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Technical Efficiency of Thermal Power Generation in India: Post-Restructuring Experience

Sahba Fatima
Discipline of Economics, School of Social Sciences,
Indira Gandhi National Open University, Maidan Garhi,
New Delhi-110068, India. Email: fatimasahba@gmail.com

Kaustuva Barik
Discipline of Economics, School of Social Sciences,
Indira Gandhi National Open University, Maidan Garhi,
New Delhi-110068, India. Email: kbarik@ignou.ac.in

ABSTRACT: The Indian power generation industry has undergone a paradigm shift during the past two decades largely due to private sector participation and restructuring of the sector. In order to assess the performance of the power generation sector, the present study takes annual data of 14 major states in India for the period 2000-01 to 2007-08 and estimates a stochastic translog production frontier. The decline in technical efficiency of the Indian power generation sector over the study period, as obtained from the econometric estimation, appears to indicate that it has failed to bring in the desired results in terms of efficiency improvement. The total factor productivity (TFP) of the power generation industry, which includes technical change, technical efficiency change, and scale change, however, has shown some improvement. Technical efficiency of the power generation industry is explained by technical manpower employed, per capita state domestic product, year of unbundling of State Electricity Boards (SEBs) and time variable. The study concludes that inefficiency in Indian power sector is caused by the above mentioned factors rather than stochastic error.

Keywords: Stochastic Frontier Analysis; Power Sector Reforms; Total Factor Productivity; India
JEL Classifications: D24; L94; O13

1. Introduction

The Indian power sector passed through a crucial phase during the past two decades as it had to cope with rapid changes in the economy in the wake of economic reforms. The series of economic liberalization measures which affected the power sector as well, required radical changes in the structure, ownership and functioning of the power sector firms. Private sector participation, corporatization of hitherto departmentally-run State Electricity Boards (SEBs), and unbundling of generation, transmission and distribution activities marked distinct departures from the past.

Prior to Independence (in 1947) the Indian power sector was privately owned mostly by the British, notwithstanding the presence of a few Indian conglomerates (Kale, 2004). In view of the fact that remote and far off rural areas need electrification and private firms would not be interested in supply of electricity to these areas on the ground of viability[1], the Indian government initiated steps towards nationalization of the power sector. This was compatible with contemporary thinking that power sector firms are natural monopolies and their product falls in the realm of merit goods[2]. The Electricity Act of 1948 paved way for creation of Central Electricity Authority (CEA) and State Electricity Boards (SEBs). While the CEA was mandated to ‘develop a sound adequate national power

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[1] According to Bardhan (1984) Indian entrepreneurs supported the government plans to build large publicly-owned utilities and plants to produce needed inputs for manufacturing. No doubt power plants require large capital investment, long gestation period, and still longer time period to attain profitability (cited in Kale 2004).
[2] Merit goods refers to those goods and services where exclusion principle holds, but these are found to be so meritorious that their production by the state is justified [Musgrave 1957].

policy' and coordinate the activities of planning agencies, the SEBs housed all activities related to power sector such as production of electricity at power plants, laying down transmission lines through nook and corner of the country, and distribution of power to consumers in urban as well as far flung rural areas. By the time the Five Year Plan (FYP) took off (in 1951) the process was complete and this arrangement continued for the next four decades. During this period the Indian power sector witnessed rapid expansion courtesy large scale public investment and hiring of employees. In the early stage of green revolution,[3] subsidized electricity was given to farmers so that growth of agricultural sector can be accelerated. The emergence of regional parties in many states during the 1970s and 1980s fuelled a competition among political parties to woo voters, particularly the poorer segment that constituted a large proportion, in the form of subsidized goods and services including electricity, if voted to power. The Indian power sector became a victim of such rat race and many unviable decisions (such as free power supply to farmers, tariff regulation and cross-subsidization among different segments of consumers) were taken. Excessive political intervention in the state-run power sector led to a conflict between the social objective of equity and the economic objective of production efficiency. The work culture also deteriorated as it was beset with frequent strikes by employees who could steer policy in their way largely because of the characteristics of the power sector itself – large firms riddled with strong trade unionism, essential nature of services provided by the power sector, large employee strength and political support from several factions. The SEBs became an instrument of populist politics[4] (see Kale (2004) for elaborate discussion on this issue), suffered severe losses and became a major drain of resources for the government[5].

In the aftermath of economic reforms, particularly after promulgation of the Electricity Act in 2003, the Indian power sector was restructured on the following lines: one, the sector was de-licensed which allowed private participation in the power sector. Two, SEBs were converted to corporations rather than functioning as government departments. Three, major activities, viz., generation, transmission and distribution of power, which were historically run by a single entity, that is, the SEBs, got unbundled. These policy changes are expected to have improved the production efficiency of the power sector through the following three channels. First, the Electricity Act 2003 is supposed to have reduced political and bureaucratic control in the Indian power sector. Second, entry of private players could have increased competition in the sector as they have set up plants and started production. Third, the extent of cross-subsidization and consequent revenue loss would have gone down as free power to agricultural sector is not advocated by the regulatory authorities.

Against this backdrop the present paper attempts to estimate and analyze technical efficiency[6] of the thermal electricity generation segment of the power sector in 14 major states of India for the period 2000-01 to 2007-08[7]. In the process it envisages evaluation of the changed policy environment permeating the Indian power sector in the wake of reforms in the Indian power sector. The paper is organized as follows: Section 2, which follows, brings out a brief profile of the Indian power sector with emphasis on thermal power generation segment. Section 3 outlines the methodology adopted and database used to estimate technical efficiency of the thermal power generation sector. Section 4

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[3] Green revolution refers to the thrust on food grains production by the Indian government during the late-1960s and 1970s. The emphasis was on genetically improved seeds, chemical fertilizer and irrigation facilities which resulted in increases in yield and cropping intensity.

