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# A Cost Frontier Model for Indian Electricity Generating Utilities: A Stochastic Approach

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***Abstract*— A econometric cost frontier model is applied to a sample of 30 electricity generating utilities operating in India for the panel data of 4 years from 2004-05 to 2007-08. The objective of this study is to contribute to a deeper understanding of which factors influence cost inefficiency in electricity generation. The results show significant opportunities for cost reduction in the generation industry that could result in price reductions to electricity consumers. The foremost policy allegation of this study is that increased regulation is exhibiting chief position in cost efficiency improvement of electricity generation companies of India and the privatization of GENCOs is not found to be more cost efficient than state owned utilities. In short, the work focused on offering a way for developing an outline for incentives for utility efficiency and productivity levels through the introduction of competition among the utilities by providing suitable cost benchmarks. Thus, these benchmarks would arise as one instrument for improving performance, promoting market competition in generation industry, and defining regulatory policy within a broad deregulatory context.**

***Index Terms*— Benchmarking, Cost Frontier, GENCO, Stochastic Frontier Analysis, efficiency.**

## I. Introduction

The electricity scenario in India since independence has been passed through a crucial phase as it has to cope with the rapid increase in demand due to growing economy. This has resulted in massive spending in the power sector resulting in phenomenal increase in the installed generating capacity, and the demand for electricity [1]. With the installed capacity of 1,73,626 MW as on 31/3/11 India is fifth largest generation country in the world but there is not much improvement in bridging the demand-supply gap. Between 1998 and 2010 the peak power deficit has touched a maximum of 16.6% in the year 2007-08 and annual energy deficit has gone up to 11.1 % in the year 2008-09 [2]. Figure 1 shows the target and achievement of Five year plans[1]. It can be identified that for eighth, ninth and tenth five year plan almost 50 % of the target is met on the power generation capacity additions. So the failure to meet targets set by ministry of power every five year plan is the foremost indicator of this pitiable track record of Indian power sector. India has really been unsuccessful to fulfill generation targets by a significant margin and so the deficit on generation continuously affected power generation sector. The target for eleventh plan is 78700 MW, of which only 24542 MW is added till 30/09/2010. The deficits experienced during the last two decades can be attributed to two main reasons. One reason is the huge growth in demand for electricity, mostly from industries and agriculture and the other reason is the enormous level of inefficiencies at all stages between electricity generation and its end use. India has been known to be exhibiting one of the lowest levels of efficiency in the overall management of a vital resource like electricity [1].

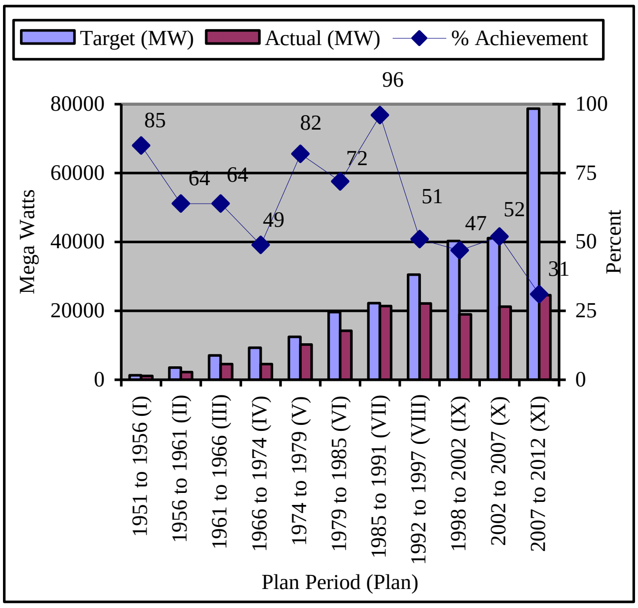


Figure 1 Target and Achievement of Five year Plans

*Source: Ministry of Power Website (www.powermin.nic.in)*

Though the introduction of privatization and deregulation has relieved the utilities to some extent from the financial burden but the problems faced by the electricity generation sector of India are diverse, and privatization and deregulation cannot solve all of them. It was ensured that the power sector reforms are designed to benefit the power sector and to totally match the demand with the supply of electricity. Following a period of power sector reforms, now it is suitable to inquire the degree to which these reforms have benefited the power sector. By viewing the present power status it is apparent these structural changes made in the power sector have still left a demand-supply gap.

