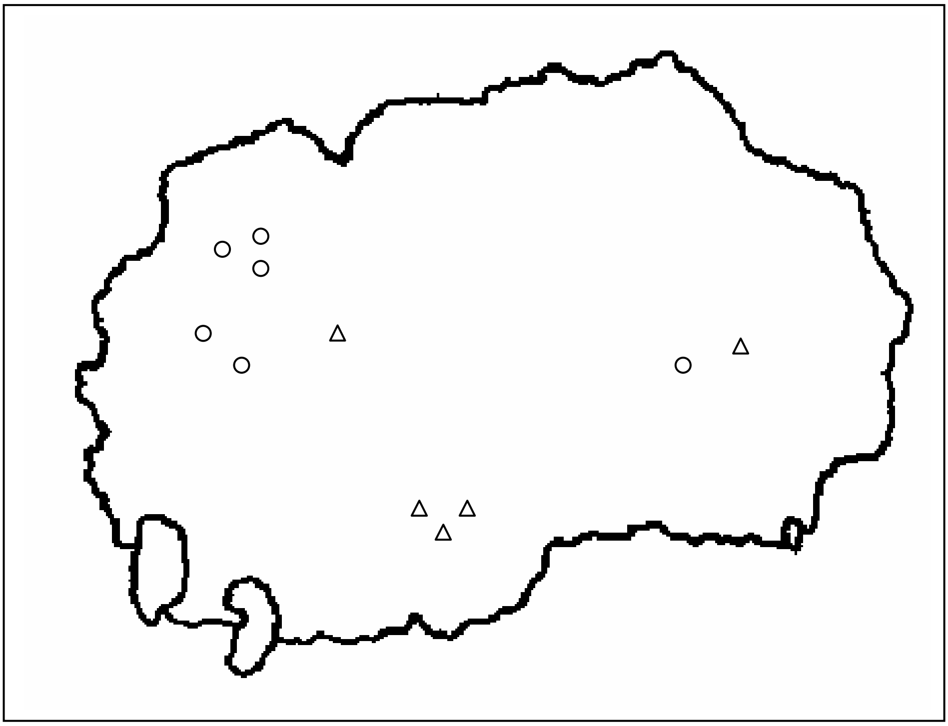
Overall, from Table 1 we can see that the number of consumers is increasing while the electricity sold has reached its peak in 1996 and then it stabilizes. However, the growth of consumption is higher in that period than the growth of consumers. The number of employees in the distribution districts is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

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

2.2. The specifics in the Macedonian sector

The layout of the power plants in Macedonia

The following Figure illustrates a map of the Republic of Macedonia that is with area of 25713 km^2 and around 2-mln population[9]. The layout focuses power plants heavily on the western part of the country. That must be taken into account especially when we analyze the distribution efficiency in the eastern and western part of the country.



The Skopje distribution District

The Skopje distribution district comprises enviable amount of resources from the variables above. Therefore, the rationale for excluding Skopje is preferable in some model analyses. The next Table 2 shows us the fraction of variables devoted to the distribution district Skopje.

	Percentage of total
Power lines (km)	24 %
Electricity sold (MWh)	54 %
Employees	32 %
Transformer capacity (kVA)	43 %
Number of consumers	44 %

Table 2

[9] Census, year 1994.

2.3. The DEA Models

Different multiple output/input DEA models will be analyzed as shown in Table 3. The rationale for those models is shown in Table 4. The DEA efficiency scores will be analyzed by the correlation with some productivity indices as well.

	INPUT(S)	OUTPUT(S)
MODEL 1	a) km-of lines (sum) b) KVA-installed transformer capacity c) labor (blue and white shirt)	a) consumers (sum) b) MWh-sale (sum)
MODEL 2	a) km-of lines high voltage b) KVA-installed transformer capacity c) labor (blue and white shirt)	a) consumers high voltage b) MWh-sale high voltage
MODEL 3	a) km-of lines low voltage b) KVA-installed transformer capacity c) labor (blue and white shirt)	a) consumers low voltage b) MWh-sale low voltage
MODEL 4 SKOPJE excluded	a) km-of lines (sum) b) KVA-installed transformer capacity c) labor (blue and white shirt)	a) consumers (sum) b) MWh-sale (sum)
MODEL 5	a) labor (blue and white shirt)	a) km-of lines (sum) b) KVA-installed transformer capacity c) consumers (sum) d) MWh-sale (sum)
MODEL 6 EAST and WEST	a) km-of lines (sum) b) KVA-installed transformer capacity c) labor (blue and white shirt)	a) consumers (sum) b) MWh-sale (sum)

