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Estimating the Impact of Restructuring on Electricity Generation Efficiency

The Case of the Indian Thermal Power Sector

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Estimating the Impact of Restructuring on Electricity Generation Efficiency: The Case of the Indian Thermal Power Sector

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Abstract

This paper examines the impact of the unbundling of generation from transmission and distribution on the operating efficiency of state-owned thermal power plants in India. Using information collected by India's Central Electricity Authority, we construct a panel data set for thermal power plants for the years 1994–2008. We take advantage of variation across states in the timing of reforms to examine the impact of restructuring on plant performance and thermal efficiency. We estimate difference-in-differences models that control for state-level time trends and plant and year fixed effects. The models suggest that unbundling significantly improved average annual plant availability by about 4.6 percentage points and reduced forced outages by about 2.9 percentage points in states that unbundled before 2003. Restructuring has not, however, improved thermal efficiency. This may reflect the fact that unbundling has not yet attracted independent power producers into the market to the extent that it has in the United States.

Key Words: Indian power sector, electricity reform

JEL Classification Numbers: O13, O25, Q4, L43, L94

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1. Introduction

Beginning with Chile in 1982 the last two decades of the 20th century were marked by the restructuring of the electricity sector in countries throughout the world. Utilities that were functioning as vertically-integrated monopolies were unbundled and privatized in an attempt to increase competition and lower costs. Electricity deregulation paved the way for the entry of independent power producers and the creation of wholesale electricity markets. The resulting gains in operating efficiency and reduction in costs have been documented using plant-level data for the US and cross-country data for developing countries (Fabrizio et al. 2007, Davis and Wolfram 2011, Zhang et al. 2002). In this paper we estimate the effects of restructuring of the Indian electricity sector on the performance of state-owned thermal power plants.

In the decades following independence, the Indian power sector, like those of many developing countries, was characterized by inadequate generating capacity, frequent blackouts, and high transmission and distribution losses. The thermal efficiency of Indian power plants was low compared to similar plants in high-income countries.[1] Electricity pricing was characterized by direct government subsidies, with high tariffs to industry cross-subsidizing low tariffs for residential and agricultural consumers. Following the nationalization of the power sector in 1956, most generating capacity was government owned.

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[1] It is well established that the thermal efficiency of power plants in developing countries is lower than that in Organisation for Economic Co-operation and Development member countries (Maruyama and Eckelman 2009). Persson et al. (2007) report an average thermal efficiency of 29 percent for Indian coal-fired plants in 1998. This is lower than the average efficiency reported for South Korea and more than 10 percent lower than Japan, the most efficient country examined.

The first steps toward the reform of the Indian electricity sector were taken two decades ago. In 1991, legislation was passed to encourage independent power producers (IPPs) to enter the electricity market. This policy was in accordance with the government's broader macroeconomic liberalization and privatization agenda. However, it failed to substantially increase private sector entry into electricity generation and, in 1998, 60 percent of generation capacity and approximately 85 percent of the transmission and distribution network in India remained under the ownership and control of state electricity boards (SEBs). The SEBs operated as vertically integrated, regional monopolies. Political interference in pricing and connection decisions resulted in large operating losses and the inability to maintain or upgrade existing infrastructure. Transmission and distribution losses were high—nearly 30 percent of electricity produced—and tariffs covered less than 70 percent of costs. Frequent power outages and voltage fluctuations imposed real economic costs on residential and commercial consumers. Recurring financial losses constrained the investment needed to expand generation and distribution capacity to the large number of people without access to power in rural India. In addition, low average thermal efficiency (below 30 percent) and plant load factor (below 55 percent) meant that existing generation capacity was being used far below its potential.

