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Efficiency analysis of coal-based thermal power generation in India during post-reform era

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Abstract: Coal-based thermal power stations are the leaders in electricity generation in India. This study employs the stochastic frontier production function methodology for panel data to measure the technical efficiency (TE) of coal-based thermal power plants in India during 1994–1995 to 2001–2002. Efficiency varies widely across plants and regions, while the TE is time-invariant. The average TE is approximately 73%, indicating a substantial scope for increasing thermal power generation in the country, with improved application of existing technology and without employment of additional resources. The western region is technically more efficient than other regions and young plants are more efficient than their old counterparts. We hope that the findings will prove useful to development agencies and policy-makers in devising appropriate strategies to improve electricity generation in India.

Keywords: panel data; stochastic frontier; technical efficiency; thermal power.

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1 Introduction

Electricity is an essential input in various sectors of an economy such as industry, agriculture as well as commercial and domestic sectors. In India, the electricity sector was a public monopoly and received high priority during the four decades of planned economic development in the country, before the onset of overall economic reforms in 1991.[1]

As depicted in Table 1, the installed power generation capacity in utilities in India has increased seven-fold since 1970–1971, reaching a capacity of 101,154 MW in 2000–2001. Similarly, gross power generation in utilities in the country has grown nine-fold since 1970–1971, reaching approximately 500,000 million KWh in 2000–2001. Moreover, the demand for electricity in the country has been rising at a faster pace (exceeding 9%) than anywhere else in the world, despite the fact that India's per capita electricity consumption is very small (only 374 KWh in 2000–2001, according to TERI, 2002).

Table 1 Installed power generating capacity and gross power generation in India

Years	*Installed power generating capacity (utilities) in* MW	*Installed power generating capacity (thermal plants) in* MW	*Share of thermal plants in installed power generating capacity* (%)	*Gross power generation (utilities) in million* KWh	*Gross power generation (coal based thermal plants) in million* KWh	*Share of thermal plants in gross power generation* (%)
1970–1971	14709	7508	51	55828	27796	50
1975–1976	20117	10579	53	79231	42760	54
1980–1981	30214	17122	57	110844	60714	55
1985–1986	46769	28809	62	170350	112540	66
1990–1991	66086	43004	65	264329	178322	67
1995–1996	83294	53479	64	379877	273744	72
1998–1999	93294	57954	62	448544	310014	69
1999–2000	97837	59901	61	480011	NA	NA
2000–2001	101154	60655	60	499450	NA	NA

Source: CMIE (2002).

Coal-based thermal power stations are the leading providers of electricity in India, followed by hydro, nuclear, gas and diesel-based power plants. As Table 1 shows, thermal power plants have the largest share (more than 50%) of installed electricity generation capacity in the country, while their share in actual power generation in India is even larger.

However, in spite of the rapid advance in electricity generation in the country, chronic peak deficits and energy shortages are still frequent. For instance, in 2000–2001, the peak and energy deficits were 13% and 7.8%, respectively (TERI, 2002). Moreover, the performance of coal-based thermal power plants remains very unsatisfactory, due to poor quality of coal used, lack of facilities for processing coal, inadequacy of trained workforce and control equipment as well as aging of stations (TERI, 2001).

Government of India has designed an energy policy to guarantee sufficient power supply in the country at the least cost, while preserving the environment. Following large-scale economic reforms in 1991, the government has devised various strategies to eliminate shortages of electricity in the country, such as plant renovation and modernisation, new capacity creation and private sector participation. In particular, the government intends to create 100,000 MW of generation capacity during the next decade, costing $180 billion (including transmission and distribution costs). Private sector electricity producers are expected to raise approximately half of the above required funds (*The Hindu*, March 4, 2001, Chennai, India).

As part of its overall strategy for reforms in the electricity sector, the government plans to expand the installed capacity of coal-based thermal power stations, given adequate coal reserves in the country. However, even though India has sufficient coal reserves, transport bottlenecks and environmental regulations may cause a decline in the supply of domestic coal. In this case, imported coal, or multi-fuel options can be substituted for domestic coal to maintain electricity generation in the country (TERI, 2001).

