PLANT EFFICIENCY IN INDIAN THERMAL ELECTRIC-POWER INDUSTRY
A Frontier Function Approach

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In this paper, technical efficiency has been estimated at plant level for the Indian thermal electricity industry, with the help of a frontier production function. A static linear programming exercise was solved with the 1988-89 data. The most efficient plants turn out to be Ramagundem-B, Vijayawada, and Tuticorin. The plant efficiency in Northern and Western regions depends on some qualitative factors. On the other hand, capacity utilisation is an important determinant of plant efficiency in Southern and Eastern regions.

PURPOSE

In India, about 71% of the total electrical output is generated by the thermal electric-power industry. The capacity expansion of the industry over the last three decades shows one distinct feature. Power generating sets of bigger and bigger sizes have been installed in the power stations (plants), resulting in a substantial rise in the average capacity of plants, total capacity divided by number of plants. Their average capacity, which was 113 MW at the end of 1960, is now 480 MW. Since the construction of a set exhibits a high degree of capital intensity, ties up resources for a minimum period of 5 years, and appropriates a significant amount of the investment expenditure of the Government, it is expected of the industry to operate its plants at a reasonable level of technical (production) efficiency.

In this paper, we have made an attempt to measure the technical efficiency of each plant of the industry, and to investigate the factors responsible for causing efficiency variations across the plants. For the purpose, the rest of the paper is divided into four sections; namely, Methodology, Data Base, Results and Conclusions.

METHODOLOGY

In a thermal plant, fuel, capital and labour are used as inputs for generating electricity. As labour is non-substitutable for fuel or capital[1], electrical output is generally treated to be dependent on fuel and capital. But, when it comes to estimating the production efficiency of a plant, we need to compare its output with some engineering or empirical norm. Since we are not making an ex-ante study nor do we know whether there exists a plausible engineering norm, the production efficiency of a plant has been computed in relation to an empirical standard as developed by M.J. Farrell (1957).

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The empirical standard is derived from a frontier production function[2] which, computed with the input-output observations across a number of plants, indicates the maximum output that a plant could have obtained from the same combination of inputs as used for its actual output. Therefore, the production (technical) efficiency of a plant in a group of plants is defined as the ratio of its actual output to the frontier (maximum) output.

$$\lambda = \frac{Q(H, K)}{Q_m(H, K)} \tag{1}$$

Where,

Q =Actual output, 10^{σ} KWH, of the plant[3];

H =Heat consumption, 10^{σ} Kilo-calories, of the plant;

K =Capital input, 10^{σ} KWH, of the plant;

Q_m =Maximum output, 10^{σ} KWH, derived from a frontier function, and

λ =Technical efficiency, ratio, of the plant; $\theta \leq \lambda \leq 1$

This method of measuring the technical efficiency of a plant has widely been accepted for three reasons. First, the frontier approach assumes that every plant tries to economise the use of its inputs in the generation of electric-power. This is a reasonable assumption to make, in so far as the building-up of a power plant is enormously capital intensive. Second, the management of an inefficient plant may try to find out the factors accountable for creating the deviation of its output from the frontier output, with a view to improving the working of its inefficient plant. Finally, the pattern of efficiency estimates of all the plants may provide the industry necessary guidance to co-ordinate the operations of its plants in a more economical way.

We shall now turn to the estimation of Q_m. It involves assigning some functional form to Q_m in the inputs, and then finding out Q_m in such a manner that it is equal to or greater than the output of each of the plants under consideration. For the sake of simplicity, we are assuming that a plant generates electricity in accordance with the rules of a two-input Cobb-Douglas production function.

$$Q_m = \alpha H^{\beta} K^{\gamma} \tag{2}$$

Where,

α, β, and γ = Parameters.