[4] Promise of free power supply to farmers has been a part of election manifesto of not only small regional parties but also of mainstream national parties in many state assembly elections. On coming to power many state governments have actually extended subsidized power supply to farmers and poor households (Lal, 2005).

[5] A study by World Bank shows that for the year 2001-02 the deficit traceable to cheap power amounts to 1.2 per cent of GSDP in Andhra Pradesh and 1.5 per cent of GSDP in Karnataka (World Bank 2001).

[6] Production efficiency or technical efficiency refers to the proportion between actual and potential output (Meeusen and Broeck, 1977).

[7] There are 28 states and 7 union territories in India. Of these, the study considers 14 major states for which consistent data for the study period are available, viz., Andhra Pradesh, Bihar (undivided Bihar and Jharkhand), Delhi, Gujarat, Haryana, Karnataka, Madhya Pradesh (undivided Madhya Pradesh and Chhatisgarh), Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh (undivided Uttar Pradesh and Uttarakhand) and West Bengal. It is worth mentioning that these states constitute 91.48 per cent of the total population in India (2011 census) and 60.58 per cent of GDP (2009-10).

presents empirical results of the exercise while Section 5 gives brief summary and major conclusions of the paper.

2. Profile of the Indian Power Sector

The Indian power sector is quite heterogeneous with respect to ownership, production technology and plant size. Electricity is produced from several sources such as hydel, thermal, nuclear and wind although thermal and hydel power remain the major sources. As per estimates obtained for 2010-11 thermal power accounted for about 65 per cent of installed capacity while hydro power contributed approximately 22 per cent; the remaining 13 per cent coming from non-conventional sources such as nuclear power and wind energy (Indiastat, 2011).

Thermal power can be generated from coal, lignite, natural gas, diesel oil, fuel oil as well as renewable sources like biomass, municipal waste and solar energy. Abundant availability of coal influences India to rely primarily on coal, that fulfils approximately 55 per cent of its energy needs and 75 per cent of its coal is consumed in power generation. Coal deposits spread over 27 major coalfields are mostly confined in eastern and southern parts of the country. As of 2005, the Geological Survey of India and other agencies have identified 92960 million tonnes of proven coal reserves in India. Thermal power plants, however, have operated under less than optimum capacity due to erratic supply of coal[8] and the use of low quality coal often resulted in lower efficiency[9].

The power sector falls under the concurrent list of the Indian constitution in the sense that both central and state governments can claim stake on the sector. While the jurisdiction of the central government is mainly on formulation of overall policies for the sector (through CEA), state governments are responsible for implementation of policies (through SEBs). Notwithstanding the fact that the ministries of power at both the state and central levels formulate policy, according to Kale (2004) the involvement of state governments has increased greatly over the years.

The installed capacity of the Indian power sector was only 1358 MW at the time of Independence. Over time, however, it has reached the level of 171926.40 MW (111324.48 MW thermal, 37367.4 MW hydro, 4780 MW nuclear and 12009.14 MW wind and rest from other renewable sources of energy) as on 28.02.11. Electricity generation has increased manifold over time from 5106 GWh in 1950 to 746626 GWh in 2008-09 (Indiastat, 2011). Despite high population growth India has been able to increase per capita electricity consumption from 18.17 kWh in 1950 to 733.14 kWh in 2009, a growth of 40 times. While 3061 villages were electrified at the time of Independence, number of electrified villages reached 489532 in 2009 (CEA, 2009).

Per capita primary energy use (before transformation into other end-use fuels) in kilograms of oil equivalent (kgoe), is one of the lowest in India. It remained at 510 kgoe per capita in 2006 compared to a world average of 1818 kgoe per capita, the highest in the world being that of the USA at a level of 7778 kgoe per capita in the same year. Out of the one billion (2001 Census) population of India only 55 per cent have access to electricity (Reddy, 2010). In per capita terms consumption (612 kWh in 2010), installed capacity (1.24MW in 2010) and generation (630 kWh in 2010) of electricity are quite low compared to world average. Domestically power generation from coal-based plants reaches 30.5 per cent conversion efficiency whereas the best performing plants operate at 42 per cent and Germany claims to achieve 46 per cent conversion efficiency.

Power generation as an industry is characterized by the unique feature that it cannot be stored except for a very limited amount, and for a very limited period of time. Keeping this feature in mind, growth in installed capacity should be commensurate with growth in demand to keep the market in equilibrium. In the Indian case, however, the growth in production has not been in synchronization with the demand for electricity, resulting in huge shortfall in supply. During 2010-11 peak demand

[8] The extent of uncertainty in input supply can be appreciated from the fact that in 2010 the actual coal stock available was only 11.5 million tonnes which was sufficient only for 12 days. In 24 thermal power stations the coal stock availability was critical, i.e., less than 7 days of requirement could be met (including super critical). In 14 thermal power stations coal stock availability was super critical, i.e., sufficient only for 4 days (Lok Sabha Unstarred Question No. 2158 dated 06.08.2010).

[9] Since F Grade coal is mostly used in the coal based thermal power plants, it is likely to be less efficient as well as less productive along with containing huge amount of ash (Ministry of Power website).

was 122,287 MW while peak supply was 110,256 MW, the extent of shortfall being 9.8 per cent (Indiastat, 2011).

The acute shortage of power in India has largely been fallout of persistent shortfall in achievements compared to targets set over FYPs towards capacity additions. Capacity addition as a percentage of targets has varied between 49.4 per cent during the fourth FYP (1969-74) and 96.2 per cent during the seventh FYP (1985-90) (CEA 2009). In recent years, particularly during the Eighth and the Ninth FYPs (1992-93 to 2001-02), there is a steep decline in the achievements compared to targets[10]. Second year (2008-09) of the Eleventh FYP could achieve only 45.9 per cent (CEA, 2009) of the targeted capacity addition.