Before going for further investment it is necessary to have empirical analysis of the extent to which the structural change of Indian electric power industry is working. Such analysis can be carried out by in-depth study of performance of generation utilities in India by employing benchmarking techniques for evaluating the efficiencies. There have not been serious efforts to improve the efficiency levels to the international best practice levels, which alone would have eliminated the deficits completely. Bridging the gap in demand and supply has become critical and consequently this

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[1] The ministry of power attempts to set the target every five year plan. Presently XI five year plan is in progress

strongly necessitates review of performance of generation utilities. The requirement of large investments in the power sector and the rising cost of electricity provision have intensified the need for increased efficiency. As the investment required in generation of electricity is huge, even a small improvement in production efficiency may result in significant benefits. Increasing demand and consumption of electricity requires higher efficiency for power generation units and lower cost for consumers.

When reform is being contemplated, performance appraisal is an essential condition for determining the exigency of that reform and how much gain can be expected and also performance appraisal over time is decisive in assessing the triumph of that process (including regulatory components) in generating enhanced outcomes. The incentive based regulatory regimes can be created based on performance analysis and benchmark competition amongst a number of utilities can be promoted. Since the country has not reached a mature stage in the development of electricity infrastructure unlike the case of developed countries, there is a very good opportunity to learn from mistakes and adopt a suitable model for the country [1]. Cost efficiency improvements are always win-win options for the existing utilities as benchmarking the operational and financial aspects can free up resources, which can bring down the overall resource requirement for utilities [3]. All of this would however, require application of formal benchmarking techniques to evaluate performance at regular intervals. Benchmarking has proven to be powerful way in pressurizing utilities to provide better services to customers.

The cost benchmarking of utility performance for regulation is tough and requires precise cost evaluations. There are important differences among companies in business conditions that influence cost and so it is difficult to establish benchmarks that properly control for such conditions even with abundant and high quality data [4]. Here an attempt is made for assessment measure cost efficiency opportunities for Indian electric generation facilities. The cost efficiency analysis would be useful for the regulators in decreasing the electricity price and offer valuable lessons to ensure that the new structure being adopted is better than the regulatory and legislative framework designed a few decades back [5].

## II. Methodology

The cost benchmarking of utilities can be carried out so that cost controls can be implemented. Inefficiency can be resulted from technological deficiencies or non-optimal allocation of resources into production. This approach provide a very straight- forward method of computing inefficiency measures for each utility based on deviations from a cost frontier as with regard to accuracy, there is currently no effectual means to recognize the sustainable minimum cost of utility service. The efficiency in the Indian electricity industry has been analyzed by Chitkara [6], Shanmugam *et al.* [7], Behera *et al.*[8], Thakur *et al.* [9], Meenakumari *et al.* [10], Yadav *et al.* [11] but the available literature does not convey little information about the cost benchmarking of generation companies (GENCOs) for India. This clearly indicates one immediate step to be taken is to have a cost analysis of generation companies in India by using benchmarking tools. It is clear that for the first time a work is carried out for the cost benchmarking of the generation companies of India using a parametric approach.

The Stochastic Frontier Analysis (SFA) was originated by Aigner, Lovell and Schmidt and Meeusen and Van den Broeck in 1977 [12, 13]. SFA is a parametric method used to estimate the efficient frontier and efficiency scores. In this approach econometrics is used to construct a parametric frontier over the data (with adjustments for noise). The main advantage of this approach is that it takes into account influence of measurement errors and other noise. It also permits the estimation of standard errors and tests of hypotheses. SFA requires specification of a cost or production function involving assumptions about the firms' production technologies. Assessment of efficiency scores in SFA is similar to that of COLS. In addition, SFA recognizes the possibility of stochastic errors. This reduces reliance on measurements of a single efficient firm. However, accounting for stochastic errors requires specification of a probability function for distribution of the errors and distribution of inefficiencies (e.g. half normal).

