Are Power Plants in India Less Efficient than Power Plants in the United States?

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In spite of recent economic growth, India is a country with serious deficits in its power sector. Four hundred million Indians lack access to electricity, blackouts have become front-page news, and generating capacity has failed to keep up with targets set in the government's last several five-year plans. An additional question—the one we address in this paper—is how efficiently existing power plants are operated. Seventy percent of India's electricity is generated from coal. In this paper we compare the thermal efficiency of coal-fired power plants in India with the thermal efficiency of coal-fired power plants in the United States and speculate on reasons for the differences that we find.

We compare power plants in the two countries over the period 1988-2009, focusing on state-owned power plants in India. In 2009, 52 percent of coal-fired generating capacity in India was owned by state governments, 38 percent by the federal government and 9 percent by private companies. Historically, plants owned by the federal government and private plants have been regarded as more efficiently operated than state-owned plants, when judged in terms of plant availability and percent of capacity used to generate electricity (i.e., plant load factor) (Malik et al. 2013). Data on thermal efficiency is, however, incomplete for federal and private plants, hence we focus on state-owned power plants.

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We find that state-owned plants in India are significantly less thermally efficient than publically-owned plants in the US when we match plants on nameplate capacity, the average age and vintage of equipment and plant load factor. The efficiency gap increases when we compare state-owned plants in India to divested plants in the US, after electricity markets were restructured. When we also control for the heating value of the coal burned, state-owned plants in India appear less thermally efficient than publically-owned plants in the US, but the gap is narrowed. Measuring the efficiency gap is complicated in both cases by the fact that data on operating heat rate and the heating value of coal in India are missing for some state plants. We therefore believe, for reasons explained below, that our estimates of thermal inefficiency for state plants may be understated.

We surmise that management practices account for the differences in thermal efficiency between US and state-owned Indian power plants. It is possible to improve thermal efficiency by pulverizing coal before it is burned and by performing regular maintenance of boilers (Bushnell and Wolfram 2007). Whether plant managers in India have an incentive to do this depends, in part, on the way in which plants are compensated, which we discuss below.

I. An Overview of the Indian Electricity Sector

Most generating capacity in India is government-owned. The 1948 Electricity Supply Act created State Electricity Boards (SEBs) and gave them responsibility for the generation, transmission, and distribution of power, as well as the authority to set tariffs. SEBs operated on soft budgets, with revenue shortfalls made up by state governments. Electricity tariffs set by SEBs failed to cover costs, generating capacity expanded slowly in the 1960s and 1970s, and blackouts were common. To increase generating capacity, the Government of India in 1975 established the National Hydroelectric Power Corporation and the National Thermal Power Corporation (NTPC), which built generating capacity and transmission lines that fed into the SEB systems. In 1990, 63 of installed capacity was owned by SEBs, 33 percent by the federal government and 4 percent by private companies (Tongia 2003).

Beginning in 1996, attempts were made to reform SEBs by establishing State Electricity Regulatory Commissions (SERCs) and by unbundling generation from transmission and distribution—traditionally the first step in electricity sector reforms. By 2009, 85 percent of coal-fired generating capacity owned by SEBs had been unbundled, but the purchase of generating capacity by independent power producers has not yet occurred. SERCs were also to reform the method by which generators were compensated (Malik et al. 2013).

Under the 2003 Electricity Act SERCs were to follow the Central Electricity Regulatory Commission's (CERC's) guidelines in compensating generators. The CERC compensates the power plants under its jurisdiction based on performance. Compensation for energy used in generation is paid based on scheduled generation and depends on operating heat rate. Compensation for fixed costs (depreciation, interest on loans and finance charges, return on equity, operation and maintenance expenses, interest on working capital, and taxes) is based on plant availability. There is, however, evidence that SERCs have set compensation for fuel use based on very high estimates of operating heat rate, suggesting that this may not provide much of an incentive for plants to improve thermal efficiency (Crisil Ltd. 2010).

II. Measuring Thermal Efficiency

We measure thermal efficiency by net operating heat rate: the heat input used to generate a unit of saleable electricity, measured in MMBtu per kWh. A related measure of thermal efficiency is auxiliary generation—the difference between the gross and net amounts of electricity produced by the plant, expressed as a percent of gross electricity generated. The difference represents electricity used by for plant operations.