Hence, coal-based thermal power stations are likely to dominate the supply of electricity in India even in the future. In this context, it becomes imperative to assess the performance and efficiency of coal-based thermal power plants in India. A power plant is considered inefficient, or more precisely, *technically* inefficient if the plant's existing resources or inputs are utilised sub-optimally, as a consequence of which the plant's power generation is less than its *potential* or maximum possible generation given existing inputs/technology. In general, technical inefficiency, as defined above, is indicative of poor plant performance, while an improvement in plant efficiency, or *technical* efficiency (TE) leads to greater electricity generation given existing inputs and hence superior plant performance.

Singh (1991) has studied the efficiency of thermal power stations in India during the pre-reform period, using cross-section data for 1986–1987. More recently, Shanmugam and Kulshreshtha (2002) have measured the technical efficiency of coal-based thermal power plants in India from 1994–1995 to 1996–1997. In this paper, we employ the stochastic frontier function approach for panel data to measure the technical efficiency of 56 coal-based thermal power stations in India during the post-reform period (1994–1995 to 2001–2002). This approach allows us to test whether TE of a plant varies over time or not.[2] We also analyse the factors that cause variations in the technical efficiency levels in different plants.

This study proceeds as follows. Section 2 provides useful background information on the performance of coal-based thermal power plants in India during the post-reform period, while Section 3 presents the methodology. Data, model and variables are explained in Section 4 and the empirical results are discussed in Section 5. Lastly, Section 6 summarises the findings and provides the policy implications of the study.

2 Performance of coal-based thermal power stations in India: a post-reform scenario

During the post-reform period, the average plant load factor (PLF) of coal-based thermal power stations in India has varied from 55% to 69% during 1991–1992 to 2000–2001 (Table 2). The PLF values have remained low because of low operating availability of stations, given large forced outage rates experienced by the plants. Moreover, forced outage rates have remained high because of poor quality of coal employed (suffering from very excessive carbon emissions, low calorific value and high ash content), weak transmission systems, inadequate station maintenance and defective plant equipment (Bhattacharyya, 1994).

Table 2 Performance of coal-based thermal power stations in India

Years	*Average plant load factor (PLF %) of thermal power plants*	*Losses due to forced outages (as % of maximum possible generation)*	*Average auxiliary power consumption (as % of gross generation)*	*Average T&D losses (as % of availability in state power depts.)*
1991–1992	55.3	15.19	9.63	22.8
1992–1993	57.1	16.19	9.76	19.8
1993–1994	61	NA	9.43	20.2
1994–1995	60	12.42	9.38	20.3
1995–1996	63	11.95	8.76	22.2
1996–1997	64.4	10.79	8.91	24.5
1997–1998	64.7	NA	NA	24.8
1998–1999	64.6	NA	NA	NA
1999–2000	67.3	NA	NA	NA
2000–2001	69	NA	NA	NA

Source: TERI (2002), CEA (1995–1996) and CEA (1996–1997).

The losses due to forced outages in India have varied from 16% (in 1992–1993) to 11% (in 1996–1997). Thermal power stations in India also incur losses because of auxiliary power consumption and transmission and distribution (T&D) losses. Although average auxiliary power consumption of thermal power plants has declined somewhat (from 9.63% in 1991–1992 to 8.91% in 1996–1997; see Table 2), the average T&D losses of plants have risen slightly as well (from 22.8% in 1990–1991 to 24.8% in 1996–1997). Moreover, T&D losses of stations are excessive because of technical reasons such as low-tension distribution network, and low load densities, and other factors such as illegal electricity connections, improper billing and defectively functioning meters.

Distortions due to government policies such as a high tariff on coal imports have also affected the functioning of thermal power stations in India, by limiting the import of good quality coal into the country. In the past, thermal power stations in India have been unable to use washed coal since the government has neither permitted setting up of coal-washeries, nor allowed private investment in washeries. However, government has recently lowered the import duty on coal, leading to higher coal imports by thermal power stations in the country (TERI, 2002). Private investment in coal washeries is also permitted, as many coal washeries are now being set up (Khanna and Zilberman, 1999).