The first reform initiative targeting the SEBs began in the state of Orissa in the mid-1990s, with the support of the World Bank. Following that, the Government of India initiated market-oriented reforms to address the underlying causes of the sector's inefficiency. The electricity acts of 1998 and 2003[2] led to the creation of the Central Electricity Regulatory Commission (CERC) and similar regulatory bodies at the state level (the state electricity regulatory commissions or SERCs). The acts also paved the way for the unbundling of generation, transmission, and distribution functions; the privatization of distribution companies; and the restructuring of the electricity tariff structure—both for end consumers and for generators. Despite variation in the nature and timing of the reforms across states, most states have, over the past decade, completed initial reforms. They have established independent regulatory commissions; unbundled vertically integrated utilities into generation, transmission, and distribution companies; corporatized (and, in some cases, privatized[3]) distribution companies; and taken steps toward tariff restructuring.

[2] These were the Electricity Regulatory Commissions Act, 1998; and the Electricity Act, 2003.

[3] Delhi and Orissa were the only states to privatize their distribution networks.

Although more than a decade has passed since the first restructuring reforms, no comprehensive study has assessed their impacts on the plants targeted by the initiatives. In this paper, we examine whether these reforms have increased the operating efficiency of state-owned thermal power plants. Studies of efficiency in electricity generation typically either determine how far individual plants (or electric generating units [EGUs]) are from the production frontier (Knittel 2002; Shanmugam and Kulshreshtha 2005; Singh 1991) or examine variation across plants in various performance measures, such as operating heat rate and plant availability (Joskow and Schmalensee 1987). In this paper, we follow the second approach. Our analysis of performance measures focuses on thermal efficiency, which determines fuel costs, and plant reliability. Thermal efficiency is measured by operating heat rate—the energy used to generate a kilowatt-hour (kWh) of electricity—and by the deviation of operating from design heat rates. Plant reliability is measured by the percentage of time that a plant is available to generate electricity—the theoretical maximum number of hours less forced outages and planned maintenance.

We hypothesize that the unbundling of generation from transmission and distribution could improve performance in several ways. Separating generation from network functions is likely to promote greater autonomy and transparency in operations. Further, it is likely to lead to increased exposure to market forces and consequently to greater efficiency in resource allocation within a plant. Finally, unbundling thermal power plants may improve efficiency by reducing diseconomies of scope—allowing managers to focus on decisions related solely to generation, rather than considering the system as a whole. This could result in improved plant maintenance, which would increase plant availability and reduce forced outages. Better management could lead to the use of imported coal, or coal-washing, which would improve operating heat rate.

We investigate the impact of unbundling using a panel data set of thermal power plants for the years 1994–2008, which we have constructed using information collected by India's Central Electricity Authority (CEA). We take advantage of the variation across states in the timing of reforms to examine the impact of the unbundling of generation from transmission and distribution on plant availability and thermal efficiency. Specifically, we estimate difference-in-differences models for plant availability, forced outages, operating heat rate, and other performance measures. The models control for the capacity, design heat rate, and age of EGUs in the plant, as well as state-level time trends, and plant and year fixed effects.

Our results suggest that the reorganization of the SEBs significantly has improved average annual plant availability and thus enabled increased electricity production from existing capacity. The results also suggest that a significant portion of the increased availability is due to a reduction in time lost due to forced outages. However, the unbundling of SEBs appears, on average, to have had little impact on operating heat rate of the state-owned power plants. Our estimations show considerable variation in the magnitude of these impacts across states. The biggest improvements following unbundling have occurred primarily in the states that were among the first to unbundle—that is, those states that unbundled generation from transmission and distribution before the Electricity Act of 2003. On average, plant availability increased by approximately 400 hours per year. This could represent a duration-of-treatment effect: the impacts of reform take time to be realized. Alternatively, it could indicate that states that unbundled earlier differed in unmeasured ways from states that unbundled later.

The paper is organized as follows. Section 2 provides background on the Indian power sector and on the nature of reforms. Section 3 briefly reviews the recent literature on the evaluation of electricity sector reforms, as well as the literature on generation efficiency in the Indian power sector. Our econometric models and data are described in section 4. Section 5 presents empirical results, and section 6 concludes.

2. Institutional Background

Coal-fired power plants currently produce approximately 70 percent of the electricity generated in India[4]. Of the coal-fired EGUs, 90 percent are subcritical[5], with a maximum achievable thermal efficiency of 35 to 38 percent. However, in 1998, the average thermal efficiency of these plants was less than 30 percent, due in part to technical factors—e.g. poor coal quality—and in part to inefficiencies in management.

