THREE ESSAYS ON PERFORMANCE EVALUATION OF ELECTRICITY GENERATION INDUSTRY IN INDIA

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ABSTRACT

India's electricity sector is dominated by fossil fuels, in particular coal. Utilities, especially electricity supply in India, rarely operate with prices and costs determined under competitive markets. Under this scenario, the market economic performance indicators namely profit and returns may only reflect the distortions and not the performance accurately. Therefore, indicators like efficiency and productivity may better signal firm's performance. We endeavor to make an elaborate assessment of the performance of Indian electricity generation industry through efficiency analysis using the non-parametric, linear programming-based frontier estimation technique of Data Envelopment Analysis (DEA) and also utilize econometric regression techniques to investigate the impact of several variables on different facets of performance.

The dissertation focuses on coal-fired power plants due to the dominance of fossil fuels particularly coal in the Indian power sector. In terms of total electricity generated from 2011 to 2017, the share of coal-fired power plants has remained greater than 66 per cent during the entire period. Also, Indian power sector contributes nearly half of the country's CO_2 emissions. Even as coal has played a major role in meeting its energy needs, there are gaping inefficiencies in energy use as well as rising CO_2 emissions over time. Indian power sector has undergone a significant change in its outlook in the last two decades. Comprehensive reforms addressing various aspects of the power sector, such as restructuring, private participation (independent private producers-IPPs), independent regulation (establishment of electricity regulatory commissions), fair tariff for electricity generated and assured return on investment have been undertaken. Also, several energy use and environmental policies were initiated across sectors in India some of which were also applicable to the power sector.

This dissertation is motivated by studying the reforms undertaken in the Indian power sector with an objective to analyze the performance of the sector in light of these reforms. The second motivation is to assess how regulation of the sector has impacted the energy and environmental performance of the sector.

Finally, it also attempts to examine the carbon abatement price for Indian plants in light of various emission abatement policies available to policy makers.

In our first essay, we use a comprehensive data set covering almost all Indian coal-fired power plants over the period 2005-14 to evaluate the technical efficiency of power plants using the Slacks-Based Measure model. Our data set includes 759 observations on 129 private, state and central power plants over the period 2005-2014, covering 93% of the total installed coal-fired generation capacity in the country as of 2014. We find that average technical efficiency falls from 0.847 in 2005 to 0.742 in 2014, indicating substantial scope for efficiency improvement. This trend is driven primarily by declining energy efficiency rather than declining managerial (non-energy) efficiency. We use Simar and Wilson's bootstrapped truncated regression approach to analyze the determinants of technical efficiency. We find an inverted-U shaped relationship exists between efficiency and plant age, with maximum efficiency levels observed between 22 to 23 years of age. Privately owned plants operate at higher efficiency levels than their State-owned counterparts. Large plants are more efficient than small and medium size plants. Coal quality has no significant influence on efficiency as usage of higher calorific value coal is not accompanied by a concomitant reduction in coal use. Foreign equipped plants operate at higher efficiency levels than Indian equipped plants.

Our second essay considers the federal structure of regulatory regulation in electricity generation in India, which is exposed to several regulatory jurisdictions resulting in varied norms for operational performance, tariffs and incentives as well as regulatory practices. This may cause plants to face different production frontiers and bias of technology between the group frontier and meta-frontier due to the regulatory heterogeneity. Such regulatory heterogeneity and its impact on electricity generation performance has not been explored, particularly in Indian context, which we attempt in this essay. We incorporate regulatory heterogeneity by classifying Indian electricity generation plants into two groups-(i) regulated by State electricity regulatory commissions (SERC), and (ii) regulated by Central electricity regulatory commission (CERC); and evaluate their performance over the period 2005-14 using the non-radial directional distance function model in a meta-frontier framework. In the second stage, we observed that CERC regulated, bigger unit sized and coal mine situated plants performed better than others. Major findings include: Energy and CO2 emissions performance of all plants deteriorates; SERC regulated plants (24.5%) were more inefficient than CERC regulated plants (19.0%), and; a secular and broad-based decline in performance is seen over most of the study period. In light of these findings, our regulatory reform proposal includes: (i) tighter de novo energy use norms and explicit CO2 emissions norms, (ii) harmonize the differences in norms and practices across regulators, and (iii) normative performance indicators may be devised using benchmarking techniques such as DEA for identifying better performing plants against which others could be compared. Our proposal might be useful for countries with coal dominant electricity generation capacities exposed to different regulatory authorities and witnessing performance issues.