Over the years, instead of fulfilling the growth objectives as per the FYPs, the SEBs however ran into losses. Several restructuring policy measures such as the New Economic Policy 1991, Electricity Regulatory Commission Act 1998, Electricity Act 2003 and National Electricity Policy 2005 provided for more autonomy to generation units, and unbundled the SEBs into separate generation, transmission and distribution units. The objective was to end the monopoly prevalent in the sector and open it up for competition to bring in efficiency.

De-licensing freed the power sector from many of the bottlenecks that prevented the private generation units from undertaking production, with the exception of hydro power where clearance on environmental grounds is still mandatory. Prior to reforms, mostly during the 1970s and 1980s, the SEB managers complained of frequent interference of their elected superiors in the forms of *ad hoc* extensions to grids to address the needs of particular constituencies, forced subsidies without government compensation, and transfer of the appointed officials at whims. (Dubash and Rajan, 2001; Mathur and Johal, 2004). Book adjustments rather than cash payment was the norm.

The Electricity Act 2003 provided for privatization thereby limiting the political and bureaucratic interference. Cross subsidies, as discussed earlier were essential to sustain SEBs but the Electricity Act 2003 argued against it. Agricultural power consumption which is about 12–15 per cent on an all-India basis is actually financed by the industry (Narendranath et al., 2005). In order to counter the erratic power supply and payment for cross-subsidization, many Industrial houses have opted for captive power plants. This allowed small players to participate in the power market along with widened power supply (Thakur et al., 2005).

Reform efforts by the government are marred by vote bank considerations and the political party in power adopts reforms as a pragmatic approach but continues only in the first three years when voted to power and the last two years are spent in mollifying voters for the next general election. Electricity Regulatory Commission Act, 1998 provided for a Central Electricity Regulatory Commission (CERC) at the apex level and State Electricity Regulatory Commissions (SERC) at the state level to promote the development of power market, fix tariff, and enforce standards with respect to quality, continuity and reliability of services by the licensees[11]. Inability or lack of consensus, or a combination of both, makes the approach of regulators an *ad hoc* one, and no timeframe is set to do away with the agricultural power subsidies (Lal, 2005).

Apart from World Bank pressure to adopt liberalization, privatization and globalization, India was trying to attain efficiency in production to survive international competition. All the states have signed MoU / MoA with the Ministry of Power for unbundling/ corporatisation of SEB's/ Power Departments / Electricity Departments. So far out of 21 States in which all matters relating to generation, transmission and distribution of electricity were managed by respective SEBs, 18 have reorganized their SEBs, viz,. Andhra Pradesh, Assam, Chhattisgarh, Delhi, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Meghalaya, Odisha, Rajasthan, Tamilnadu, Uttar Pradesh, Uttarakhand and West Bengal. Punjab and Himachal Pradesh have also issued transfer scheme. However, Bihar, Jharkhand and Kerala have requested the Central Government under section 172(a) of the Electricity Act 2003 for extension of time for reorganization of their respective SEBs which has been agreed to on a case to case basis. Except Odisha and Delhi, however, none of the states have privatized their distribution activities (Haldea, 2001). The States are in various stages of unbundling

[10] The achievement during the Eighth FYP (1992-97) was 53.8 per cent of the target while the Ninth FYP (1997-2002) saw a further decline in achievement to 47.5 per cent of the target.

[11] The CEA however has been retained for planning and regulation of supply-demand gap and capacity building.

of their State Electricity Boards (see Table 1) since the implementation has not been forced upon the states.

Table 1. Year of Unbundling of SEBs

Sl. No.	Year of Unbundling	State (Rating in March 2005)
1.	1996	Odisha (13.63)
2.	1998	Andhra Pradesh (57.03), Haryana (35.16)
3.	1999	Karnataka (51.46), Rajasthan (37.50), Uttarakhand (18.60), Uttar Pradesh (42.14)
4.	2001	Delhi (51.91), Madhya Pradesh (22.79)
5.	2003	Gujarat (53.61)
6.	2004	Assam (27.32)
7.	2005	Maharashtra (37.25)
8.	2007	West Bengal (44.60)

Note: Figures in parentheses indicate the rating of the power sector of the Indian states (Parliament starred question no. 181, dated 05.08.2005).
Source: Indiastat (2011)

The Electricity Act 2003 promoted Independent Power Producers (IPPs) that reduced the pollution intensity of generating capacity, but not to the extent noticed in the developed world (Perkins, 2005). The basic issue however remains: power plants do not operate at full capacity, use low grade fuels, and operate with limited autonomy with respect to price setting and scale of operation. This leads to wastage of scarce resources, resulting in lower production efficiency. Growth in efficiency and productivity is expected to revive the sector and also reduce its carbon footprints.

Government policy towards power sector appears to have reached a plateau as no major change in policy is seen in recent years. At this juncture an assessment of the impact of reforms of the Indian power sector, particularly of the Electricity Act 2003, appears to be appropriate. The present paper seeks to answer the question as to whether production efficiency of the Indian power sector improved after reforms, particularly after unbundling of generation, transmission and distribution activities.

3. Methodology and Database

The present study estimates a translog stochastic production frontier and finds out technical efficiency of the Indian thermal power sector as per the framework suggested by Battese and Coelli (1995). Technical Efficiency refers to performance of a firm in relation to its peers usually the best practice firms. When a firm lies on the frontier it is considered to be 100 per cent efficient while deviation from the frontier reflects inefficiency. Further, it decomposes total factor productivity (TFP) into technical change, technical efficiency change and scale change to be defined below. The study envisages estimation of a translog production frontier with single output (electricity generated) and four inputs (capital, labour, energy and material). For this purpose it takes data on output, inputs and explanatory variables that account for inefficiencies in the power generation sector of 14 major states of India for the period 2000-01 to 2007-08.