The heat content of coal used in Indian plants in 1990 averaged 4,000 kilocalories (kcal)/kilogram (kg)[6], with ash content between 25 and 45 percent (Khanna and Zilberman 1999). Domestic Indian coal, with low heat content and high ash content, requires greater heat input to produce electricity. Imports of coal with higher heat and lower ash content were effectively prohibited by high tariffs (the tariff on imported coal in 1993 was 85 percent).

[4] They account for 55 per cent of the installed capacity (source: Ministry of Power, http://www.powermin.nic.in/JSP_SERVLETS/internal.jsp)

[5] As opposed to super-critical EGUs that operate at higher steam pressures and greater thermal efficiency.

[6] Compared to 6,000 kcal/kg in 1960. The average coal quality has declined in India on partly because an increasing share of production is from large scale open cast mines.

Facilities designed to wash coal to reduce its ash content were not widely available in the early 1990s.

In 1990, 63 percent of thermal generating capacity was owned by SEBs,[7] which 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. There was a need to reform the existing tariff structure, which sold electricity cheaply to households and farmers and compensated by charging higher prices to industry. This prompted firms to generate their own power rather than purchasing it from the grid, an outcome that further reduced the revenues of SEBs. The result was that most SEBs failed to cover the costs of electricity production. Reform of the distribution network was necessary because of the extremely large power losses associated with the transmission and distribution of electric power—both technical losses and losses due to theft (Tongia 2003).

Beginning in 1991, the Government of India instituted reforms to increase investment in power generation, reform the electricity tariff structure, and improve the distribution network. Under the Electricity Laws Act of 1991, IPPs were allowed to invest in generating capacity. They were guaranteed a fair rate of return on their investments, with tariffs regulated by CEA. The Electricity Regulatory Commissions Act of 1998 made it possible for the states to create SERCs to set electricity tariffs. States were to sign memoranda of understanding with the federal government, agreeing to set up SERCs and receiving, in return, technical assistance to reduce transmission and distribution losses and other benefits. The Electricity Act of 2003 made the establishment of SERCs mandatory and required the unbundling of generation, transmission, and distribution (Singh 2006). Table 1 shows the year in which the SERC became operational in each state and the year in which generation, transmission, and distribution were unbundled.[8]

Another objective of the 2003 Electricity Act was to reform the electricity tariff structure—both for end users and for generators. SERCs are to follow the 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

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[7] In 1990, 33 percent of capacity was owned by the central government and 4 percent by private companies. In 2006, 51 percent of thermal generating capacity was owned by SEBs, 37 percent by the central government, and 12 percent by private companies (CEA 2007).

[8] Table 1 lists only those states containing thermal power plants. Our study focuses on coal- and lignite-fueled plants.

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. In addition, an availability-based tariff (ABT) was instituted in 2002 to regulate the supply of power to the grid. If a generator deviates from scheduled generation, the ABT imposes a tariff that depends on system frequency (Chikkatur et al. 2007).

In addition to the electricity reform acts of 1998 and 2003, the tariff on imported coal has been lowered, and coal washing has been encouraged. The current duty on imported, non-coking coal is 5 percent. Beginning in 2001, the use of coal with ash content exceeding 34 percent was prohibited in any thermal power plant located more than 1,000 kilometers from the pithead, or in urban or sensitive or critically polluted areas.

The strategy of electricity reform in India drew from the experience of reforms in other countries but was shaped by the local political and economic context. Unlike the US and Chile, where vertically integrated generating capacity was unbundled and sold to private operators, State Electricity Boards (SEBs) in India were unbundled but not privatized—they were “corporatized.” The question is what impact this reorganization, in the absence of ownership change, has had on power plant performance.