For a generating unit the amount of energy required to produce a kWh of electricity should depend on the unit's design heat rate, the quality of coal used and the age of the unit (Joskow and Schmalensee 1987). Units with higher design heat rates will burn more coal per kWh than units with lower design heat rate, and coal with a higher heating value (heat content) can be burned more efficiently than coal with a lower heating value.[2] Generally speaking, unit performance should deteriorate with age, although performance may actually improve after the first few years of operation. Increasing boiler size should reduce coal required per kWh, up to some point. And, units with higher load factors and fewer forced outages will burn less coal due to the fact that they need to be shut down and started up less often.

Auxiliary generation will increase if coal with low heating value is burned, implying that a greater volume of coal must be pulverized to deliver the same amount of energy. It will also increase if electricity is used to run pollution abatement equipment, such as electrostatic precipitators (ESPs) and flue-gas desulfurization units (scrubbers). We note although coal-fired power plants in both countries have ESPs, only 3 plants in India currently have scrubbers.

III. Characteristics of US and Indian Coal-Fired Power Plants

Table 1 presents summary statistics for coal-fired power plants in the US and for state-owned plants in India, divided into plants that have data on operating heat rate and those that do not. The table shows plant nameplate capacity and the mean and median age (vintage) of

[2] We do not have data on design heat rate for US plants. For state-owned Indian plants the average ratio of operating heat rate to design heat rate was 1.27 in 1988 and 1.21 in 2009.

equipment, calculated as the capacity-weighted average of the ages (vintages) of units at each plant. The table also lists plant load factor, the heating value of coal burned, auxiliary generation and operating heat rate (OPHR).

The table shows that in 1988 coal-fired power plants in the US were both older than plants in India (22 years v. 11 years) and, on average, larger. Both sets of plants had similar load factors (about 51%). The heating value of US coal was, however, approximately 50% higher than Indian coal. Indian plants had heat rates that were about 12% higher than plants in the US.

Between 1988 and 2009 coal-fired generating capacity expanded considerably in India, but very little in the US: the median age of plants increased by only 12 years in India, whereas median age increased by 19 years in the US. In 2009, however, plants reporting OPHR data in India were, on average equal in size to plants in the US and were operated a larger fraction of the time. OPHRs for Indian plants that reported them were approximately the same as for plants in the US; however, differences in age, plant load factor and the heating value of coal make direct comparisons inappropriate.

Econometric comparisons between the two sets of plants are complicated by the fact that a significant fraction of state-owned Indian plants do not report OPHR: in 1988 only 5 plants did not report OPHR; in 2009, 20 plants did not report it. Table 1 suggests that the plants that did not report OPHR were older, smaller and had high auxiliary generation, suggesting that they might be less efficient than plants that did report OPHR. In any event, it is clear that auxiliary generation—which is reported by all state-owned plants, was much higher, on average, than for US plants.

IV. Thermal Efficiency of Indian v. US Plants

To compare the thermal efficiency of US and Indian plants we use both regression-based and matching estimators. To estimate the average difference in operating heat rate between US and Indian plants, we pool data on both sets of plants for 1988 through 2009 and regress the logarithm of operating heat rate on polynomials in the average age of generating capacity, average unit vintage, the nameplate capacity of the plant, and plant load factor.[3] We include year dummies, a dummy variable to indicate if a plant is investor-owned and a dummy for IOUs in US states that restructured their utility sectors, after restructuring occurred. The average difference in efficiency between US and Indian plants (average treatment effect) is the coefficient on an indicator for Indian plants interacted with year dummies.

We also compute a nearest neighbor matching estimator (Abadie et al. 2003), matching Indian plants to US plants based on vintage, nameplate capacity, plant load factor and whether the plant is publically owned.[4] Specifically, we match each plant to its 5 nearest neighbors using a Mahalanobis distance metric. Because the set of Indian plants reporting OPHR varies from one year to the next, the analysis is performed separately for each year.

Results from the regression and matching estimators are close. The coefficients from the regression model are plotted in Figure 1. They suggest that, between 1988 and 2009, Indian plants had operating heat rates that were, on average 8% higher than publically owned US plants, holding constant plant characteristics other than coal quality.[5] The pattern, however, shows a clear improvement over time: Indian plants had heat rates that were, on average, 12.2% higher

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[3] Note that OPHR data is not available for India for 1992-96.
[4] Plant load factor is likely to be correlated with unmeasured factors that affect OPHR; in future work, we will instrument for it.
[5] The average treatment effect is 7.8% based on the matching estimator.

than US plants over the period 1988-1991 but only 6.8% higher after 1997. The matching estimator produces similar results: the average difference in OPHR is 12.2% for 1988-1991 and 6.5% for 1997-2009.[6]