The three parameters are to be estimated in such a way that $Q_m \geq Q$, a condition that a frontier function must satisfy. Since $Q_m \geq Q$, $Q_m e^{-\mu} = Q$ can be written with $e^{-\mu}$ being less than or equal to one. Taking natural logs of both the sides of $Q_m e^{-\mu} = Q$ and of (1), we get

$$L_n\, Q_m - \mu = \text{Ln}\, Q \ldots \qquad (3)$$

$$\text{Ln}\, Q_m + \text{Ln}\, \lambda = \text{Ln}\, Q \quad \ldots \qquad (4)$$

From (3) and (4), we obtain

$$\lambda = (1/e^{\mu}) \quad \ldots \qquad (5)$$

According to (5), the technical efficiency, let us say, of the i-th plant is the reciprocal of e^{μ_i}. Therefore, we have got to estimate the series $\mu_1, \mu_2, \mu_3, \ldots, \mu_N$ for N number of plants in such a manner that $Q_m \geq Q_i \,; i = 1, 2, 3, \ldots, N$. This problem has been structured as an exercise of linear programming.

Considering $a = \text{Ln}\, \alpha$, $h = \text{Ln}\, H$, $k = \text{Ln}\, K$, and $q = \text{Ln}\, Q$, we can formulate our exercise of linear programming as follows :

Minimise

$$\sum_i \mu_i + 0 \times a + 0 \times \beta + 0 \times \gamma \qquad (6)$$

$$i = 1, 2, 3, \ldots, N$$

Subject to two constraints :

1.Frontier function

$$a + \beta h_i + \gamma k_i - \mu_i = q_i \qquad i = 1, 2, 3, \ldots, N \qquad (7)$$

2.Marginal productivity,

$$a \geq 0 \quad \ldots \qquad (8)$$

$$0 \leq \beta \leq 1 \quad \ldots \qquad (9)$$

$$0 \leq \gamma \leq 1 \quad \ldots \qquad (10)$$

The solution of this programming exercise, (6) - (10), is made up with the estimates of $\mu_1, \mu_2, \ldots, \mu_N, a, \beta$, and γ. The estimates of $\mu_1, \mu_2, \ldots, \mu_N$ have also been used to calculate the structural efficiency of each state in the following manner :

$$\xi = \frac{\sum_t \mu_t C_t}{\sum_t C_t} \quad \ldots \qquad (11)$$

$$t = 1, 2, 3, \ldots, T$$

Where,

ξ =Structural efficiency, ratio, of the state;

μ_t =Technical efficiency, ratio, of the t-th plant of the state;

C_t =Size, MW, of the t-th plant of the state; and

T =Number of plants in the state.

The next part of the methodology relates to finding out the determinants of the efficiency index of a plant. In this connection, it shall be mentioned that, for the development of electric-power sector, all the states of India have already been divided into five regions; namely, Northern, Western, Southern, Eastern, and North-eastern. Within each region, the operations of all kinds of power plants- Hydro, Thermal, Nuclear, Gas, and Diesel- are co-ordinated through a transmission grid. Hence, the following regression equation has been estimated for the plants of each region.

$$\lambda = b_0 + b_1 J + b_2 C + b_3 V + b_4 D + E \quad \ldots \qquad (12)$$

Where,

b_0 = Intercept,

$b_1, b_2, b_3,$ and b_4 = Regression co-efficients,

J = No. of sets in the plant,

C = Size, MW, of the plant;

V = Age of the plant, years;

D = Degree of utilisation of the plant, percentage, and

E = Residual term.

DATA BASE

For the computations of our programming and regression exercises, we required plantwise information with regard to output, capital input, heat consumption, and age for as many plants of the Indian thermal electricity industry as possible for any one year. There were 66 plants that the industry possessed on 31st March 1988, out of which complete data could be prepared only for 53 plants. The source of information is a review prepared by Central Electricity Authority (1990).

Now we shall describe the variables used in the present study.

(i) Output (Q) : The electrical output of a plant has been taken in term x of 10^{σ} KWH, as given in the review.

(ii) Capital (K) : For each plant, the definition of capital input has been adopted to be the same as described in a paper by P.J. Dhrymes and M. Kurz (1964, pp. 312).

$$K = L \times \sum_j S_j \times Z / 10^3 \quad \ldots \qquad (13)$$

$$j = 1, 2, 3, \ldots, J$$

Where,

L = Number of hours in a year, 8760;

S_j = Size, MW = 10^3 KW, of the j-th set of the plant;

$$Z = \frac{\sum_j W_j \times S_j}{L \times \sum_j S_j} \quad \ldots \qquad (14)$$

Where,

W_j = Number of available hours of the j-th set of the plant[4];

Z = Availability factor, ratio, of the plant; and

K = capital input, 10^{σ} KWH.