3. Literature Review

3.1 Studies of the Productive Efficiency of Thermal Power Plants

A large literature measures the productive efficiency of thermal power plants.[9] This includes both cross-country studies and studies that compare the efficiency of plants within a country. A number of studies measure productive efficiency by comparing the actual amount of electricity generated by a plant (Q) to the maximum generation possible, given inputs of capital and fuel (Q_m). Maximum possible output is calculated from a production frontier, which is estimated either by statistical (e.g., stochastic production frontier) or linear programming (e.g., data envelopment analysis) methods. In many studies, the technical efficiency (TE) of each plant

[9] Our review focuses on measures of productive, as opposed to allocative, efficiency.

(Q/Q_m) is then explained as a function of variables such as the age of the capital stock or the nature of plant ownership (e.g., public or private).[10]

Other studies focus on the thermal efficiency of the plant—the amount of fuel used to produce a kilowatt-hour of electricity[11]—and other measures of how efficiently a plant is operated. The latter include auxiliary consumption, which is the amount of electricity used for plant operations (i.e., the difference between gross and net generation); the percentage of time that a plant is available for use (plant availability); or the percentage of time the plant is actually generating electricity (i.e., the PLF). Variation in these measures across plants is often explained as a function of the vintage of capital equipment, average unit capacity, and/or by plant ownership variables. One advantage of this approach is that efficiency measures are observed directly, rather than being calculated from a production frontier.

Examples of the first approach in the literature on the Indian electricity sector include Singh (1991), Chitkara (1999), and Shanmugam and Kulshreshtha (2005). Singh (1991) uses linear programming methods and a cross-section of data for 1986 and 1987 to estimate the TE of state-owned coal-fired power plants for each year. The range of TE across plants is wide, varying from 0.40 to 1.00. When plants are grouped by power sector region (see Table 2), plants in the South are, on average, more efficient than plants in other regions; however, the region dummy is insignificant in a multivariate regression.[12] Plants with higher PLFs are, as expected, more efficient than plants that are used a smaller fraction of the time.

Shanmugam and Kulshreshtha (2005) estimate a stochastic frontier production model to measure the TE of 56 coal-based power plants for the period 1994–2001. Using panel data methods, they test whether TE parameters changed during the period of their analysis. Their results suggest that TE levels did not vary during this period; however, they found considerable variation in TE across plants (from 0.96 to 0.46). When TE is regressed on plant age and region dummies, TE decreases with age and is lower for plants located in the North than in other power regions.

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[10] Other studies allow variables that may explain differences in efficiency to affect the mean of the error term of the stochastic frontier (see, e.g., Khanna et al. [1999], Knittel [2002], and Hiebert [2002]).

[11] Operating heat rate is defined as the fuel input (in kilocalories or British thermal units) per kilowatt-hour of electricity produced. Thermal efficiency is proportional to the power output of the plant, divided by the heating value of the fuel.

[12] Singh (1991) regresses measures of TE from two linear programming approaches on region dummies, PLF, and plant size (in megawatts of installed capacity).

Khanna and Zilberman (1999) use data (1987–1988 to 1990–1991) for 63 coal-fired power plants to analyze the contributions of regulatory and technical factors to plant efficiency. They measure efficiency by the heat input required to produce a net kilowatt-hour of electricity and by auxiliary electricity consumption. Efficiency at the EGU level is explained as a function of ownership of the plant (whether state-owned, privately owned, or owned by the central government), boiler manufacturer, coal quality, age of boiler turbine, and PLF. Khanna and Zilberman find that energy efficiency increases with the use of coal with higher heat content and is lower at plants operated by SEBs than at private plants, holding factors such as plant age and capacity utilization constant. Specifically, they find that improving management practices to match those in the private sector could raise average thermal efficiency from 25.66 to 26.93 percent; use of high-quality coal could raise it further, to 29.2 percent.