The model under consideration is

$$y_{it} = \exp(x_{it}\beta + V_{it} - U_{it}) \qquad (1)$$

where y_{it} is electricity generated by the i^{th} state in the t^{th} time period,

x_{it} is a ($1 \times k$) vector of inputs of the i^{th} state in the t^{th} time period, the inputs considered being capital (K), labour (L), energy (E), and material (M),

β is a ($k \times 1$) vector of parameters to be estimated, the β coefficients representing elasticity of output with respect to the inputs,

V_{it} is random error which follows *iid* N (0, σ_v^2), and U_{it} is non-negative random variable, associated with technical inefficiency of production, having a truncated-normal distribution at 0 with mean $z_{it}\delta$ and variance σ_u^2

Technical inefficiency U_{it}, in the stochastic frontier model is specified as

$$U_{it} = z_{it}\delta + w_{it} \quad (2)$$

where the random variable w_{it} is defined by the truncation of the normal distribution with zero mean and variance σ_u^2 such that the point of truncation is $-z_{it}\delta$, i.e., $w_{it} \geq -z_{it}\delta$.

z_{it} is a $(1\times m)$ vector of explanatory variables associated with technical inefficiency of production of the states over time, and δ is an $(m\times 1)$ vector of unknown coefficients.

Four explanatory variables, viz., technical manpower, per capita state domestic product (SDP) at factor cost, year of unbundling, and time variable are taken into consideration as factors that account for variation in technical efficiency.

Four alternative specifications regarding the one-sided error term, U_{it}, necessitating four null hypotheses are considered. The first null hypothesis, H_o: μ = 0, where μ is the mean technical efficiency of the sector, implies the case of traditional half-normal distribution in error term (Aigner, Lovell, Schmidt, 1977). The second hypothesis, η = 0, where η is the number of inefficiency components under consideration, implies the case of time-invariant technical efficiency (Pitt and Lee, 1981). The third null hypothesis, γ = 0 implies that all deviation from the frontier is caused only due to stochastic error. The fourth null hypothesis is a combination of the above three, i.e., H_o: μ = η = γ = 0. These hypotheses are tested against the alternate hypothesis of H_1: μ ≠ η ≠ γ ≠ 0 based on likelihood ratio test, critical values for which are taken from Kodde and Palm (1986). A test of the hypotheses specified above can shed light on the inefficiency pattern in the Indian power sector.

Technology is assumed to follow translog functional form (Christensen et al., 1973) keeping in view its flexibility and applicability in the case of variable returns to scale since constant returns to scale is found to be non-existent in Indian industries in some studies (see, for example, Jha and Sahni 1991, Jha, Murty and Paul 1991; and Pradhan and Barik 1999). The production frontier taken for estimation is

$$y_{it} = \beta_0 + \sum_{j=1}^{k}\beta_j x_{jit} + \sum_{j=1}^{k}\beta_{jt} x_{jit}.t + \frac{1}{2}\sum_{j=1}^{k}\sum_{k=1}^{k}\beta_{jk}x_{jit}x_{kit} + \frac{1}{2}\beta_{tt}t^2 + \beta_t t + v_{it} - u_{it} \quad (3)$$

where, output y and input x are taken in natural logs, represents the j^{th} input of the i^{th} state in the t^{th} time period. A time trend, *t*, representing the rate of technical change or shift in the production function over time is included in the frontier.

Two sources of growth in output, viz., input growth and productivity growth are envisaged in the production frontier framework. The residual of output growth, after subtraction of input growth is attributed to TFP growth. The growth rate of TFP in the case of panel data can be decomposed into three components, viz., technical change, technical efficiency change, and scale change as given below (Kumbhakar and Lovell, 2000).

$$T\dot{F}P_{it} = T\Delta_{it} + (e-1)\sum_j (e_{jit}/e_{it})\,\dot{x_{jit}} + TE\Delta_{it} \quad (4)$$

where

$T\dot{F}P_{it}$ is the growth rate of TFP of the i^{th} state in the t^{th} time period,

$T\Delta_{it}$represents the rate of technical change of the i^{th} state in the t^{th} time period,

$TE\Delta_{it}$ is technical efficiency change of the i^{th} state in the t^{th} time period,

$\dot{x_{jit}}$ is growth rate of the j^{th} input of the i^{th} state in the t^{th} time period,

e_{jit} is input elasticity of the j^{th} input of the i^{th} state in the t^{th} time period, and

e_{it} is the aggregation of input elasticities across inputs for the i^{th} state in the t^{th} time period such that, $e_{it} = \sum e_{jit}$

Technical change, $T\Delta_{it}$, in the translog production frontier formulation can be represented by time derivative of (3) such that

$$T\Delta_{it} = \beta_t + \beta_{tt}t + \sum_j \beta_{jt}x_{jit} \quad (5)$$

Technical change can be positive, negative or zero with technical change shifting the production frontier up or down or leaving it unchanged respectively.

$\widehat{TE}\Delta_{it}$, given by $-\frac{\partial u_{it}}{\partial t}$, in a panel data framework takes the form (Kumbhakar and Lovell, 2000)

$\widehat{TE}\Delta_{it} = \widehat{u_i}.\hat{\gamma}.\exp\{-\hat{\gamma}(t-T)\}$ (6)

where $\widehat{u_i}$ is the estimated inefficiency of the i^{th} state, $\hat{\gamma}$ is the percentage of deviation from the frontier due to the explanatory variables included in the frontier[12],
t is the initial time period, and T is the terminal time period.

$TE\Delta_{it}$ may increase, decrease or remain constant, implying that the producer moves closer, farther or does not move at all, from the production frontier, which is itself time-variant and may shift overtime.

The input elasticity of the i^{th} firm in the translog framework is given by

$e_{jit} = \beta_j + \beta_{jj}x_{jit} + \sum_{j\neq k}\beta_{jk}\, lnx_{jit} lnx_{kit} + \beta_{jt}$ (7)

The sum of input elasticities across inputs provides returns to scale (e_{it}) of the Indian power sector.