The stochastic cost frontier can be defined as

$$\ln(C_i) = f(y_i, w_i; \beta) + v_i + u_i, \qquad i = 1,2,\ldots N, \qquad (1)$$

where $C_i$ = observed cost of production for the $i_{th}$ firm;

$f(.)$ = suitable functional form (such as cobb-douglas or the translog);

$y_i$ = output quantity;

$w_i$ = $(K \times 1)$ vector of (exogenous input prices);

$\beta$ = vector of unknown parameters to be estimated;

$v_i$ = random errors, and are assumed to be independently distributed; and

$u_i$ = non-negative cost inefficiency effect (which is often assumed to have a half-normal or truncated-normal distribution).

The overall cost/economic efficiency $(EE_i)$ may be calculated as the ratio of frontier minimum cost (with $u_i = 0$) to observed cost,

$$EE_i = \exp(-u_i), \qquad 0 \le EE_i \le 1 \qquad (2)$$

## III. Model Specifications And Result Analysis

SFA has been applied as an analytical tool to assess the efficiencies and subsequently derive the cost benchmarks based on the comparison of the 30 Indian electricity generating companies (GENCOs) consisting of 7 SEBs, 8 Electricity/Power departments (EDs/PDs), 1 Power Corporation (PC) and 14 entities comprised the unbundled state owned electric utilities (SOEUs)[2].

### *A. SFA Cost Frontier Model:*

In modeling electricity cost function for power generating company except hydro power generating company, it is understood that electricity is produced by three inputs;

[2] See appendix

capital, labor and fuel. The capital cost of the power station depends upon the capacity of the power station In the above SFA model some key environmental variables are also included such as plant load factor, max demand and per capita consumption; and five dummies parameters like : REG, PRIV, THER, HYDR and THER+HYDR are also incorporated.

Lower the maximum demand of the power station, the lower is the capacity required and therefore lower is the capital cost of the plant. Similarly higher load factor means more average load or more number of units generated for a given maximum demand and therefore overall cost per unit of electrical energy generated is reduced due to distribution of standing charges which are proportional to maximum demand and independent of number of units generated [14]. The other variable is per capita consumption which directly conveys information about the economic development of the country and is considered to be an important variable which may affect the technical efficiency.

Since out of 30 companies under study, only 14 are unbundled of which two (Delhi and Orissa) are privatized, therefore it is necessary to identify there is any efficiency performance differences between regulated companies in states, which regulate the market, and the ones, which are deregulated the effect is analyzed by including dummies REG and PRIV. This exercise aims to help the understanding of the main determinants of the evolution of cost efficiency, focusing its relationship with the restructuring process implemented in the 1990s. Also thermal power constitutes 64.6 % of total electricity production in India and the majority of the companies included in the study are having one or more thermal based plants, consequently it is obliged including a variable investigating this effect. Hence the remaining three dummies: THER, HYDR and THER+HYDR are included to take in the effect of type of power plants (thermal, hydro and thermal plus hydro) of generating company.

The cost data for the generation companies is taken from the Report of Power Finance Corporation (PFC) on state power utilities of India and the remaining parameters are taken from the different years from “General Review” published by CEA [15, 16]. The description and summary statistics of parameters is revealed in table I.

The company's total cost of generating electricity can be represented by:

$$C = f(Y, P_K, P_L, P_F, Z_1, Z_2, Z_3, REG, PRIV, THER, HYDR, THER+HYDR, T) \quad (3)$$

The variables outlined above are highly correlated[3]. The generation utilities are presumed to minimize cost and share the same production technology. As a result, equations of the cost frontier function must be non-decreasing, concave, linearly homogeneous in input prices and non-decreasing in output.