(iii) Heat input (H) : For every plant, heat consumption, 10^{σ} Kilo-calories, has been treated as the product of two factors : Coal consumption (10^{σ} Kg), and calorific-value of coal, Kilo-calories/kg. However, oil is another input in the generation of power. Since it contributes very little to the heat input of electrical output, its consumption has been ignored.

(iv) Degree of utilisation (D) : For each plant, this variable, ratio of the actual output to potential output, has been computed as follows:

$$D = \frac{Q \times 10^3}{L \times \sum_j S_j} \times 100 \quad \ldots \qquad (15)$$

(v) Age (V) : The age of a plant has been regarded as a weighted average in the following manner :

$$V = \frac{\sum_j S_j \times g_j}{\sum_j S_j} \quad \ldots \qquad (16)$$

Where,

g_j = Age of the j-th set of the plant, on the 31st March 1988.

RESULTS

It ought to be mentioned that the programming exercise, (6) - (10), was solved with the help of a Fortran Program described in a book by A.H. Land and S. Powell (1973). As to the statistical exercise, (12), it was computed with ECOS, a statistical package.

The efficiency estimates derived from (5) and (11) are mentioned in Table 1.

The table reveals three interesting points. First, the most efficient plants do not belong to the most efficient state. There are three most efficient plants: Ramagundem - B (Andhra Pradesh), Vijayawada (Andhra Pradesh), and Tuticorin (Tamil Nadu). But Karnataka shows the highest degree of production efficiency. Second, the dispersion of efficiency indices is wider for plants. The efficiency range for plants is 0.31-0.1; whereas, that for states is 0.52-0.93. Third, the industry is generating power under constant returns to scale, as is evident from the sum of β and γ being equal to one.

Table 1 :Power Plants and Efficiency Estimates

State	Power Plant	Estimates Plant	Estimates States
(1)	(2)	(3)	(4)
1. Delhi	1. Badarpur	.79	.79
	2. I.P. Station	.78	
2. Haryana	1. Faridabad (Extn.)	.60	.68
	2. Panipat	.72	
3. Panipat	1. Bhatinda	.71	.63
	2. Ropar	.58	
4. Rajasthan	1. Kota	.52	.52
5. Uttar Pradesh	1. Singrauli	.82	.81
	2. Obra	.82	
	3. Harduaganj-B	.71	
	4. Harduaganj-A	.45	
	5. Panki	.76	
	6. Paricha	.81	
	7. Anpara	.85	
6. Gujarat	1. Ukai	.79	.80
	2. Gandhi Nagar	.68	
	3. Wanakbori	.84	
	4. AECo	.71	

(1)		(2)		(3)	(4)
7.	Madhya Pradesh	1.	Korba-STPS	.90	.72
		2.	Vindhyachal-STPS	.31	
		3.	Satpura	.71	
		4.	Korba (East)	.65	
		5.	Amar Kantak	.78	
		6.	Korba (West)	.70	
8.	Maharashtra	1.	Nasik	.80	.77
		2.	Koradi	.73	
		3.	Paras	.60	
		4.	Bhusawal	.78	
		5.	Parli	.76	
		6.	Chandrapur	.74	
		7.	Trombay	.82	
9.	Andhra Pradesh	1.	Ramagundem-STPS	.63	.78
		2.	Kothagundem	.83	
		3.	Ramagundem-B	1.00	
		4.	Vijayawada	1.00	
10.	Tamil Nadu	1.	Ennore	.80	.82
		2.	Tuticorin	1.00	
		3.	Mettur	.59	
11.	Karnataka	1.	Raichur	.93	.93
12.	Bihar	1.	Patratu	.66	.64
		2.	Barauni	.61	
		3.	Muzzafarpur	.61	
13.	DVC	1.	Chandrapura	.59e	.65
		2.	Durgapur	.79	
		3.	Bokaro	.62	
14.	Orissa	1.	Talcher	.55	.55
15.	West Bengal	1.	Farakka-STPS	.49	.59
		2.	Bandel	.66	
		3.	Santaldih	.51	
		4.	Kolaghat	.70	
		5.	CESCo.	.60	
		6.	Titagarh	.85	
		7.	DPL	.51	