Database: For estimation of technical efficiency of the Indian power sector in the framework mentioned above we require data on output, inputs and variables that explain inefficiency of the power sector. All the variables need to be in real terms so that the effect of price change is neutralized. Keeping in view data availability, the study takes annual state level data of 14 major states in India for the time period 2000-01 to 2007-08 and confines to the thermal segment of power generation in the states. It will not be out of context to mention that thermal power is the main source of electricity in India. The installed capacity of thermal power in a state and actual thermal power generation in the state as of October 2010, are given in Table 2. It can be observed from the table that the overall share of thermal power in installed capacity as well as actual generation is substantial.

Table 2. Share of Thermal Power in Installed Capacity and Power Generation (October 2010)

States	Capacity (MW)	Generation (MU)	States	Capacity (MW)	Generation (MU)
Andhra Pradesh	7298 (66.23)	27076 (84.07)	**Maharashtra**	10857 (78.99)	31260.9 (90.57)
Bihar	310 (100.00)	104 (100.00)	**Odisha**	1020 (33.46)	2209 (43.14)
Chhattisgarh	3380 (96.57)	14978 (99.22)	**Punjab**	2620 (71.37)	10579 (79.76)
Delhi	735 (100.00)	2600.4 (100.00)	**Rajasthan**	4204 (91.09)	13170 (99.67)
Gujarat	9550 (82.76)	33600 (92.49)	**Tamilnadu**	1648 (43.71)	15879 (84.82)
Haryana	3160 (100.00)	8518.7 (100.00)	**Uttarakhand**	nil	nil
Jharkhand	1550 (92.26)	3449 (99.91)	**Uttar Pradesh**	4672 (90.29)	13318 (97.06)
Karnataka	4134 (53.56)	10839.7 (65.68)	**West Bengal**	6175 (86.34)	19329 (96.27)
Madhya Pradesh	2933 (77.03)	8041.7 (89.73)			

Note: Figures in parentheses indicate percentage share of total installed capacity and generation, respectively.
Source: Indiastat (2011)

As pointed out earlier, the study takes a single output, i.e., electricity generated (Y) and four inputs, viz., K, L, E and M for estimation of the translog production frontier. Data availability is a major limitation for a study of the present nature. Earlier studies on Indian power sector have used Annual Survey of Industries (ASI) data wherein data on all the required variables are available. Beginning with 1998-99, however the ASI clubs data on electricity with many other industries. An

[12] Sum of variance of the errors is given by $\sigma^2 = \sigma_u^2 + \sigma_v^2$ where σ_u^2 is the variance of the inefficiency term u_i and σ_v^2 is the variance of the stochastic error, v_i . The parameter γ is defined as σ_u^2/σ^2.

alternative source of data on Indian power sector is the 'General Review: All India Electricity Statistics' published by CEA, of course with the limitation that it does not provide data on capital stock or investment undertaken by power sector in various states. The present study combines data from General Review with that of other sources to obtain the required variables. Details of the variables taken for estimation are given below.

Output: The study takes gross generation[13] obtained from the General Review: All India Electricity Statistics (CEA, various years) as a measure of output. As this variable is given in real terms in 'GWh' it does not require further transformation.

Capital: As mentioned earlier, the General Review does not provide data on investment or capital stock, even though capital is an important input in production process. As a proxy for capital input the study takes net capital stock for individual states as a measure of capital variable. The National Accounts Statistics, which is a reliable source of data on capital stock, gives the value of net capital stock for 'electricity, gas and water supply' on an annual basis at the national level, not for individual states. Thus there is a need to apportion the national capital stock across states. In order to estimate the net capital stock at the state level the study follows the method suggested by Garofalo and Yamarik (2002), in which national level capital stock is apportioned to each state in proportion to their SDP. This requires an assumption that the ratio of SDP to capital stock is the same across states for the power sector. Since net capital stock is available at constant prices, NAS data does not require further transformation.

Labour: The General Review provides data on total manpower involved in generation, transmission and distribution activities. In the absence of data on labour force involved in thermal power generation the study takes 'total manpower' as given in the General Review (CEA, various issues) as a measure of labour input. Assuming that the workforce is equi-proportionally distributed across states, the best possible proxy for labour employed by thermal power generating units is 'total manpower'. As the data is normalized on an annual basis the relative magnitude of variation in manpower employed in power generation remains unchanged. Since this variable is the number of persons, it does not need further conversion.

Energy: Certain amount of electricity is used up in the production process in activities such as operation of turbines, overall functioning of the plant, etc. This input usage in the production process is captured by auxiliary consumption, which is the difference between gross generation and net energy available at the switchyard. The study takes the quantity of auxiliary consumption as given in the General Review as a measure of energy input. Since this variable is in GWh it does not need further transformation.

Table 3. Calorific Value of Fuels

Fuel	Net Calorific Value	Reference
Coal	3360 kcal/kg	(Ministry of Coal, Government of India)
Lignite	1450 kcal/kg	(5th Conv. UNFCCC)
Natural Gas	14641.97 kcal/kg	(IMTE AG)
Diesel Oil	10349.91 kcal / kg	(IEA, 2004)
Naphtha	10749 kcal/kg (IEA)	(IEA, 2004)
LSHS/HHS	9752 kcal/kg	As proportion of Gross Calorific Value
LDO/HSD	9951 kcal/kg	As proportion of Gross Calorific Value
Furnace Oil	9599.93 kcal/kg	(IEA, 2004)

Material: The raw material used in power generation in the Indian power sector are diverse types of fuels such as coal, lignite, natural gas, diesel oil, naphtha, etc. These inputs cannot be added directly to obtain a scalar quantity reflecting the level of material input used in the production process. The General Review provides data on quantities of these fuels used by various states which need to be combined for obtaining an aggregative value of material input. In order to reach a comparable figure,

[13] Gross generation as a measure of output at the plant level for certain states has been taken by earlier studies such as Shanmugam and Kulshrestha (2005).

we multiply the quantity consumed of each fuel type by its net calorific value so that the total calories used in the production process are obtained. The net calorific value taken for each fuel type is given in Table 3.