The performance of coal-based thermal power stations can be greatly improved to increase electricity generation in India. Efforts can be made to reduce T&D losses, while optimal grid operations can be used to bring down consumption of coal as well as carbon emissions. Moreover, technological processes can be employed to improve coal quality and reduce its ash content (Bhattacharyya, 1994). The plant-specific efficiency values provided in this study can also help policy makers in benchmarking plant performance and identifying causes of plant inefficiency.

3 Methodology

In this study, we employ the stochastic frontier production function methodology for panel data to measure technical efficiency of coal-based thermal power stations in India. The frontier production function can be defined as the maximum possible, or potential output (power) that a firm (station) can produce with a given level of inputs and technology. The actual production function of a power station can be written as:

$$Q_{it} = f(x_{it}; \beta) \exp(-u_{it}) \quad 0 \le u_{it} < \infty \quad i = 1,2, \ldots, n \quad t = 1,2, \ldots, T \tag{1}$$

where Q_{it} represents the actual output for the ith sample plant in period t; x_{it} is a vector of inputs and β is a vector of parameters that describe the transformation process; $f(.)$ is the frontier production function, or potential output of a plant and u_{it} is a one-sided (non-negative) residual term.

If the operation of a plant is inefficient (efficient), the actual output produced by the plant is less than (equal to) its potential output. Therefore, we can treat the ratio of the actual output Q_{it} and potential output $f(.)$ of a plant as a measure of the technical efficiency, or TE of a plant in period t. The residual term u_{it} is zero when the plant produces the potential output (full TE) and is greater than zero when production is below the frontier (less than full TE). In general, the residual term and a plant's TE are *inversely* related. The residual term u_{it} is also referred to as the efficiency effect, or TE effect of plant i in period t.

To capture the effects of measurement errors/omitted variables, a random noise v_{it} (i.i.d normal with mean 0 and variance σ_v^2) can also be included in equation (1) as:

$$Q_{it} = f(.) \exp(v_{it} - u_{it}) \tag{2}$$

Following Battese and Coelli (1992), we can write:

$$u_{it} = u_i \eta_{it} = u_i \exp\{-\eta(t - T_i)\} \quad i = 1, \ldots, n \quad t \in g(i) \tag{3}$$

where $u_i s$ are non-negative random variables, assumed to be independently and identically distributed (i.i.d) as truncated normal with mean μ and variance σ_u^2, η is an unknown parameter to be estimated and $g(i)$ is the set of T_i time periods for which observations for plant i are available. Hence, according to Battese and Coelli, the TE effect of plant i in period t (i.e., u_{it}) is the product of random variable u_i and the exponential function, whose value depends on parameter η and the number of remaining periods ($t - T_i$). Note that u_{it} equals u_i when $t = T_i$ and hence, random variable u_i can be treated as the TE effect of plant i in the last period T_i.

Using equation (3), it is easy to verify that as t increases, u_{it} decreases, remains constant, or increases, depending on whether η is greater than, equal to, or less than zero (recall that u_i is always non-negative). Therefore, since the residual term u_{it} and a plant's TE are inversely related, it is easy to verify that a plant's technical efficiency increases, remains the same, or decreases over time (i.e., TE can be *time-variant*), according to whether η is positive, zero, or negative. Following the model specified by equations (2) and (3), a measure of the technical efficiency of ith plant in period t is given by the conditional expectation of $\exp(-u_{it})$, given the composite error term $\varepsilon_{it}(= (v_{it} - u_{it}))$ and can be specified as $E[\exp(-\eta_{it}u_i)|\varepsilon_{it}]$.

The model can be estimated by the maximum likelihood (ML) method. Various parametric restrictions in the model bring about a number of interesting cases. Setting μ equal to zero reduces the model to the traditional half-normal distribution model (other distributions such as gamma and exponential are not checked by the above model). If η equals zero, then TE is time-invariant (i.e., plants never improve their TE). Also, note that parameter $\gamma = \sigma_u^2/\sigma^2$ (where $\sigma^2 = \sigma_u^2 + \sigma_v^2$), which is the fraction of the output variation that is explained by the residual term, takes values between 0 and 1. If u_i is always zero and hence u_{it} equals zero (full TE), then γ equals zero (since $\sigma_u^2 = 0$) and deviations from the frontier are entirely due to noise v_{it}. Similarly, when γ equals one ($\sigma_v^2 = 0$), all deviations from the frontier are due to technical inefficiency. One can test the hypothesis that $\gamma = \eta = \mu = 0$ using the generalised likelihood-ratio test statistic, which equals two times the difference between the logarithmic likelihood values of the unrestricted and restricted ($\gamma = \eta = \mu = 0$) ML estimates. The test statistic is a mixed χ^2, with degrees of freedom equal to 3.[3]

