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Why Are Power Plants in India Less Efficient than Power Plants in the United States?[†]

By Hei Sing (Ron) Chan, Maureen L. Cropper, and Kabir Malik*

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, 53 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., capacity factor) (Malik et al. 2013). Data on thermal efficiency are, however, incomplete for federal and private plants; hence, we focus on state-owned power plants.

We find that state-owned plants in India are significantly less thermally efficient than publicly owned plants in the United States when we match plants on nameplate capacity and the average age of equipment. The efficiency gap increases when we compare state-owned plants in India to divested plants in the United States, 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 publicly owned plants in the United States, 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

* Chan: University of Maryland, 3114 Tydings Hall, College Park, MD 20742 (e-mail: chan@econ.umd.edu); Cropper: University of Maryland and Resources for the Future, 3114 Tydings Hall, College Park, MD 20742 (e-mail: cropper@econ.umd.edu); Malik: World Bank, 1818 H Street, Washington, DC 20433 (e-mail: kmalik@worldbank.org). We would like to acknowledge helpful comments from Dallas Burtraw, Lucas Davis, Steve Gabriel, Ben Hobbs, Guido Kuersteiner, Josh Linn, Erin Mansur, and Jeff Smith. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not represent the views of the World Bank, its Executive Directors, or the countries they represent.

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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 percent 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 salable 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 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 rates, and coal with a higher heating value (heat content) can be burned more efficiently than coal with a lower heating value.[1] 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 capacity 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 three 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 United States 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 equipment, calculated as the capacity-weighted average of the ages (vintages) of units at each plant. The table also lists plant capacity factor, the heating value of coal burned, auxiliary generation, and operating heat rate (OPHR).[2]

The table shows that in 1988 coal-fired power plants in the United States were both older than plants in India (22 years versus 11 years) and, on average, larger. Both sets of plants had similar capacity factors (about 51 percent). The heating value of US coal was, however, approximately

[1] 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.

[2] The sources of our data are described in an online Appendix.

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
Capacity factor (percent)	51.10	53.19	19.58	406	52.52	55.80	22.39	406
Heat content of coal	11,077	11,655	1,801	406	10,314	10,545	1,806	404
Auxiliary gen (percent)	—	—	—	0	7.97	7.32	3.13	334
Heat rate	11,010	10,589	1,508	406	11,326	10,746	1,836	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
Capacity factor (percent)	50.75	52.33	14.88	38	71.35	75.88	18.31	36
Heat content of coal	7,289	7,488	1,039	37	6,431	6,485	664.7	29
Auxiliary gen (percent)	10.71	10.48	1.82	37	10.32	9.45	2.68	36
Heat rate	12,355	11,962	2,409	38	11,615	10917	2,233	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
Capacity factor (percent)	55.88	58	13.49	5	55.48	65.17	22.97	20
Auxiliary gen (percent)	11.57	10.71	1.76	3	11.90	11.49	2.49	20

Notes: SD = standard deviation; N = number of plants. *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.

50 percent higher than Indian coal. Indian plants had heat rates that were about 12 percent higher than plants in the United States.

Between 1988 and 2009 coal-fired generating capacity doubled at state-owned plants in India but increased very little in the United States: consequently, the median age of plants increased by only 12 years in India, whereas median age increased by 19 years in the United States. In 2009, however, plants reporting OPHR data in India were, on average, equal in size to plants in the United States 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 United States; however, differences in age, plant capacity 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 five 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 versus 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 and the nameplate capacity of the plant.[3] We include year dummies, a dummy variable to indicate if a plant belongs to an investor-owned utility (IOU),

[3] Note that OPHR data are not available for India for 1992–1996. Models are estimated by ordinary least squares, with standard errors clustered at the plant level. Estimation results are reported in an online Appendix.

and a post-restructuring dummy for IOUs in US states that restructured their electricity sectors. The year-on-year 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.[4]

We also compute a nearest neighbor matching estimator (Abadie et al. 2003), matching Indian plants to US plants based on age, nameplate capacity, and whether the plant is publicly owned.[5] Specifically, we match each plant to its five 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, 9.4 percent higher than publicly owned US plants, holding constant plant characteristics other than coal quality.[6] The pattern, however, shows a clear improvement over time: Indian plants had heat rates that were, on average, 13.7 percent higher than US plants over the period 1988–1991 but only 8.0 percent higher, on average, after 1997. The matching estimator produces similar results: the average difference in OPHR is 15.2 percent for 1988–1991 and 8.9 percent for 1997–2009.[7]

The quality of Indian coal is, however, much poorer than coal in the United States. Its heating value is 50–60 percent lower and the ash content much higher.[8] 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 are available for only 29 out of 56 plants in 2009.