Although the translog form is more flexible in that it does not impose any technological restriction and allows for variation of scale economies with output, the assumption of concavity is automatically satisfied in cobb-douglas, and the homogeneity (imposing degree one in input prices) restriction can be imposed by normalizing the costs and prices by the price of one of the input factors. The concavity condition requires that the matrix of second order derivatives of the cost function with respect to input prices be negative semidefinite [17]. After imposing homogeneity restriction, the econometric cost benchmarking model in cobb-douglas and translog form for power generation companies can be estimated as:

$$\ln\left(\frac{C}{P_K}\right)_{it} = \beta_0 + \beta_y \ln(Y_{it}) + \beta_1 \ln\left(\frac{P_L}{P_K}\right)_{it} + \beta_2 \ln\left(\frac{P_F}{P_K}\right)_{it} + \beta_t t + \delta_1 \ln(Z_{1it}) + \delta_2 \ln(Z_{2it}) + \delta_3 \ln(Z_{3it}) + \delta_4 (REG) + \delta_5 (PRIV) + \delta_6 (THER) + \delta_7 (HYDR) + \delta_8 (THER + HYDR) + v_{it} + u_{it}$$

$$i = 1,2...30 \qquad t = 1,2...4 \qquad (4)$$

$$\ln\left(\frac{C}{P_K}\right)_{it} = \beta_0 + \beta_y \ln(Y_{it}) + 0.5\beta_{yy}[\ln(Y_{it})]^2 + \beta_1 \ln\left(\frac{P_L}{P_K}\right)_{it} + \beta_2 \ln\left(\frac{P_F}{P_K}\right)_{it} + 0.5\beta_{11}\left[\left(\frac{P_L}{P_K}\right)_{it}\right]^2 + 0.5\beta_{22}\left[\left(\frac{P_F}{P_K}\right)_{it}\right]^2 + \beta_{y1}\left\{\ln(Y_{it})\left[\ln\left(\frac{P_L}{P_K}\right)_{it}\right]\right\} + \beta_{y2}\left\{\ln(Y_{it})\left[\ln\left(\frac{P_F}{P_K}\right)_{it}\right]\right\} + \beta_{12}\left\{\left[\ln\left(\frac{P_L}{P_K}\right)_{it}\right]\left[\ln\left(\frac{P_F}{P_K}\right)_{it}\right]\right\} + \beta_{yt}[\ln(Y_{it})]t + \beta_{1t}\left[\ln\left(\frac{P_L}{P_K}\right)_{it}\right]t + \beta_{2t}\left[\ln\left(\frac{P_F}{P_K}\right)_{it}\right]t + \beta_t t + 0.5\beta_{tt}t^2 + \delta_1 \ln(Z_{1it}) + \delta_2 \ln(Z_{2it}) + \delta_3 \ln(Z_{3it}) + \delta_4 (REG) + \delta_5 (PRIV) + \delta_6 (THER) + \delta_7 (HYDR) + \delta_8 (THER + HYDR) + v_{it} + u_{it}$$

$$i = 1,2...30 \qquad t = 1,2...4 \qquad (5)$$

which corresponds to following restrictions:

$$\sum_{j=1}^{2} \beta_j = 1; \ \sum_{j=1}^{2} \beta_{1j} = 0; \ \sum_{j=1}^{2} \beta_{2j} = 0; \ \sum_{j=1}^{2} \beta_{jt} = 0 \qquad (6)$$

Symmetry is also imposed such that $\beta_{12} = \beta_{21}$. These restrictions decrease the number of parameters to be estimated. In this analysis, these conditions were not imposed, but may be inspected from the estimated parameters.

[3] Pearson correlation is 0.788 for Total cost-Units generated; 0.962 for Total cost-Capital cost; 0.661 for Total cost-Labor cost; 0.847 for Total cost– Fuel cost ;0.676 for Units generated-Capital Cost; 0.658 for Units generated-Labor cost; 0.930 for Units generated– Fuel cost; 0.580 for Capital cost-Labor cost; 0.710 for Capital cost-fuel cost; and 0.691 labor cost-fuel cost.