In the third essay, we estimate the marginal abatement costs of CO_2 emissions from the Indian electricity generation industry and analyze their determinants under three policy scenarios - business as usual, emissions reduction only, and simultaneous emissions reduction and energy efficiency enhancement. This facilitates policymakers to allocate emissions abatement targets to power plants in line with their marginal abatement costs and emissions abatement potentials under different policy scenarios. To do this, we employ a plant level cross-sectional dataset covering 93% of installed capacity in 2014, and use a parametric quadratic directional output distance function to estimate marginal abatement costs by applying deterministic linear programming methods. We find that marginal abatement costs of emissions range between USD 36.29 and 64.41 per ton of CO_2, depending on the scenario. Although greater emissions reductions are possible under the emissions reduction only scenario than under the simultaneous emissions reduction and energy efficiency enhancement scenario, both scenarios are compatible with meeting the Paris agreement goals, albeit with different abatement costs. Plant age, location,

size, ownership, and CO_2 intensity of electricity generation are all significant drivers of marginal abatement costs, permitting identification of potential net suppliers of tradable emissions permits.

Keywords: CO_2 emissions; Data envelopment analysis; Econometric techniques; Efficiency; Indian electricity generation industry; Marginal abatement costs; Meta-frontier; Non-radial directional distance function; Regulatory heterogeneity; Slacks-based Measure.

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ABBREVIATIONS

APC - Auxiliary power consumption
BCC - Banker Charnes Cooper
BC-MTI - Bias-corrected meta technology inefficiency
BCTE - Bias corrected technical efficiency
BTG - Boiler, turbine and generator
BV - Bias-Variance
CEA - Central Electricity Authority
CERC - Central electricity regulatory commission
CRS - Constant returns to scale
DDF - Directional distance function
DEA - Data Envelopment Analysis
DMUs - Decision-making units
DODF - Directional output distance function
EE - Energy efficiency
ETS - Emissions Trading Schemes
EU-ETS - European Union Emissions Trading Scheme
GHG - Greenhouse gas
GMI - Group Managerial Inefficiency
GWh - Gigawatt hour
IC - Installed capacity
LMI - Location Management Instruction
MAC - Marginal abatement costs
ME - Managerial efficiency
MTI - Meta technology inefficiency
MW - Megawatt
NAPCC - National Action Plan on Climate Change
NDDF - Non-radial directional distance function
NMEEE - National Mission for Enhanced Energy Efficiency
PAF - Plant availability factor
PAT - Perform Achieve and Trade
PLF - Plant load factor
R & M - Renovation and modernization
RTS - Returns to scale
SBM - Slacks-based Measure
SERC - State electricity regulatory commission
SERCs - State electricity regulatory commissions
SFA - Stochastic Frontier Analysis
SFC - Secondary fuel oil
SPC - Shadow price of CO_2 emissions
SSA - Sample size adjusted
TGI - Technology gap inefficiency
VRS - Variable returns to scale

3.6 Tables

Table 3.1: Descriptive statistics for Indian thermal power industry (2014).

Variable	**Unit**	**Obs.**	**Mean**	**Std. dev.**
Inputs				
IC	MW	129	1,126.21	885.14
APC	GWh	129	482.93	406.38
Coal Consumption	Thousand Tons	129	4,108.21	3,847
Outputs				
Gross Generation	GWh	129	6,111.94	6,031.71
CO_2 Emissions	Tons	129	56,77,041	52,41,573
Electricity Price	Paise/KWh	102	403.82	133.65
Explanatory Variables				
State	1=yes;0=No	129	0.45	0.50
Age	Years	129	14.43	12.55
CO_2 intensity	Thousand Tons/GWh	129	0.98	0.14
Small	1=yes;0=No	129	0.22	0.41
N-zone	1=yes;0=No	129	0.26	0.44
W-zone	1=yes;0=No	129	0.36	0.48
S-zone	1=yes;0=No	129	0.17	0.38

Note: All inputs/outputs used in this essay are in volume terms.

Table 3.2: Parameter estimates of DODF under three direction vectors.