Table 3

Models	Rationale for the analyses
MODEL 1	Transmission and distribution efficiency analyses
MODEL 2	Transmission efficiency analyses (strategic efficiency)
MODEL 3	Distribution efficiency analyses (operative efficiency)
MODEL 4 SKOPJE excluded	Equivalent environmental conditions efficiency analyses
MODEL 5	Labor productivity analyses
MODEL 6 (EAST and WEST)	The power plants layout impact analyses

Table 4

We would like to gain some insights into the productivity change in this sector, as well as in the other efficiency scores TE, TC, SE. The comparison among districts will be through those efficiency scores. We can see that models are with multiply input and multiply output structure.

Model 1 will cover the overall sector efficiency and productivity change in the period and among the DMU. The inputs will be labor and the capital in the light of transformers and the network length. The outputs are the electricity sold and the consumers that are serviced.

Model 2 is the same as model 1 with only one essential difference in taking into account the high voltage fraction of the variables only. The high voltage service belongs to the transmission part of the sector. As we said in Part I, when we were discussing about the losses, the transmission is of strategic importance because it is a link between the generation sector (power plants) of the electricity industry and the distribution districts[10].

Model 3 is analyzing the distribution part of the sector i.e. the low voltage fraction of the variables from model 1only. The DMU under this analysis are directly in connection with the final consumers and this is the operational part of this sector.

We saw from Table 4 that district Skopje is the biggest DMU compared to the other districts regarding input/output variables. In that way Skopje can have use of economies of scale and we must take into account those proportionality issues in operation under equal environmental conditions if we would like to estimate proper data envelopment. This is Model 4.

The usual indicator to estimate productivity in DMU is the labor and/or transformer productivity. Probably the district's management is using some simple indices such as total consumers/labor, MWh/MVA, network length/labor and/or MWh/labor in order to measure the productivity. Model 5 is dealing with labor productivity regarding how productive are the employees in servicing the network, transformers and consumers. Unfortunately, we didn't have separate data on blue and white shirts so, we couldn't go in more deeply labor productivity DEA analyses.

We saw from Figure that the layout of the power plants in Macedonia is biased towards the western part of the country. This will require longer network for service to the districts from the eastern part of the country and higher economies of scale opportunity for the western districts. That's the reason for Model 6. The input/output structure in the DEA estimation for this model 6 is the same as in the model 1.

[10] We will abstract ourselves from the direct consumers in these analyses.

2.4. The Results[11]

The following table is an illustration on the efficiency and productivity scores for the Model 6.

MODEL 6	a) km-of lines (sum) b) KVA-installed transformer power c) labor (blue and white shirt)	a) consumers (sum) b) MW-sale (sum)

WEST

		TE	TC	TFP		TE	PE	SE
	1993	0.00	0.00	0.00	**1993**	1	1	1
	1994	-2.12	4.40	2.37	**1994**	0.979	0.97	1.01
	1995	0.20	4.21	4.40	**1995**	1.002	0.999	1.004
	1996	0.80	13.98	14.76	**1996**	1.008	0.994	1.014
	1997	-0.50	-9.87	-10.31	**1997**	0.995	1.019	0.976
	1998	6.95	48.92	55.85	**1998**	1.072	1.027	1.043
	mean	**1.09**	**12.31**	**13.37**	**mean**	**1.011**	**1.002**	**1.009**
	firm	**TE**	**TC**	**TFP**	**firm**	**TE**	**PE**	**SE**
TETOVO	**1**	1	1.014	1.014	**1**	1	1	1
OHRID	**2**	1	1.021	1.021	**2**	1	1	1
BITOLA	**3**	0.987	1.028	1.014	**3**	0.987	0.986	1.001
PRILEP	**4**	0.997	1.103	1.1	**4**	0.997	1	0.997
GOSTIVAR	**5**	1	1.048	1.048	**5**	1	1	1
DEBAR	**6**	1.02	1.226	1.25	**6**	1.02	1	1.02
KICEVO	**7**	1.044	1.215	1.269	**7**	1.044	1.031	1.013
STRUGA	**8**	1.003	1.154	1.157	**8**	1.003	1	1.003
MA.BROD	**9**	1	1.347	1.347	**9**	1	1	1
RESEN	**10**	1.058	1.206	1.275	**10**	1.058	1	1.058
	mean	**1.011**	**1.131**	**1.143**	**mean**	**1.011**	**1.002**	**1.009**

Model 6
-West-

The summary of the efficiency and productivity scores from the models above is illustrated in the following Table 5.