TABLE I
EXPLANATION OF VARIABLES FOR COST FRONTIER MODEL OF GENCOS

| Variable | Description | Mean | Std Dev. | Max | Min |
|---|---|---|---|---|---|
| C | Total cost of generation of electricity (Rs Crores) | 4652.9 | 4527 | 18245 | 12 |
| Y | Electricity generated (GWh) | 13144 | 16912 | 72770 | 1.32 |
| PK | Capital price (Rs/MW) | 2.61 | 2.69 | 15.6 | 0.02 |
| PL | Labor price (Rs/number of employees) | 0.05 | 0.14 | 0.87 | 0.01 |
| PF | Fuel price (Rs/GWh) | 0.1 | 0.14 | 0.62 | 0 |
| Z1 | Plant load factor (%) | 32.26 | 37.42 | 91.4 | 0 |
| Z2 | Max demand (MW) | 3672 | 4146 | 18441 | 45 |
| Z3 | Per capita consumption (GWh) | 768.58 | 551.91 | 2692 | 75.06 |
| REG | Dummy variable to indicate unbundled utility | 0.45 | - | 1 | 0 |
| PRIV | Dummy variable to indicate privatized generation company | 0.067 | - | 1 | 0 |
| THER | Dummy variable to indicate thermal power generating company | 0.55 | - | 1 | 0 |
| HYDR | Dummy variable to indicate hydro power generating company | 0.667 | - | 1 | 0 |
| THER+HYDR | Dummy variable to indicate generating company producing both thermal and hydro power | 0.467 | - | 1 | 0 |

*B. Hypotheses Test Results and Parameter Estimates*

The results of the likelihood ratio tests are presented in table II. The first hypothesis is conducted to find whether the Cobb Douglas is the right functional form. The first hypothesis that the Cobb-Douglas functional form was the best-fit functional form for the data was rejected. The second hypothesis that there was absence of inefficiency effects in the production process was rejected, while the third hypothesis that the half normal representation is correct distributional form for the data is also rejected. The fourth hypothesis technically inefficiency effects are absent from the production function model i.e. model is equivalent to the average response function (Full Frontier Model), which can be efficiently estimated by ordinary least square (OLS) regression is also rejected for all the three models. The last hypothesis that the panel data is not applicable for the model is rejected that means the panel data can be applied to the model.

The results of hypotheses clearly show the presence of technical inefficiency and that the truncated-normal representation is correct distributional form for the data. It is confirmed from table III that the variables have the expected signs[4], with the total cost increasing with the price of labor which is significant at 10 % with value of 0.1406. Moreover, the total cost increases with energy generated. Furthermore, the cross-variables also explain the total cost.

[4]The fuel price is having an unexpected negative sign but is found to be insignificant.

All the three environmental variables involved in the cost efficiency analysis are not significant. Dummies REG, THER and TER+HYD are significant at 5%, 1 % and 1% level of significance respectively. It is concluded that regulation does play a vital role in the cost efficiency drive of the Indian electricity generating companies. The result is different from the conclusion identified from the results of Barros *et al.* who analyzed the cost efficiency in the hydroelectric generating plants of a main Portuguese electricity enterprise EDP (Electricity of Portugal) between 1994 and 2004 and found that increased regulation is not playing any major role in efficiency development of hydroelectric dams [18]. The dummy PRIV in the model suggests that privately owned utilities are not more cost efficient than publicly owned utilities. Policymakers are thus advised not to uncritically adopt the position that continuing privatization will generate cost reductions. The companies generating both hydel and thermal power is also indicating the positive effect in cost efficiency as compared to thermal generating companies concluding that the thermal-based power may be a constraint in improving the cost efficiency is a misconception to some extent. This fact is further verified by the insignificance of the coefficient of fuel price in the model.

The coefficients of the time trend are interpreted as a measure of technical change. The trend is positive with elasticity of 0.3445 indicating technical progress of 34.45 % per annum. The trend square is negative, which signifies that cost increases over time at a decreasing rate. This is an expected result for this industry. The generation companies whether thermal based or hydro based are driven by technology improvements based on extreme competition observed in the energy market; therefore a negative sign is expected for the square trend in the cost frontier. The gamma efficient parameter signifies that on average 60 % of the costs are imputable to inefficiency according to the frontier. Moreover, the sigma has a value of 64%, signifying heterogeneity in this data set, therefore the policy designed to increase efficiency has to take into account this heterogeneity.