Coefficient	**Variable**	**$(g_y, g_b) = (1, 1)$**	**$(g_y, g_b) = (0, -1)$**	**$(g_y, g_b) = (1, -1)$**
α_0	intercept	0.07	0.19	0.09
α_1	x_1	0.20	-0.10	-0.02
α_2	x_2	0.62	-0.04	-0.02
α_3	x_3	0.31	0.10	0.03
β_1	y_1	-1.00	-1.08	-0.53
γ_1	b_1b_1	0.00	1.00	0.47
α_{11}	x_1x_1	-0.18	0.03	-0.02
α_{12}	x_1x_2	0.28	0.07	0.04
α_{13}	x_1x_3	-0.10	-0.05	-0.01
α_{22}	x_2x_2	-0.28	-0.02	0.02
α_{23}	x_2x_3	-0.15	-0.03	-0.05
α_{33}	x_3x_3	0.10	0.03	0.05
β_{11}	y_1y_1	0.26	0.03	0.00
γ_{11}	b_1b_1	0.26	0.00	0.00
δ_{11}	x_1y_1	-0.20	0.00	0.02
δ_{21}	x_2y_1	-0.13	0.00	0.00
δ_{31}	x_3y_1	-0.03	0.00	0.00
η_{11}	x_1b_1	0.20	0.00	0.02
η_{21}	x_2b_1	0.13	0.00	0.00
η_{31}	x_3b_1	0.03	0.00	0.00
μ_{11}	y_1b_1	-0.26	0.00	0.00

Table 3.3: Estimates for DODF, CO_2 intensity, CO_2 reduction potential and shadow prices*.

Parameter	**$(g_y, g_b) = (1, 1)$**	**$(g_y, g_b) = (0, -1)$**	**$(g_y, g_b) = (1, -1)$**
Inefficiency (DODF)			
Mean	0.19	0.15	0.07
Std. Dev.	0.13	0.10	0.05
CO_2 intensity (Kg/KWh)			
Mean	0.98	0.83	0.77
Std. Dev.	0.14	0.09	0.10
CO_2 reduction potential (Thousand Tons of CO_2)			
Mean	-	782.29	393.63
Std. Dev.	-	1525.19	796.62
Shadow price (USD/Ton of CO_2)			
Mean	36.29	64.41	60.48
Std. Dev.	23.81	18.69	18.50

*Shadow prices have been converted into USD using the 2014 average exchange rate i.e. 1 USD=INR 61.14 (RBI 2015).

Table 3.4: Top 5 plants (lowest shadow prices) and CO_2 reduction potential **(**Thousand TonsCO_2)**.**

Sl. No.	**$(g_y, g_b) = (0, -1)$**		**$(g_y, g_b) = (1, -1)$**	
	Plants	**CO_2 reduction potential**	**Plants**	**CO_2 reduction potential**
1.	Korba-II	239.09	Korba-II	107.11
2.	Singrauli	425.53	Singrauli	0.00
3.	I.B.Valley	371.77	I.B.Valley	167.32
4.	Bhilai	369.84	Bhilai	167.28
5.	Anapara C	338.04	Anapara C	110.83

Table 3.5: Determinants of shadow prices.

Dependent Variable: Shadow Prices	**Model 1**	**Model 2**	**Model 3**
	$(g_y, g_b) = (1, 1)$	**$(g_y, g_b) = (0, -1)$**	**$(g_y, g_b) = (1, -1)$**
State	-12.47***	-6.22	-4.63
	(4.52)	(3.83)	(3.80)
Age	0.31*	-0.37**	-0.40**
	(0.19)	(0.16)	(0.16)
CO_2 intensity	-26.19	35.03**	38.12***
	(16.55)	(14.03)	(13.94)
Small	-29.94***	7.21	8.07*
	(5.38)	(4.56)	(4.53)
N-zone	-0.27	7.76	7.28
	(5.89)	(4.99)	(4.96)
W-zone	-1.71	-7.24	-6.96
	(5.73)	(4.86)	(4.82)
S-zone	6.93	11.96**	10.50*
	(6.53)	(5.53)	(5.50)
Constant	69.99***	35.42***	28.08**
	(15.83)	(13.42)	(13.33)
p-value	0.00	0.00	0.00
R^2	0.40	0.31	0.30
F (7,94)	9.22	6.00	5.85
No. of Obs.	102	102	102