4 Data, model and variables

This study uses *annual* data provided by Uttar Pradesh Electricity Regulatory Commission (UPERC), India, pertaining to 56 coal-based thermal power stations, distributed over various geographical regions of India. The data covers an eight-year period – from 1994–1995 to 2001–2002. Since the data for some plants are not available in certain years due to missing information or zero values, the final data set is an *unbalanced* panel of 385 observations on plant output and inputs.

Plant output is measured as power-generated in Giga Watt Hour or GWh (denoted as POWER), while plant inputs used are:

- capital employed (CAPITAL)
- specific coal consumption in tons (COAL)
- specific secondary oil consumption (OIL CONSUMPTION)
- auxiliary power consumption in % terms (AUXILIARY CONSUMPTION).[4]

The capital variable is calculated following Dhrymes and Kurz (1964) and Singh (1991) as: CAPITAL = $(S \times T)/10^3$, where S is the installed plant capacity in MW, and T is the number of hours in a year.[5] Table 3 reports the *means* and *standard deviations* of the study variables.

Table 3 Descriptive statistics of study variables

Variables	*Mean*	*Standard deviation*
POWER (in GWh)	3324.13	2977.40
CAPITAL (= capacity × days × 24 hours/1000)	5427.06	3853.68
CAPACITY (in MW)	636.71	440.09
COAL (in tons)	2450489.59	2142169.64
OIL CONSUMPTION	10094.07	465.84
AUXILIARY CONSUMPTION (%)	13.73	62.80
Sample (N)	385	

In a preliminary analysis, we tried fitting various available functional forms of a plant's frontier production function, such as Cobb-Douglas form, transcendental logarithmic (translog) form and constant elasticity of substitution (CES) form. We found that the Cobb-Douglas form fitted the available data best. Therefore, we specify the following stochastic frontier production function model using the Cobb-Douglas form, for any given plant i in period t as:

$$\begin{aligned}\text{Ln}(\text{POWER}_{it}) = \beta_{0t} &+ \beta_{1t}\,\text{Ln}(\text{CAPITAL}_{it}) + \beta_{2t}\,\text{Ln}(\text{COAL}_{it}) \\ &+ \beta_{3t}\,\text{Ln}(\text{AUXILIARY CONSUMPTION}_{it}) \\ &+ \beta_{4t}\,\text{Ln}(\text{OIL CONSUMPTION}_{it}) + (v_{it} - \eta_{it}u_i) \qquad (4)\end{aligned}$$

where β_{jt}'s are parameters to be estimated.

5 Empirical results

Table 4 presents the empirical estimation results of equation (4). Column 1 of Table 4 depicts the OLS estimation results. As expected, the parameters associated with all input variables except AUXILIARY CONSUMPTION are positive and statistically significant at 1% level. Coal is the dominant factor input in the thermal power production in the country as its parameter value is the highest. Contrary to the expectation, the effect of AUXILIARY CONSUMPTION is negative and significant.

Column 2 of Table 4 shows the MLE estimates of equation (4) without imposing any restrictions on the parameters of the model.[6] As in column 1, the coefficients of CAPITAL and COAL variables are positive and statistically significant at 1% level. However, the impacts of OIL CONSUMPTION and AUXILIARY CONSUMPTION variables are insignificant at 5% level. The parameter σ^2, which equals the total variation in plant output ($\sigma_u^2 + \sigma_v^2$), is positive and statistically significant at 1% level. Moreover, the parameter $\gamma (= \sigma_u^2/\sigma^2)$, which captures the fraction of the total variation in plant output that is attributable to variation in plant-specific TE, is also positive and statistically significant at 1% level. The statistical significance of parameters σ^2 and γ implies that a plant's actual output differs significantly from its frontier or potential output, both due to differences in plant-specific TE (which is within the control of power stations) and due to random factors (which are beyond the control of power plants).