The quality of Indian coal is, however, much poorer than coal in the US. Its heating value is 50-60% lower and the ash content much higher.[7] Both factors imply that more tons of coal must be burned to yield the same MMBtu of energy. This is likely to raise auxiliary electricity consumption and thus raise net OPHR. Controlling for coal characteristics is, however, difficult: we do not know the ash content of coal for individual plants. We do know the heating value of coal, but not for all plants for which we have OPHR. The missing data problem increases after 1997—for example, data on the heating value of coal is available for only 29 out of 56 plants in 2009.[8]

When the logarithm of the heating value of coal is added to our model the average treatment effect for the entire period falls to about 3.2%.[9] The average treatment effect for 1988-1991, a period in which data on heating value is available for at least 80% of Indian plants, falls by about 33%, compare to a model that does not control for the heating value of coal. These results suggest that the lower heating value of Indian coal can explain between one-third and half of the difference in thermal efficiency between publically-owned Indian and US coal-fired power plants.

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[6] Using the same matching approach to compare differences in auxiliary consumption implies that auxiliary generation at Indian plants was 2.6% higher over the 1997-2009 period than at US plants.
[7] The ash content of Indian coal is, on average, over 30% by weight (Malik et al. 2013). In contrast, the ash content of Powder River Basin coal is about 5% by weight, and the average ash content of US bituminous coal is about 10%.
[8] Dealing with the selectivity problem is complicated by the fact that data are missing on both the dependent variable (OPHR) and a key explanatory variable (heating value of coal) that is likely to be correlated with the error term in the OPHR equation.
[9] In this model the number of observations falls from 10,199 to 9,641. The average treatment effect in a model without the heating value of coal but with 9,641 observations is 7.5%.

V. Conclusions

Our analysis suggests that state-owned Indian power plants are less efficient than publically-owned power plants in the US. Part of this difference can be explained by differences in the heating value of Indian coal: the heating value of Indian coal is, on average, about 60% of the heating value of coal burned in the US. This increases the amount of coal that must be burned to generate a given heat input, implying higher auxiliary electricity consumption to power grinding equipment, conveyors and pumps. This, however, does not explain all of the differences in thermal efficiency. For this we look to operating and maintenance practices. For example, grinding coal more finely can reduce excess air in the boiler and increase thermal efficiency by reducing heating loss (Linn et al. 2013). A recent study (ESMAP 2009) compares operation and maintenance practices at Indian power plants owned by the NTPC with practices at state-owned power plants. It points out areas in which improved maintenance (e.g., of the milling system and boiler pressure parts) at state plants could improve plant efficiency.

What are the incentives for doing this? Although the Electricity Reform Act of 2003 has encouraged compensating generators based on OPHR, this practice has been implemented in few states (Crisil Ltd. 2010). And, the unbundling of generation from transmission and distribution, per se, has not improved thermal efficiency (Malik et al. 2013). The literature suggests that the restructuring of electricity markets in the US and the purchase of plants by independent power producers has improved thermal efficiency at coal-fired power plants. Bushnell and Wolfram (2005) estimate that the divestiture of utilities in the US improved thermal efficiency by about 2%; Chan et al. (2013) find that restructuring led to 1.4% increase in fuel efficiency at investor-owned plants in states that restructured their utility sectors. Although reforms of the electricity sector are underway in India, the plants we study are still publically owned and operated. With private ownership and better market incentives are likely to come improvements in the efficiency of state-owned power plants.

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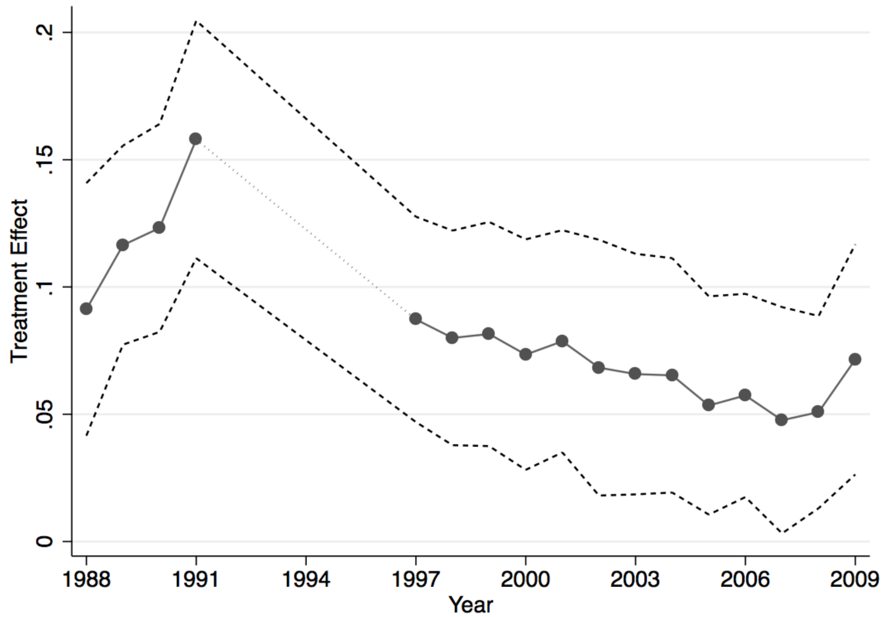
Table 1 - Characteristics of US and Indian Coal-Fired Power Plants