TABLE II
RESULTS OF HYPOTHESES FOR COST FRONTIER MODEL OF GENCOS

| Null Hypotheses | $\chi^2$-critical value | $\chi^2$-calculated value | Decision |
|---|---|---|---|
| $H_0$: $\beta_{jk}$ =0 | 18.3 | 126.18 | $H_0$: Rejected |
| $H_0$: $\gamma = 0$ | 5.138 | 125.16 | $H_0$: Rejected |
| $H_0$: $\mu = 0$ | 7.045 | 127.8 | $H_0$: Rejected |
| $H_0$: $\gamma = \delta_0=\delta_1= \delta_2= \delta_3= 0$ | 17.67 | 92.14 | $H_0$: Rejected |
| $H_0$: $\eta = 0$ | 3.84 | 6.46 | $H_0$: Rejected |

TABLE III
ESTIMATION OF PARAMETERS FOR COST FRONTIER MODEL OF GENCOS

| Variables | Parameters | Coefficient | T-ratio |
|---|---|---|---|
| Cost function factors | | | |
| Intercept | $\beta_0$ | 1.4917* | 9.7039 |
| In(units generated) | $\beta_y$ | 1.18978 | 15.9143 |
| In(units generated) *ln(units generated) | $\beta_{yy}$ | 0.1731* | 10.4428 |
| In(labor price) | $\beta_1$ | 0.1631** | 2.3169 |
| In(fuel price) | $\beta_2$ | -0.0284 | -0.5867 |
| In(labor price)*ln(labor price) | $\beta_{11}$ | -0.0086 | -0.5483 |
| In(fuel price)*ln(fuel price) | $\beta_{22}$ | 0.0258** | 2.3833 |
| In(units generated)*In(labor price) | $\beta_{y1}$ | -0.0502* | -4.1966 |
| In(units generated)*In(fuel price) | $\beta_{y2}$ | -0.121*** | -1.7100 |
| In(labor price)*ln(fuel price) | $\beta_{12}$ | 0.0269*** | 1.7723 |
| In(units generated)*time | $\beta_{yt}$ | -0.0016 | -0.0964 |
| In(labor price)*time | $\beta_{1t}$ | -0.0171 | -0.7766 |
| In(fuel price)*time | $\beta_{2t}$ | 0.0117 | 0.9245 |
| Time | $\beta_t$ | 0.3445** | 2.5028 |
| Time squared | $\beta_{tt}$ | -0.1484** | -2.6889 |
| Inefficiency factors | | | |
| Intercept | $\delta_0$ | -0.2581 | -0.5717 |
| In(Plant load factor) | $\delta_1$ | -0.0205 | -0.2583 |
| In(Max demand) | $\delta_2$ | -0.1655 | -1.3439 |
| In(Per capita consumption) | $\delta_3$ | -0.0526 | -0.5502 |
| Dummy REG | $\delta_4$ | -1.9000* | -3.1982 |
| Dummy PRIV | $\delta_5$ | 0.3515 | 0.4521 |
| Dummy THER | $\delta_6$ | 1.8604* | 5.1514 |
| Dummy HYD | $\delta_7$ | 0.4100*** | 1.6758 |
| Dummy THER+HYD | $\delta_8$ | -1.9986* | -4.8440 |
| Variance factors | | | |
| Sigma squared | $\sigma^2$ | 0.4100** | 2.3286 |
| Gamma | $\gamma$ | 0.6024** | 2.5686 |
| Loglikelihood function | LLF | 22.1728 | |
| LR test of one side error | LR | 92.1477 | |
| Restrictions | R | 10 | |

***Note**: This value is obtained from table 1 of Kodde and Palm (1986) which gives critical values for the tests of null hypotheses.*
**, **, *** Estimate is significant at 1%, 5%, 10% level of significance respectively.*