Table 4 OLS and MLE estimates of stochastic frontier production function, coal-based Indian thermal power stations, 1994–1995 to 2001–2002 (Dependent variable: logarithm of POWER)

Variables	*OLS* *(1)*	*MLE (Unrestricted)* *(2)*	*MLE (Restricted)* *(3)*
Constant	–11.2003 (7.260)	–6.0397 (4.818)	–6.1185 (4.915)
Ln CAPITAL	0.0663 (2.596)	0.1706 (4.654)	0.1645 (4.578)
Ln COAL	0.9750 (42.918)	0.8439 (30.784)	0.8452 (31.256)
Ln AUXILLARY	–0.1452 (4.557)	–0.0288 (1.273)	–0.0259 (1.146)
Ln OIL	0.5104 (3.060)	0.0666 (0.503)	0.0773 (0.591)
σ^2	0.0324	0.0412 (4.516)	0.0443 (4.278)
γ	–	0.7247 (11.403)	0.7429 (11.910)
μ	–	0.3122 (4.500)	0.3161 (4.485)
η	–	0.0092 (1.338)	–
Log-likelihood	116.071	238.410	237.495
χ^2	–	244.678	242.849
R^2 (F)	0.973 (3402.19)	–	–
No. of iteration	–	20	19

The sample size: 385.

Figures in parentheses indicate absolute *t* values in OLS and asymptotic *t* values in MLE.

Furthermore, the generalised likelihood ratio test statistic χ^2 (= 244.678) exceeds the critical χ^2 value with three degrees of freedom (9.21 for 99% level of confidence). Therefore, we can reject the null hypothesis of a traditional half-normal distribution model with full and time-invariant TE (i.e., $\gamma = \mu = \eta = 0$). However, the individual parameter η is positive but not statistically significant at 5% level, indicating that the technical efficiency of coal-based thermal power stations in India is *time-invariant* (i.e., constant over time). Therefore, we impose the restriction that $\eta = 0$ and reestimate the model.

The new (restricted) estimation results are given in Column 3 of Table 4. The effects of input variables on output are similar to the results obtained in the unrestricted MLE case (in Column 2). COAL is the dominant factor in determining thermal power generation, while CAPITAL also significantly influences thermal power production. In contrast, OIL and AUXILIARY CONSUMPTION variables do not play a major role in determining power output.

Moreover, the likelihood ratio test rejects the hypothesis of traditional half normal distribution with full technical efficiency (i.e., $\gamma = \mu = 0$). The asymptotic *t*-tests for the estimated values of γ and μ in this case also support this result. The μ term is positive and statistically significant at 1% level, indicating that the TE term u_i follows the truncated normal distribution. σ^2 and γ are positive and statistically significant as in the restricted MLE case, indicating that the actual plant output differs significantly from potential output due to factors that are within the control of power plants as well as the random factors. The estimated value of γ is 0.7429, indicating that approximately 74% of the difference between the actual and frontier output of power plants can be attributed to technical inefficiency or factors that are within the control of power stations.

5.1 Estimates of plant-specific technical efficiency

Table 5 provides the plant specific-time invariant technical efficiency values. The mean TE value is only 72.66%, indicating that on an average, approximately 27% of technical potential of thermal power plants in India is not properly utilised. Therefore, on an average the thermal power plants can increase their outputs by 27% with existing resources and technology or they can reduce their existing input levels by 27% to produce the given level of output. The estimated TE of individual power plants varies from 46.97% in Barauni, in the state of Bihar (East region) to 96.04% in Dahanu, in the state of Maharashtra (West region).