Mean values	TE	TC	TFP	TE	PE	SE
Model 1	-0.60	2.08	1.39	0.994	0.999	0.995
Model 2	0.00	-1.31	-1.31	1	1.002	0.998
Model 3	-0.70	2.76	2.08	0.993	1.001	0.992
Model 4	-0.50	1.69	1.29	0.995	1.000	0.996
Model 5	-0.60	2.86	2.27	0.994	0.998	0.996
Model 6 east	-3.25	6.67	3.44	0.968	0.983	0.985
Model 6 west	1.09	12.31	13.37	1.011	1.002	1.009

Table 5

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

2.5. The correlation between the DEA models and simple productivity indices

As we said earlier, the district's management is using, most likely, a simple productivity indices in their analyses. Here we will connect the DEA efficiency results with the simple productivity indices[12]:

Index 1 = total consumers/labor[13]
Index 2 = MWh/MVA
Index 3 = network length/labor
Index 4 = MWh/labor

The following Table 6 shows the correlation between the efficiencies of the models and the indices. The index 1-index 2 correlation shows positive relationship between total consumers and electricity sale in MWh and that is understandable.

The negative correlation between index 1 and index 3 shows that more consumers requires less network length. This can be explained as because the total length is unreliable in terms of capital and service requirements. The total length may involve overground cables, underground cables, unfavorable geographic conditions, density of the grid, etc.

Model 1's efficiency shows positive correlation with all of the indices except for the index 4. This explains that if more MWh is sold the more inefficient utilize of the inputs from the Model 1 (the network, the KVA and labor) will be. This is a sign that there is some input's congestion (due to inefficient management of resources or because the networking is not optimal or some other environmental aspects are not included in the analyses).

However, if we compare Model 2 and Model 3 regarding the same index 4, we can see that the problem is in the strategic efficiency or the high voltage level. The management of the resources for the high voltage system is poorer compared to the low voltage system. Or in other words the operational efficiency (low voltage system) is higher than the strategic efficiency (high voltage system).

The highest correlation for the Model 1 is with the index 3 or the network productivity index as well as for the Model 2 and the Model 3. This means that the DEA Model 1, 2, 3 are most influenced by the km-of line input.

Model 5 has a highest correlation with the index 1 showing that labor productivity is sensitive to the number of consumers.

Further, Model 3 (operational efficiency) is more sensitive to indices 1 and 2 (utilization of transformation capacity and number of consumer's service) than Model 2 (strategic efficiency). But, Model 2 is more sensitive to the index 3 (the network). The network factor (index 3) shows less influence to the labor productivity (Model 5).

The MWh sold (index 4) shows less influence to the overall efficiency but more influence to the strategic efficiency.

	Index 1	**Index 2**	**Index 3**	**Index 4**	**Model 1**	**Model 2**	**Model 3**
Index 2	0.186	-	-	-	-	-	-
Index 3	-0.009	0.376	-	-	-	-	-
Index 4	0.499	0.476	-0.247	-	-	-	-
Model 1	0.279	0.239	0.435	-0.055	-	-	-
Model 2	0.072	0.243	0.478	-0.283	0.646	-	-
Model 3	0.215	0.307	0.322	0.187	0.731	0.488	-
Model 5	0.349	0.123	0.109	0.101	0.279	0.260	0.316

Table 6

[12] See[5].
[13] Averages for the analysed period.

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 this paper for the purpose of analyses the DEA method was utilized since it has the benefit of multy inputs/multy outputs approach.

The distribution districts DEA scores shows that there is some inputs congestion from over employment or because of the non-optimal networking. However, we saw that the problem is in the strategic efficiency or the high voltage level. The management of resources for the high voltage system is poorer compare to low voltage system. Or in other words, 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. The western districts are showing increasing returns to scale and technical change of 12.31 % per annum and the eastern decreasing returns to scale and technical change of 6.67 % per annum. We show also that the labor productivity is sensitive to the number of consumers.

We can sumarise:

- Low strategic efficiency (requires biased investment strategy towards transmission network);
- The operational efficiency (the distribution management) is more sensitive to the utilization of the transformation capacity and number of consumers;
- The strategic efficiency (the transmission management) is more sensitive to the power lines length;
- High sensitivity from the power plants layout to the returns to scale, technical change and TFP;
- The labor productivity is sensitive to the number of consumers.

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