	1988				2009			
	Mean	Median	SD	N	Mean	Median	SD	N
US Plants								
Age	21.88	22	10.48	406	40.32	41	11.86	406
Capacity	765.2	529.7	690.5	406	795.1	566.6	729.2	406
Vintage	1967	1967	10.48	406	1970	1969	11.86	406
Cap. Factor (%)	51.10	53.19	19.58	406	52.52	55.80	22.39	406
Heat Content of Coal	11077	11655	1801	406	10314	10545	1806	404
Aux. Gen (%)	-	-	-	0	7.97	7.32	3.13	334
Heat Rate	11010	10589	1508	406	11326	10746	1836	406
India Plants with Operating Heat Rate Data								
Age	10.32	10.91	5.48	38	22.66	22.42	10.04	36
Capacity	535.6	435	339.4	38	809.0	840	506.5	36
Vintage	1979	1978	5.48	38	1987	1988	10.04	36
Cap. Factor (%)	50.75	52.33	14.88	38	71.35	75.88	18.31	36
Heat Content of Coal	7289	7488	1039	37	6431	6485	664.7	29
Aux. Gen (%)	10.71	10.48	1.82	37	10.32	9.45	2.68	36
Heat Rate	12355	11962	2409	38	11615	10917	2233	36
India Plants without Operating Heat Rate Data								
Age	18.8	22	6.76	5	25.61	28.5	13.31	20
Capacity	154	200	101.4	5	615.5	385	502.3	20
Vintage	1970	1967	6.76	5	1984	1982	13.31	20
Cap. Factor (%)	55.88	58	13.49	5	55.48	65.17	22.97	20
Aux. Gen (%)	11.57	10.71	1.76	3	11.90	11.49	2.49	20

Note: Capacity is in MW, Heat Content of Coal is in Btu per pound and Heat Rate is in MMBtu/kWh. Age and vintage are capacity-weighted averages at the plant level.

Figure 1: Proportionate Difference between Heat Rate of Indian and US Plants



Note: Difference in heat rates (average treatment effect) is estimated controlling for age (third-order polynomial), quadratic functions of nameplate capacity, vintage, and plant load factor, a dummy for investor-owned utilities (as well as an interaction with deregulation status), and time dummies. Dashed lines represent the 95% confidence interval, based on standard errors clustered at the plant level. There are no estimated treatment effects from 1992 to 1996, as we do not observe operating heat rates from Indian plants for these years.

APPENDIX

Appendix: Data Sources

Detailed information about Indian power plant data can be found in Malik et al. (2013). For US plants, we obtained capacity and vintage data from EIA Form 860 and ownership information from EIA Form 861. Net operating heat rate is defined as the ratio of total heat input (in MMBtu) to net generation. Total heat input and net generation are gathered from EIA Form 906/923 for data post 2001, Forms 767 and 759 respectively for data before 2001. The heating value (heat content) of coal burned is gathered from EIA Form 767 (superseded by Form 923 in 2007). In all analyses in the paper, we exclude combined heat and power plants, industrial or commercial plants as well as plants with less than 25 MW capacity.

We rely on the Continuous Emissions Monitoring System (CEMS) to compute auxiliary consumption as CEMS reports gross generation at the boiler level. However, CEMS data on gross generation are available only after 1997 and for the subset of boilers regulated under the Acid Rain Program (ARP). To compare auxiliary consumption with Indian plants, we exclude non-ARP units and aggregate all the above-mentioned variables from

the generator level to the plant level.