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 6.8 percent.[9] The average treatment effect for 1988–1991, a period in which data on heating value are available for at least 80 percent of Indian plants, falls by about 20 percent, compared 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 20 and 30 percent of the difference in thermal efficiency between publicly owned Indian and US coal-fired power plants.

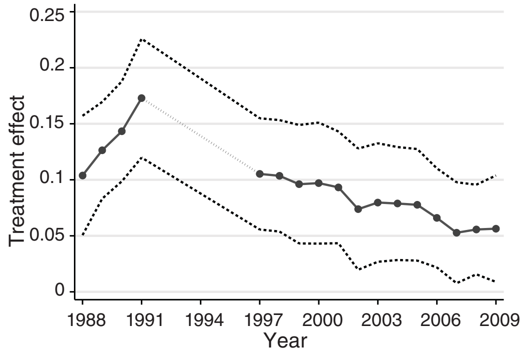

Figure 1. Proportionate Difference between Heat Rates of Indian and US Plants

Notes: Average difference in heat rates (average treatment effect) is estimated controlling for age (third-order polynomial), nameplate capacity (second-order polynomial), a dummy for investor-owned utilities, the interaction of this dummy with deregulation status, and time dummies. Dashed lines represent 95 percent confidence intervals, 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 at Indian plants for these years.

[4] Implementing selectivity correction for missing OPHR data is difficult: we do not have data on variables that explain failure to report OPHR but do not affect OPHR directly.

[5] Plant capacity factor is likely to be correlated with unmeasured factors that affect OPHR; hence, we do not control for it in our models. Average treatment effects and standard errors are reported in an online Appendix.

[6] The average treatment effect is 10.4 percent based on the matching estimator.

[7] Using the same matching approach to compare differences in auxiliary consumption implies that auxiliary generation at Indian plants was 3.48 percent higher over the 1997–2009 period than at US plants.

[8] The ash content of Indian coal is, on average, over 30 percent by weight (Malik et al. 2013). In contrast, the ash content of Powder River Basin coal is about 5 percent by weight, and the average ash content of US bituminous coal is about 10 percent.

[9] When we add the heating value of coal to the model, we include a missing dummy = 1 if the heating value of coal is missing and set missing values equal to zero. The coefficient on the missing data dummy is not significantly different from zero at conventional levels ($p = 0.26$).

V. Conclusions

Our analysis suggests that state-owned Indian power plants are less efficient than publicly owned power plants in the United States. 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 percent of the heating value of coal burned in the United States. This increases the amount of coal that must be burned to generate a given heat input, implying higher auxiliary electricity consumption to run coal grinding equipment, conveyors, and pumps. This, however, explains only part of the differences in thermal efficiency. Operating and maintenance practices can also directly impact thermal efficiency. For example, grinding coal more finely can reduce excess air in the boiler and increase thermal efficiency by reducing heating loss (Linn, Mastrangelo, and Burtraw 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). Restructuring reforms entailing the unbundling of generation from transmission and distribution have also failed to improved thermal efficiency (Malik et al. 2013). In contrast, the literature suggests that the restructuring of electricity markets in the United States 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 United States improved thermal efficiency by about 2 percent; Chan et al. (2013) find that restructuring led to a 1.4 percent increase in fuel efficiency at investor-owned plants in states that restructured their utility sectors. Although reforms of the electricity sector are under way in India, the plants we study are still publicly owned and operated. With improvements in market incentives and private ownership are likely to come improvements in the thermal efficiency of state-owned power plants.

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