***, **, and * show significance at 1%, 5% and 10% levels, respectively. Figures in parentheses are standard errors.

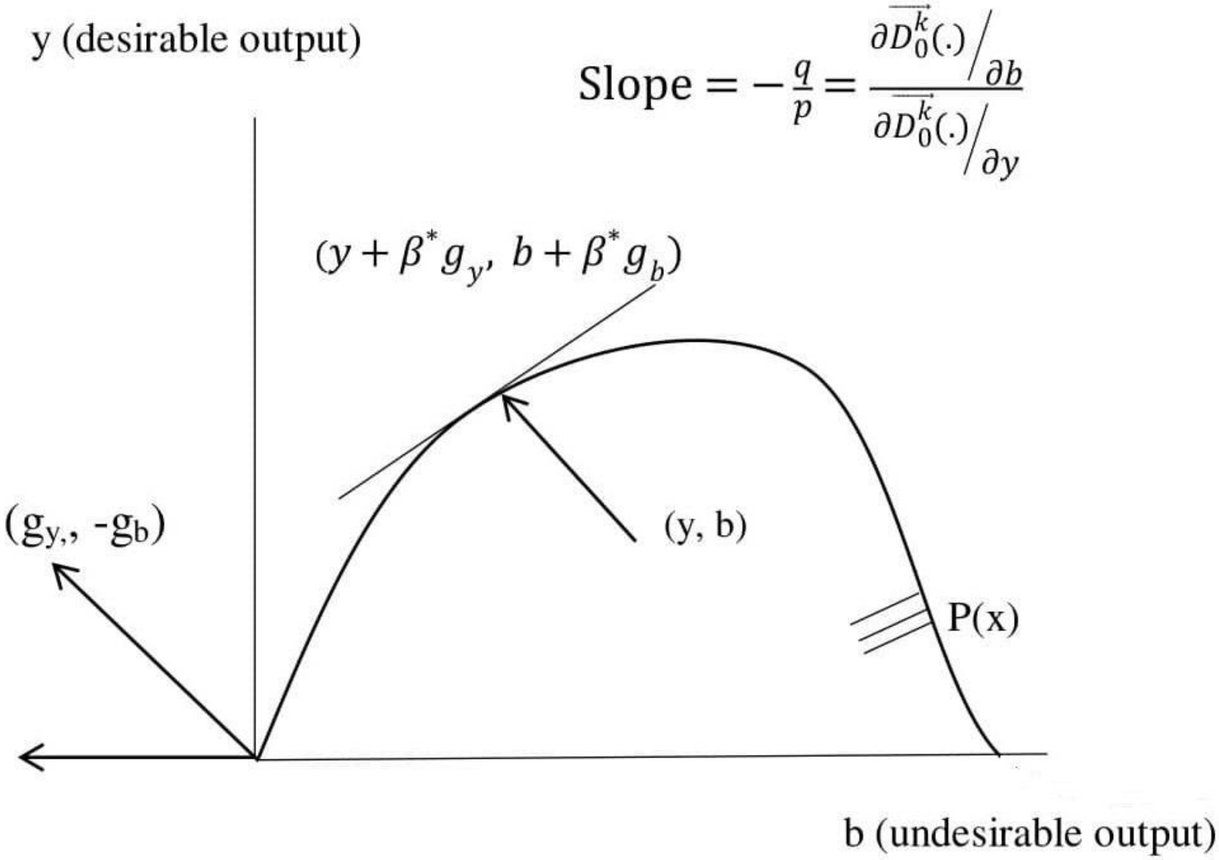
Table 3.6: Zone wise analysis of shadow prices and components.

Zone	Mean tariff	Mean slope of frontier (1,1)	Mean slope of frontier (0,-1)	Mean slope of frontier (1,-1)	SPC (1,1)	SPC (0,-1)	SPC (1,-1)
South	444.286	0.913	0.983	0.476	34.621	71.461	66.321
West	327.601	0.926	0.992	0.506	27.132	53.138	49.632
North	429.947	0.912	0.972	0.377	26.505	68.340	64.162
East	370.187	0.916	0.978	0.468	28.314	59.234	55.441

Note: The mean values here are geometric means.

3.7 Figures

Figure 3.1: Directional output distance function
(Source: Adapted from Fare et al 2006)



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