The software Frontier 4.1 is used to estimate the model, wherein we get the first order coefficients of inputs as output elasticities with respect to input, the results of which are reported below.

4. Empirical Results

Based on the methodology outlined above, translog production frontier of a panel comprising thermal power generation data of 14 major states for the period 2000-01 to 2007-08 is estimated. It may be recalled that estimation procedure pursued in the study offers scope for restricting the mean efficiency (μ) to zero with the implication that the firms are operating on the frontier. We allowed for finding out whether efficiency (η) is time-invariant or sensitive to variations in the explanatory variables included. In case efficiency of the Indian power sector is time-invariant, explanatory variables of technical efficiency need not be included in the model. We estimated all the alternative specifications and selected the appropriate model on the basis of likelihood ratio test. Four null hypotheses specified in the previous section, viz., $\mu = 0$, $\eta = 0$, $\gamma = 0$ and $\mu = \eta = \gamma = 0$ got rejected, which help discern the view that inefficiency in the Indian power sector follows $\mu \neq \eta \neq \gamma \neq 0$. An implication of the above is that inefficiency in the Indian power sector follows truncated-normal distribution with non-zero mean so that firms do not operate on the production frontier and technical efficiency varies over time.

Table 4. Estimates of Translog Production Frontier

Parameter	Estimate	t – ratio	Parameter	Estimate	t – ratio
β_0	-3.080	-3.083	β_{mt}	0.007	2.272
β_m	0.456	8.025	β_{kt}	0.074	4.902
β_k	0.166	0.205	β_{lt}	-0.061	-5.327
β_l	-0.879	-3.028	β_{et}	-0.059	-5.427
β_e	1.197	1.607	β_t	0.258	1.300
β_{mm}	-0.006	-2.428	β_{tt}	-0.018	-1.926
β_{kk}	0.055	0.632	δ_0	16.709	13.792
β_{ll}	0.072	1.928	δ_1	-0.457	-4.303
β_{ee}	-0.215	-9.053	δ_2	-1.707	-15.825
β_{mk}	-0.036	-3.252	δ_3	0.310	1.957
β_{lm}	0.000	-0.028	δ_4	0.506	12.709
β_{em}	0.019	4.509	σ^2	0.232	10.925
β_{lk}	0.009	0.344	γ	0.999	
β_{ek}	0.028	0.495	μ	80.35	
β_{le}	0.041	1.408	Log likelihood function	77.16	

a) Estimates of Production Function

Estimates of the parameters of the translog production frontier along with respective *t*-ratios are presented in Table 4. It can be observed from the table that 11 of the 21 parameters pertaining to the translog production function are statistically significant at the 5 per cent level[14]. All the first order coefficients of the inputs, except for energy, are found to be statistically significant. Material and energy inputs are negatively induced by themselves and thus, after reaching the threshold level they are needed lesser than before, to expand the total output. Labour is positively induced by itself and its requirement after a threshold level rises more steeply. Cross elasticity of material and energy is found to be positive and statistically significant implying the complementary nature of both the inputs.

[14] Alternative specification of Cobb-Douglas production function was found to be non-tenable statistically, on the basis of likelihood ratio test.

Material and Capital have a negative cross elasticity pointing towards their role as substitutes in power generation.

The coefficient β_{it} indicates technical bias in favor of, or against, the i^{th} input (Stevenson 1980). As per the positive or negative signs of the estimates obtained, technical change in the Indian power sector indicates its energy-saving, labour-saving, material-consuming, and capital-consuming nature. Remarkably, all β_{it} are statistically significant.

The estimated value of σ^2 is found to be 0.23 which reflects variation in output not ascribed to input variation. Gamma coefficient is close to unity with an extremely high t-ratio which implies that deviation from the frontier is mostly due to inefficiency and the contribution of stochastic error in such deviation is negligible.

b) Variations in Average Technical Efficiency over Time

The estimation procedure followed in the study provides technical efficiency scores for each state and for each year under consideration. In order to discern meaningful results, however, we report in Table 5 the average technical efficiency, of the Indian power sector as a whole over the years. It can be observed from the table that technical efficiency declined from 93.76 per cent in 2000-01 to 49.89 per cent in 2007-08. Notwithstanding the declining trend, technical efficiency fluctuated over the years and the range of fluctuations is striking. Various Units of Bokaro, Kolaghat, Nasik, Bandel, Koradi and Panipat Thermal Power Stations have been identified for efficiency integrated Renovation and Modernisation study through international cooperation from the Government of Germany and World Bank in order to put them in competition against the best performers (GTZ Report, 2009).

Table 5. Annual Efficiency Scores of the Indian Power Sector

Year	Efficiency Scores	Year	Efficiency Scores
2000-01	93.76	2005-06	74.57
2001-02	87.15	2006-07	82.51
2002-03	89.85	2007-08	49.89
2003-04	92.90	*Average*	80.35
2004-05	72.16		

c) Inter-state Variations in Technical Efficiency

Fluctuation in technical efficiency over time becomes more prominent when a state level analysis is carried out. The average technical efficiency along with maximum and minimum efficiency levels attained in the case of each state is presented in Table 6. It is worth mentioning that the range of variation in technical efficiency is somewhat less in states such as West Bengal, Maharashtra, Tamil Nadu, and Andhra Pradesh while it is considerably higher in states such as Uttar Pradesh, Madhya Pradesh, Delhi and Punjab.