### *C. Cost Efficiency Analysis*

SFA yearly and average cost efficiency scores for GENCOs for the period of four years are shown in table IV. GENCOs with a score equal to one are on the frontier, while those with a score lower than one are above the cost frontier of best practices. The average cost efficiency of 30 GENCOs is 0.638 as seen from table IV, signifying that the companies are approximately 36% far from the efficient frontier and could decrease their output cost by 36% without decreasing their input, which, in this case, is the price of labor and the price of fuel and still producing the same output. None of the companies are totally cost efficient. For this study, it can be accomplished that the MAHA GENCO is the most cost efficient company in sample of 30 companies or is cost efficient as compared to other companies/states, with the SFA CE score of 0.965 indicating that these are almost only 3.5 % away from the efficient cost frontier. BSEB is highly cost inefficient since it is having the average cost efficiency score of 0.126 signifying that the cost can be decreased by approximately 87%.

TABLE IV
YEARLY AND AVERAGE COST EFFICIENCIES FOR COST FRONTIER MODEL OF GENCOS

| S.No. | Utility | 2005 | 2006 | 2007 | 2008 | Mean |
|---|---|---|---|---|---|---|
| 1 | HPGCL | 0.946 | 0.943 | 0.952 | 0.939 | 0.939 |
| 2 | HPSEB | 0.582 | 0.58 | 0.591 | 0.619 | 0.592 |
| 3 | J & K PDCL | 0.941 | 0.929 | 0.951 | 0.938 | 0.94 |
| 4 | PSEB | 0.792 | 0.877 | 0.861 | 0.84 | 0.841 |
| 5 | RRVUNL | 0.96 | 0.964 | 0.963 | 0.962 | 0.962 |
| 6 | UPRVUNL | 0.956 | 0.956 | 0.961 | 0.953 | 0.956 |
| 7 | UJVNL | 0.954 | 0.955 | 0.949 | 0.942 | 0.95 |
| 8 | IPGCL | 0.801 | 0.787 | 0.796 | 0.781 | 0.791 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 9 | GSECL | 0.965 | 0.959 | 0.961 | 0.962 | 0.962 |
| 10 | MPGENCO /MPPGCL | 0.899 | 0.816 | 0.862 | 0.953 | 0.88 |
| 11 | CSPGCL | 0.826 | 0.909 | 0.858 | 0.734 | 0.826 |
| 12 | MAHAGE NCO/MSP GCL | 0.968 | 0.963 | 0.965 | 0.964 | 0.965 |
| 13 | Goa PD | 0.838 | 0.861 | 0.862 | 0.663 | 0.796 |
| 14 | APGENCO | 0.964 | 0.963 | 0.966 | 0.965 | 0.964 |
| 15 | KPC | 0.958 | 0.959 | 0.965 | 0.961 | 0.961 |
| 16 | KSEB | 0.678 | 0.74 | 0.756 | 0.745 | 0.728 |
| 17 | TNEB | 0.831 | 0.813 | 0.916 | 0.843 | 0.849 |
| 18 | Puducherry PCL | 0.972 | 0.967 | 0.939 | 0.967 | 0.961 |
| 19 | BSEB | 0.125 | 0.118 | 0.115 | 0.154 | 0.126 |
| 20 | JSEB | 0.567 | 0.568 | 0.716 | 0.583 | 0.602 |
| 21 | OPGCL and OHPC | 0.949 | 0.936 | 0.952 | 0.944 | 0.945 |
| 22 | WBPDCL | 0.962 | 0.962 | 0.963 | 0.954 | 0.96 |
| 23 | Sikkim PD | 0.556 | 0.8 | 0.462 | 0.419 | 0.527 |
| 24 | APGCL | 0.378 | 0.418 | 0.192 | 0.605 | 0.336 |
| 25 | Manipur PD | 0.701 | 0.59 | 0.556 | 0.621 | 0.613 |
| 26 | MeSEB | 0.585 | 0.505 | 0.524 | 0.612 | 0.553 |
| 27 | Nagaland PD | 0.725 | 0.618 | 0.761 | 0.836 | 0.726 |
| 28 | TSECL | 0.779 | 0.777 | 0.797 | 0.775 | 0.782 |
| 29 | Arunachal PD | 0.645 | 0.595 | 0.639 | 0.78 | 0.658 |
| 30 | Mizoram PD | 0.558 | 0.413 | 0.427 | 0.543 | 0.476 |
| | Mean | 0.649 | 0.634 | 0.598 | 0.678 | 0.638 |