Note : $\alpha=1, \beta=0.9555, \gamma=0.0445$, and minimand = 19.0256

Now we shall turn to explaining the efficiency variations across the plants in each region. Since no appropriate data could be obtained for the power stations of the North-Eastern region, the regression equation (12) was estimated separately for each of the other four regions. It needs to be stated that there were 14, 17, 8 and 14 plants in the Northern, Western, Southern and Eastern regions respectively. For analysis, the regression results for these regions are mentioned in Table 2.

The table indicates that the production efficiency of a plant in Northern region is influenced by some other factors than those considered in the study: This is evident from the R^2, co-efficient of determination, being too low, and no t-value being significant either at 1% or 5% level. The inference also holds good in the case of Western region. Nevertheless, the size of a plant has a little positive impact on its efficiency index. The region can operate more efficiently the plants of bigger sizes. The efficiency index of a power plant in Southern or Eastern region is purely determined by the utilisation of its capacity. An increase in the utilisation of a plant will always raise its efficiency level.

Table 2 : Regression Results

Region	Regression Co-efficients					
	B_0	B_1	B_2	B_3	B_4	R^2
NR	0.2705	0.0234	-0.0001	-0.0004	0.0078	0.52
	(1.36)	(1.55)	(-1.05)	(-0.08)	(2.21)	
WR	0.1500	-0.0065	0.0003	0.0111	0.0051	0.51
	(0.67)	(-0.33)	(2.29)**	(2.08)	(1.51)	
SR	0.3240	0.0372	-0.0005	-0.0014	0.0103	0.89
	(1.86)	(1.19)	(-2.22)	(-0.16)	(3.65)**	
ER	0.4031	0.0059	-0.0001	-0.0028	0.0068	0.76
	(5.08)*	(0.54)	(-0.73)	(-1.23)	(4.96)*	

Note : Brackets contain t-values.

* = Significant at 1% level.

** = Significant at 5% level.

CONCLUSIONS

This study puts forth three main conclusions. First, Rajasthan, Orissa and West Bengal should make efforts to improve the efficiency levels of their plants. This could be done following the operation and maintenance practices of the power plants in Tamil Nadu, and Karnataka. Second, the industry is generating electricity under constant returns to scale. Third, the plants of Southern and Eastern regions should sustain higher and higher levels of output. This may require exporting power to other regions. However, some qualitative information is needed to understand the efficiency variations across the plants in the other two regions.

NOTES

1. On non-substitutability, see R. Komiya (1962), P.J. Dhrymes and M. Kurz (1964), and J.R. Kopp and V.K. Smith (1980).
2. On frontier production functions, see P. Schmidt (1985-86), and F.R. Forsund and L. Hjalmarsson (1987, pp. 109-38).
3. There are two concepts of electrical output : power and energy. Power refers to the electrical output at a point of time, and is usually measured in Kilowatt (KW) or Megawatt (MW) - MW = 10^3 KW. On the other hand, energy stands for the electrical output over a period of time, and is generally taken in Kilowatthours (KWH) or Megawatthours (MWH) - 10^3 KWH = MWH. Needless to add, A-MW of power sustained for B number of hours will generate A x B amount of electrical energy, MWH.
4. For a set, the period of one year is divided into four parts. (a) : Forced outage hours-period for which the set is not operating because of accidental breakdowns. (b) : Planned maintenance hours-period during which the set is kept for periodic maintenance. (c) : Reserve shutdown hours - period for which the set does not function on account of non-availability of spare parts and coal, lack of demand for electricity, grid disturbances, etc. (d) : Available hours - operating period, number of hours in a year minus the sum of (a), (b), and (c).

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