Average technical efficiency is the maximum in West Bengal which remains at a level of 89.44 per cent while Maharashtra and Tamil Nadu are close behind at 88.85 and 84.69 per cent respectively (see Table 6). A prominent feature displayed in Table 6 is that average technical efficiency during 2000-01 to 2007-08 has been above 80 per cent in seven states which includes, apart from the three states mentioned above, Andhra Pradesh, Bihar, Odisha and Karnataka. Moderate average technical efficiency in the range of above 70 per cent is witnessed in almost all the states. This can be considered as good performance, since the world average plant load factor (PLF) which can be taken as a proxy for efficiency is about 70 per cent. But the overall technical efficiency over the years does not exhibit any clear pattern and is beset with wide fluctuations. Most of the states have reached the trough of their performance in 2007-08.

It can be observed from Table 6 that average technical efficiency is higher in states where yearly variation in technical efficiency is somewhat less and lower in states where variation is higher. Secondly, richer states have relatively higher average technical efficiency while poorer states have relatively lower average technical efficiency. Average technical efficiency, for all states combined is 80.35 per cent[15].

Table 6. Average Technical Efficiency of States during 2000-01 to 2007-08

State	Average Technical Efficiency	Maximum (year)	Minimum-(year)
West Bengal	89.44	97.69(2001-02)	72.78(2002-03)
Maharashtra	88.85	99.01(2001-02)	66.44(2007-08)
Tamilnadu	84.69	99.45(2005-06)	30.21(2007-08)
Andhra Pradesh	83.49	99.93(2000-01)	61.56(2007-08)
Bihar	83.42	98.20(2006-07)	46.36(2004-05)
Odisha	82.91	96.80(2005-06)	65.76(2004-05)
Karnataka	82.10	99.49(2003-04)	43.36(2007-08)
Rajasthan	79.92	98.42(2003-04)	50.71(2007-08)
Gujarat	78.16	99.79(2000-01)	30.62(2007-08)
Haryana	77.38	99.90(2004-05)	44.04(2005-06)
Uttar Pradesh	76.64	99.28(2002-03)	27.63(2007-08)
Madhya Pradesh	75.63	99.63(2000-01)	37.08(2007-08)
Punjab	71.59	99.28(2003-04)	33.63(2007-08)
Delhi	70.67	96.32(2000-01)	30.62(2007-08)

Three implications of above are in order: one, states should aim at reduction in the fluctuation in their efficiency so that consistency is maintained. Two, the proverbial statement that ‘growth is the panacea’ applies to power sector as well, as richer states show higher level of efficiency. Three, average technical efficiency of a state does not bear any reference to power sector reforms in the state since the best performer West Bengal and the worst performer Delhi have both introduced reforms, though Maharashtra took the plunge as late as 2005. Delhi, the second state to experiment with distribution privatization continues to be the worst performer in the group while Bihar and Jharkhand, which have still not introduced reforms, are performing above average. Odisha the first state to take up power sector reforms both in generation and distribution does not show any distinct performance, which is indeed disheartening.

d) Explanatory Factors in Technical Efficiency Variation

As mentioned earlier we included four explanatory variables, viz., i) use of technical manpower, ii) per capita SDP, iii) year of unbundling, and iv) time variable that influence technical efficiency of the Indian power sector. The results presented in Table 4 show that the coefficients of i) use of technical manpower, and ii) per capita state domestic product (SDP), are negative while that of the year of unbundling and time variable are positive. A negative coefficient implies positive relationship between an explanatory variable and technical efficiency while a positive coefficient implies an inverse relationship between the above two.

It is useful to point out that the signs of all the estimates do not meet our expectations. The coefficient of the first explanatory variable, i.e., technical manpower (∂_1) shows a negative sign implying higher technical efficiency with the use of larger technical manpower.

The second explanatory variable, per capita SDP and technical efficiency go together, as the coefficient (∂_2) is negative and statistically significant. An implication of the above is that technical efficiency of the power sector in richer states is higher, indicating the presence of thick market externality. Availability of adequate and timely maintenance of machineries, quality infrastructure,

15 Shanmugam and Kulshreshtha (2005) have estimated mean technical efficiency at plant level for various geographical regions of India during the time period 1994-95 to 2001-02 to be 72.66 per cent. On the other hand, Meenakumari and Kamaraj (2008) have estimated it to be 77.39 per cent for 2005.

work incentives to employees and higher density of consumers in an area could be the probable underlying factors.

The positive and statistically significant coefficient of the third explanatory variable, the year of unbundling (∂_3), implies that the states who have unbundled their SEBs into separate entities for generation, transmission and distribution activities have a lower efficiency. Such a result is contrary to the expectations as the reform process is oriented towards liberalization and performance improvement of the SEBs. The perverse result may be because of incomplete implementation of the reform provisions and the resistance on the part of authorities to comply with the provisions of the Electricity Act 2003.

The coefficient (∂_4) which relates to time variable is positive and statistically significant, indicating that technical inefficiency of the power sector has increased with time. This is a reinforcement of our results on declining technical efficiency over the years (see Table 5) and the initial rejection of the null hypothesis on time-invariant technical efficiency.

e) Decomposition of TFP

Average growth of TFP and its decomposition into technical change (TC), change in technical efficiency (TEC), and change due to scale economies (SC) for the period 2000-01 to 2007-08 are presented in Table 7. It can be observed from the table that TFP growth, on average, has been positive in 7 states and negative in seven other states (see table 7). This needs to be interpreted with caution as wide variation in TFP growth on a yearly basis is found in all the states and no uniform pattern across states could be observed. TFP growth has been the highest for Odisha (3.8 per cent) and the lowest for Karnataka (–160.3 per cent). Odisha which pioneered power sector reforms in India, is found to be the best performer in terms of growth in TFP. Thus a positive role of reforms on productivity of the sector is evident.