Table 5 Plant-specific TE values (%)

S. No.	*Region*	*Name of station*	*TE* (%)	*No. of years for which plant data is available*
1	West	Amarkantak – I	79.42	6
2	West	Amarkantak – II	71.57	2
3	North	Anpara TPS	80.12	6
4	East	Bandel	85.82	8
5	East	Barauni	46.97	8
6	West	Bhusawal	76.02	8
7	West	S.Gandhi(Birsinpur) – I	76.25	8
8	East	Bokaro‘b’	70.75	8
9	Northeast	Bongaigaon TPS	64.48	5
10	East	Chandrapura	62.39	8
11	West	Chandrapur	74.34	8
12	West	Dahanu	96.04	6
13	East	Durgapur	84.88	7
14	South	Ennore	55.58	8
15	North	Farakka STPS	65.03	5
16	North	Faridabad TPS	64.00	8
17	West	Gandhinagar TPS	86.83	8
18	North	Bhatinda TPS	76.90	8
19	North	Harduaganj-B	47.89	8
20	East	IB Valley	67.03	6
21	North	I.P.TPS	67.26	1

Table 5 Plant-specific TE values (%) (continued)

S. No.	*Region*	*Name of station*	*TE* (%)	*No. of years for which plant data is available*
22	West	K'kheda	76.43	8
23	South	K'Gundem	66.29	1
24	East	Kolaghat	74.88	7
25	West	Koradi	68.43	8
26	West	Korba East – II	60.10	8
27	West	Korba TPS(East)PH-III	61.95	8
28	West	Hasdeo TPS, Korba West – I	79.15	2
29	West	Hasdeo TPS, Korba WEST – II	78.22	8
30	North	Kota TPS	87.87	8
31	South	Metture	80.14	8
32	West	Nasik TPS	80.40	8
33	South	Nellore TPS	54.51	6
34	South	North Chennai TPS	82.99	7
35	North	Obra–A TPS	50.47	8
36	North	Obra 'B' TPS	63.85	8
37	North	Panipat TPS	68.72	8
38	North	Panki TPS	61.24	8
39	West	Paras TPS	69.64	8
40	North	Paricha TPS	60.94	8
41	West	Parli TPS	76.60	8
42	South	Raichur TPS	79.34	8
43	North	Rajghat TPS	72.28	8
44	South	R'Seema	77.81	7
45	South	R'Gundem-B	79.74	8
46	North	Ropar TPS	80.38	8
47	East	Santaldih	75.74	6
48	West	Satpura TPS	67.99	7
49	West	Satpura – II	72.32	3
50	West	Satpura – III	72.05	3
51	West	Sikka Replacement	95.13	7
52	East	Talchar NTPC	57.65	5
53	South	Tuticorin TPS	95.33	8
54	West	Ukai TPS	75.76	8
55	South	Vijayawada TPS	82.06	8
56	West	Wanakbori	83.00	8
Mean TE (%)			72.66	

Table 6 shows the distribution of plants by TE values. The TE is below 70% in approximately 40% of (22 out of 56) stations. These plants can raise their outputs by approximately 30% by following the best practices used in plants such as Dahanu in Maharashtra. Since significant variations in TE values exist across stations, a great deal of effort is required still to raise the efficiency of coal-based thermal power stations in India. The west region attained the highest mean TE value of 76.3% and the northeast obtained the lowest mean value of 64.5%.

Table 6 Distribution of stations by TE (%) values

TE (%)	*Number of stations*	%
Below 60	6	10.7
60–65	8	14.3
65–70	8	14.3
70–75	7	12.5
75–80	13	23.2
80–85	8	14.3
85–90	3	5.4
Above 90	3	5.4
Total	56	100.0

5.2 Determinants of technical efficiency

To determine the factors that cause variations in TE levels across plants, we regress the estimated TE values (presented in Table 5) in percentage on the vintage (or age) of plants (in years), and dummy variables for four regions – East, Northeast, West and South (North region is the reference category).[7] The regression results are shown in Table 7. The dummy for West region is positive and statistically significant at 5% level, indicating that as compared to North region, technical efficiency of power plants is significantly higher in the West region. Moreover, the regional differential between West and North regions is approximately 8% (as given by the coefficient of dummy for West region). The dummy for South region is also positive, but is statistically significant only at 10% level of significance. The regional differential between South and North regions is 6.7%. Furthermore, dummy for the East region is positive while the dummy for Northeast region is negative, but both dummy variables are not statistically significant at 5% level. As per the expectation, the effect of vintage variable on TE value is negative and statistically significant at 1% level, implying that younger power stations tend to be more efficient than their older counterparts. The estimated parameter of this variable indicates that on an average a one-year increase in the age of the plant will lead to 0.56% fall in the technical efficiency value.