## V. CONCLUSIONS

The above analysis gives the cost benchmarks for improving the performance operation of power generation companies. The application of the parametric cost frontier model to Indian power generation industry can be used as a tool for policy makers. The foremost policy allegation of this study is that increased regulation is exhibiting chief position in cost efficiency improvement of electricity generation companies of India. The regulator should be conscious that cost and quality efficiency are contradictory. Utilities are advised to reduce their share of labor price and the electricity companies still regulated should be deregulated in order reduce cost inefficiency.

This study contributes to the conclusion that the privatization of GENCOs is not found to be more cost efficient than state owned utilities. Given the varying conclusions presented on the relationship between ownership and cost efficiency in electricity generation, it is tempting to suggest that ownership does not have a significant impact but that the interaction between ownership and other factors (e.g. dynamic market conditions) produce apparently random outcomes. Finally, the analysis also shows that there is not a big difference in the cost structure of public and private companies, therefore, after adjusting the inefficiency factors like load factor, maximum demand, and per capita consumption of electricity sector could effectively be benchmarked against each other.

## VI. APPENDIX

List of utilities involved in the study.

| Region | State/UT | Utility | SEB/PD/PC/Unbundled Utility/Privatized |
|---|---|---|---|
| Northern (NR) | Haryana | Haryana Power Generation Corporation Limited (HPGCL) | Unbundled utility |
| | Himachal Pradesh | Himachal Pradesh State Electricity Board (HPSEB) | SEB |
| | Jammu & Kashmir | Jammu and Kashmir Power Development Corporation Limited (J & K PDCL) | PD |
| | Punjab | Punjab State Electricity Board (PSEB) | SEB |
| | Rajasthan | Rajasthan Rajya Vidyut Utpadan Nigam Limited (RRVUNL) | Unbundled utility |
| | Uttar Pradesh | Uttar Pradesh Rajya Vidyut Utpadan Nigam Limited (UPRVUNL) | Unbundled utility |
| | Uttrakhand | Uttrakhand Jal Vidyut Nigam Limited (UJVNL) | Unbundled utility |
| | Delhi | Indra Prastha Generation Corporation Limited (IPGCL) | Privatized |
| Western (WR) | Gujarat | Gujarat State Electricity Corporation Limited (GSECL) | Unbundled utility |
| | Madhya Pradesh | Madhya Pradesh Power Generating Company Limited | Unbundled utility |

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|---|---|---|---|
| | | (MPGENCO/MPPGCL) | |
| | Chhattisgarh | Chhattisgarh State Power Generation Company Limited (CSPGCL) | Unbundled utility |
| | Maharashtra | Maharashtra State Power Generation Company Limited(MAHAGENCO/ MSPGCL) | Unbundled utility |
| | Goa | Goa Power Department (Goa PD) | PD |
| Southern (SR) | Andhra Pradesh | Andhra Pradesh Power Generation Corporation Limited (APGENCO) | Unbundled utility |
| | Karnataka | Karnataka (KPC) | Unbundled utility |
| | Kerala | Kerala State Electricity Board (KSEB) | SEB |
| | Tamil Nadu | Tamil Nadu State Electricity Board (TNEB) | SEB |
| | Puducherry | Puducherry Power Corporation Limited (Puducherry PCL) | PD |
| Eastern (ER) | Bihar | Bihar State Electricity Board (BSEB) | SEB |
| | Jharkhand | Jharkhand State Electricity Board (JSEB) | SEB |
| | Orissa | Orissa Power Generation Corporation Limited (OPGCL) and Orissa Hydro Power Corporation Limited (OHPC) | Privatized |

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