Table 7. Decomposition of TFP in Indian Power Sector, 2000-01 to 2007-08

State	TFP	TEC	TC	SC
Odisha	0.038	0.029	0.001	0.008
West Bengal	0.034	0.036	0.000	-0.002
Andhra Pradesh	0.027	0.027	0.000	0.000
Bihar	0.025	0.029	-0.012	0.007
Maharashtra	0.023	0.030	-0.009	0.002
Delhi	0.013	0.006	-0.015	0.023
Tamilnadu	0.007	0.018	-0.006	-0.005
Uttar Pradesh	-0.001	0.005	-0.001	-0.005
Punjab	-0.004	0.006	-0.002	-0.008
Haryana	-0.005	0.009	-0.010	-0.005
Rajasthan	-0.006	0.008	-0.013	-0.001
Gujarat	-0.006	0.007	-0.023	0.009
Madhya Pradesh	-0.009	0.012	-0.017	-0.004
Karnataka	-1.603	0.022	-0.011	-1.614

It can be seen from Table 7 that average TEC is positive in all the states. It is useful to note that TEC obtained here is in sharp contrast with the inference drawn from Table V, wherein we mentioned that technical efficiency declined over time. This is because of the fact that TEC measures the change in efficiency with reference to the terminal year which has been which has been regressed upon time to get a representative figure.

An important factor in determination of TFP growth in the present exercise has been the nature of SC. A positive SC is derived in either of two cases (see second component of equation (4)): increasing returns to scale combined with input expansion, and decreasing returns to scale combined with input contraction. In case a state with increasing (decreasing) returns to scale carries out input contraction (expansion), we observe a negative SC. It is worth mentioning that returns to scale also fluctuate across the SEBs and no clear pattern appears. It can be attributed to erratic fuel and material supply for power generation. Since coal availability is abundant in India and the reserves can support the sector till 2031-32, its deteriorating quality due to opencast mines is turning the process inefficient. Also, coal supply due to huge transportation costs turns out to be infeasible as the freight charges are too high and unwashed coal is being sent from mines to the production unit,(which are usually located at a far off place from mines) add to the expenses. Scale change moves the TFP curve and the fluctuating returns to scale accompanied by declining technical efficiency is playing havoc in the Indian power sector.

It can be seen from Table 7 that TC is negative in eleven states (except Andhra Pradesh, Odisha and West Bengal) implying deterioration in production technology overtime and shifting of the frontier downwards during the period 2000-01 to 2007-08. Gujarat has shown maximum negative technical change followed by Madhya Pradesh implying deterioration in technology. Returns to scale[16] has changed its course over the years from increasing to decreasing or vice-versa but has never become constant for any of the states.

5. Summary and Conclusion

The Indian power sector has witnessed radical changes in recent years as several reforms measures have been carried out. These changes have resulted in dismantling of the erstwhile state-run SEBs followed by entry of private firms in the sector. Prior to reforms the Indian power sector was characterized by heavy losses largely due to subsidized power supply, frequent political intervention in operations, and many unviable decisions. With reforms the SEBs have been corporatized, activities in the power sector have been unbundled into generation, transmission and distribution activities, and independent power producers like Adani, Tata, Anil Dhirubhai Ambani Group (ADAG), GVK, GMR, Torrent, JP, Lanco have been taken in. The resultant increase in competition is expected to increase efficiency of the Indian power sector. Against this backdrop the present paper estimated the technical efficiency of power sector of 14 major states in India for the period 2000-01 to 2007-08. It used a stochastic translog production frontier with single output (energy generated), four inputs (capital, labour, energy and material) and four explanatory variables (use of technical manpower, per capita SDP, year of unbundling, and time variable). Contrary to expectation, however, the study finds a decline in technical efficiency over time in the Indian power sector. Such a decline is beset with fluctuation in technical efficiency over time. There is wide variation across states as far as the level of technical efficiency is concerned. States such as West Bengal, Maharashtra, Tamil Nadu, Andhra Pradesh, Bihar, and Odisha have shown a good performance while states such as Punjab and Delhi are lagging behind.

The study finds a positive relationship between use of technical manpower and technical efficiency, thereby indicating that states should emphasize on human resource development technical manpower adds to the efficiency. Secondly, richer states are found to have higher technical efficiency which calls for improvement in overall performance of a state. Positive externalities emanating from thick market efficiency may be working in richer states leading to enhancement of efficiency of the power sector. One perverse result shown by the study, however, is unbundling of power sector activities results in a decrease in technical efficiency. Perhaps Indian power sector has not yet come to terms with the reform measures and reduction of T&D losses is yet to materialize. Implementation of the provisions of Electricity Act 2003 in a comprehensive and time bound manner perhaps can bring in desired results. The negative relationship between year of unbundling and technical efficiency could be because of incomplete implementation of the provisions and the resistance on the part of authorities to comply with the Electricity Act. Growth in TFP, which comprises technical change, scale change and technical efficiency change have been positive for seven states while it is negative in rest seven states. Scale change is negative for all states except Andhra Pradesh, Bihar, Delhi, Gujarat, Maharashtra and Odisha. Technical change has been negative, on average, for all the states except Andhra Pradesh, Odisha and West Bengal. States which exhibit decreasing returns to scale should make efforts towards consolidation and management of power sector rather than expansion. It may lead to positive scale change which in turn will result in positive TFP growth. Notwithstanding the importance of technological upgradation and adequate supply of intermediate inputs, there is a need to accelerate the overall growth in the states. This will help exploit thick market externalities and improve technical efficiency in power generation.

Ideally technical efficiency should be estimated at plant level as efficiency depends upon plant specific factors such as ownership of plant, vintage of plant, etc. Taking into account data limitations,

[16] Results for returns to scale are available with the authors and can be obtained on request.

the present study estimates technical efficiency at aggregative state level the results of which however needs to be interpreted with caution. The relative efficiencies of plants within a state get averaged out thereby making it difficult to comment on plant level efficiencies.

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