Table 7 Regression estimates of TE equation

Variables	*Mean (std. dev.)*	*Coefficient (t value)*
TE (%)	72.660 (11.199)	–
Dummy for northeast region	0.017 (0.134)	–6.384 (0.628)
Dummy for west region	0.393 (0.493)	7.983 (2.382)
Dummy for south region	0.179 (0.387)	6.744 (1.660)
Dummy for east region	0.161 (0.371)	1.473 (0.352)
Vintage	19.25 (8.534)	–0.561 (3.605)
Constant	–	78.990 (19.299)
R^2 (F)	–	0.306 (4.402)
Sample size	56	56

6 Summary and policy implications

In this study, we have estimated the technical efficiency of 56 coal-based thermal power plants in India during 1994–1995 to 2001–2002. The results indicate that efficiency varies widely across power plants (from 46% to 96%) and is time-invariant (i.e., constant over time). The mean technical efficiency is approximately 73%. The major policy implication arising from our analysis is that on an average the coal-based thermal power generation can be increased by 23% via enhanced application of existing plant technology and without additional resources. Alternatively, the coal-based thermal power stations can maintain their current levels of generation, while reducing their inputs by 23%.

Coal and capital (installed capacity) are found to be significant determinants of coal-based thermal power generation in India. We also observe a wide variation in TE values across stations. The highest efficiency value attained in the country during the study period is 96% (Dahanu plant in West region) while the lowest efficiency estimate is found to be 46% (Barauni in East region). Moreover, the TE estimates of 39% thermal power stations in the study (22 out of 56) are less than 70%. One possible reason for such high variation in TE estimates across plants is excessive use of easily available resources, for instance coal, by thermal power plants, causing inefficiencies in resources utilisation and greater costs of power generation. Policy-makers ought to pay attention to power stations that use resources excessively and should encourage the management of such stations to learn and adopt the best practices of efficient plants, such as Dahanu in West region, so that these stations can raise their power generation levels without employing additional inputs.

The above facts point toward the need for the inefficient thermal power plants to improve their technical knowledge so that they can utilise the existing technology more fully. In conclusion, we are hopeful that this study will provide useful clues to development organisations and policy-makers towards raising the performance levels of coal-based thermal power plants in India, keeping in mind the government's objective to ensure sufficient electricity supply at the least possible cost.

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Notes

[1] During the past two decades, the electricity sector has undergone large-scale structural, institutional and regulatory reforms in many developed as well as developing countries. For example, developed nations such as Australia, Finland, New Zealand, Norway, Portugal, Sweden, UK and USA and developing countries such as Argentina, Bolivia, Chile, Columbia, India, Malaysia, Peru, Philippines and Thailand (Rao *et al*., 1998; Yunos and Hawdon, 1997).

[2] Aigner *et al.* (1977), and Meeusen and Broeck (1977) independently developed a stochastic frontier approach to measure TE using cross-sectional data. In recent years, the stochastic frontier approach has been extended to estimate time-specific TE using panel data. A number of comprehensive literature reviews are available, such as Battese and Coelli (1992), Greene (1993), Kalirajan and Shand (1994) and Kumbhakar *et al.* (1997).

[3] In this model, TE is monotone over time and one rate of change (over time) applies to all sample plants. That is, TE must either increase or decrease for all stations simultaneously. Besides, this model is not useful in testing for other possible distributions of TE term such as exponential or gamma distribution.

[4] Labour is also an input in power generation. However, data on manpower employed is not available for many stations. Besides, in many previous studies, such as Komiya (1962), Kopp and Smith (1980) and Singh (1991), it has been argued that labour is non-substitutable for fuel and capital. These studies have generally treated electricity output as dependent on fuel and capital only. Therefore, we do not include labour as an explanatory variable in our analysis.

[5] This variable is constructed on the basis of the fact that capacity is a good proxy for capital employed by thermal power stations. However, one may question the method of construction of capital variable.

[6] The 'FRONTIER' computer package (version 4.1), developed by Coelli (1994) is used to estimate the equation (4).

[7] The vintage variable refers to the latest year for which the data on the plant was used in the analysis.