Table A1: Model to Explain Log(Net Heat Rate)

Variable	(1)	(2)
India	0.081***	
	(0.017)	
India × Year 1988		0.091***
		(0.025)
India × Year 1989		0.116***
		(0.020)
India × Year 1990		0.123***
		(0.021)
India × Year 1991		0.158***
		(0.024)
India x Year 1997		0.087***
		(0.021)
India x Year 1998		0.080***
		(0.022)
India x Year 1999		0.082***
		(0.022)
India x Year 2000		0.073***
		(0.023)
India x Year 2001		0.079***
		(0.022)
India x Year 2002		0.068***
		(0.026)
India x Year 2003		0.066***
		(0.024)
India x Year 2004		0.065***
		(0.023)
India x Year 2005		0.053**
		(0.022)
India x Year 2006		0.057***
		(0.020)
India x Year 2007		0.048**
		(0.023)
India x Year 2008		0.051***
		(0.019)
India x Year 2009		0.072***
		(0.023)

Age	0.007***	0.009***
	(0.002)	(0.002)
Age^{2} #	-0.245***	-0.283***
	(0.075)	(0.078)
Age^{3} #	0.003***	0.003***
	(0.001)	(0.001)
Capacity #	-0.185***	-0.184***
	(0.018)	(0.018)
$Capacity^{2}$ $	0.049***	0.049***
	(0.007)	(0.007)
Vintage	0.057	0.001
	(0.112)	(0.115)
$Vintage^{2}$ $	-13.996	0.271
	(28.279)	(29.088)
Plant Load Factor	-0.005***	-0.005***
	(0.001)	(0.001)
$(Plant\ Load\ Factor)^{2}$ #	0.021***	0.021***
	(0.005)	(0.005)
IOU Dummy	-0.025***	-0.025***
	(0.009)	(0.009)
IOU x Deregulated	-0.025***	-0.026***
	(0.008)	(0.008)
Year Dummies	Yes	Yes
Number of Observations	10199	10199
Adjusted R^2	0.483	0.485

Note: Dependent variable is Log(Heat Rate). Standard errors, clustered at the plant level, are reported in the corresponding parentheses. ***, **, * indicate 99%, 95% and 90% statistical significance respectively. Capacity factor is in % terms. Variables in '#' and '$' are scaled 1/1,000 and 1/1,000,000 respectively for exposition purpose.

Table A2: Treatment Effects for Operating Heat Rate, using Matching Estimator

Year	ATT	Standard Error	p-value
1988	0.094***	0.024	0.000
1989	0.120***	0.020	0.000
1990	0.126***	0.021	0.000
1991	0.149***	0.023	0.000
1997	0.089***	0.021	0.000
1998	0.016	0.028	0.571
1999	0.082***	0.022	0.000
2000	0.081***	0.023	0.000
2001	0.063**	0.027	0.018
2002	0.080***	0.027	0.003
2003	0.062***	0.024	0.010
2004	0.078***	0.024	0.001
2005	0.037*	0.021	0.087
2006	0.073***	0.020	0.000
2007	0.066***	0.022	0.003
2008	0.046**	0.021	0.030
2009	0.069***	0.025	0.006

Note: Dependent variable is Log(Heat Rate). ***,**,* indicate 99%, 95% and 90% statistical significance respectively. Coefficients indicate the bias-adjusted average treatment effects on the treated (ATT); i.e., the proportion by which OPHR at Indian plants exceeds that at US plants. 5 nearest neighbors are matched to each Indian plant (by year) using a Mahalanobis distance metric. Matching variables are: whether investor-owned, vintage, nameplate capacity and plant load factor.

Table A3: Treatment Effects for Auxiliary Consumption, using Matching Estimator

Year	ATT	Standard Error	p-value
1997	2.396***	0.360	0.000
1998	2.921***	0.408	0.000
1999	2.794***	0.418	0.000
2000	2.102***	0.525	0.000
2001	3.258***	0.390	0.000
2002	1.959***	0.484	0.000
2003	2.523***	0.403	0.000
2004	2.882***	0.331	0.000
2005	1.563***	0.372	0.000
2007	3.709***	0.429	0.000
2008	2.860***	0.396	0.000
2009	2.676***	0.568	0.000

Note: Dependent variable is auxiliary consumption in % term. ***, **, * indicate 99%, 95% and 90% statistical significance respectively. Coefficients indicate the bias-adjusted average treatment effects on the treated (ATT); the percentage point difference between auxiliary heat rate at Indian plants and US plants. 5 nearest neighbors are matched to each Indian plant (by year) using a Mahalanobis distance metric. Matching variables are: whether investor-owned, vintage, nameplate capacity and plant load factor.