Khanna and Zilberman's study suggests that inefficient operating procedures, lack of coal-washing facilities, and high tariffs were, in 1991, barriers to higher thermal efficiency in coal-fired power plants. In a subsequent study, Khanna and Zilberman (2001) examine whether plants would choose to use washed domestic coal if coal-washing facilities were available, or would import coal if the tariff on imported coal were lowered from 1991 levels. Assuming that all plants maximize profits, they estimate that, when the tariff on imported coal is reduced to 35 percent and washed coal is available, 68 percent of units would use washed coal, and 18 percent would use imported coal. These proportions change to 52 percent and 34 percent, respectively, when the tariff on imported coal is reduced to zero. Since publication of the studies by Khanna and Zilberman, the Indian government has gradually reduced the tariff on imported coal and has also mandated the use of washed coal under certain circumstances (see section 2). An interesting question is whether plants in states that unbundled their generation facilities have taken advantage of these policy reforms.

3.2 Studies of Electricity Sector Reforms

Over the past two decades, many member countries of the Organisation for Economic Co-operation and Development and more than 70 developing countries have taken steps to reform their electricity sectors (Bacon and Besant-Jones 2001; Khanna and Rao 2009). A large literature uses cross-country data to examine factors conducive to reform and the nature of reforms undertaken (Bacon and Besant-Jones 2001). Studies have also examined the impacts of reforms on the efficiency of generation and distribution and on electricity pricing (Jamasb et al. 2005). Much of this literature, which is summarized by Jamasb et al. (2005) and by Khanna and Rao (2009), focuses on the impact of privatization on performance and uses cross-country panel data. Below, we discuss studies that examine the impact of reforms on generation efficiency using plant-level data.

Most of the studies that have examined the impact of reforms on generation efficiency using plant-level data employ either stochastic frontier or data envelopment analysis methods. Jamasb et al. (2005) summarize and critique four such studies in developing countries.[13] In the United States, Knittel (2002) and Hiebert (2002) use stochastic frontier analysis to study the impact of reforms on generation efficiency. Knittel (2002) estimates a stochastic production frontier that allows the mean of the efficiency component of the error term to depend on the compensation program that the generator faces.[14] He finds greater production efficiency for plants that operate under programs that provide direct incentives for increased efficiency by compensating generators based on heat rate and plant availability (compared with plants compensated on a cost-plus basis).

Hiebert (2002) estimates a stochastic frontier cost function to examine the efficiency impacts of unbundling and open access to transmission and generation using U.S. data for the period 1988–1997. As in Knittel (2002), he jointly estimates the parameters of the stochastic frontier and the factors determining the efficiency component of the error term. His analysis shows that investor-owned utilities and cooperatively owned plants are more efficient than publicly owned municipal plants. Hiebert adds dummy variables for states that unbundled generation from transmission and distribution in 1996 and 1997. The results indicate efficiency gains in 1996 (but not 1997) for coal-fired plants that were operating in states that implemented reforms.

Fabrizio, Rose, and Wolfram (2007) study the impact of electricity restructuring on generation efficiency in the United States using a difference-in-differences approach to measuring efficient input use. Using a plant-level panel (1981–1999) of gas- and coal-fired thermal power plants, the authors estimate cost-minimizing input demands as a function of plant characteristics while controlling for the regulatory regime. They show that privately owned utilities in restructuring states experienced greater gains in efficiency of nonfuel input use

[13] The studies are Plane (1999), Arocena and Waddams (2002), Hattori (1999), and Delmas and Tokat (2005). See also Pombo and Ramirez (2005).

[14] Knittel examines six different programs: compensation based on heat rate, compensation based on an equivalent availability factor, price-cap programs, rate-of-return range programs, fuel-cost pass-through programs, and revenue-decoupling programs. His sample includes both gas- and coal-fired power plants.

compared to similar utilities in non-restructuring states and cooperatively or publicly owned generators that were insulated from the reforms. Because of the nature of the restructuring process in the United States, their restructuring measure combines the effect of unbundling of generation from transmission and distribution with opening the generation sector to retail competition. The authors, however, attribute most of their impact to the unbundling of generation, as retail competition was limited to only seven states during the period of analysis.

Although the literature examining the impact of reforms in the Indian electricity sector is growing (e.g., Thakur et al. 2006; Singh 2006; Chikkatur et al. 2007), the only econometric study that attempts to estimate ex-post generation efficiency gains is Sen and Jamasb (2010). The authors use panel data at the state level for the period 1990–2007 to test the impact of reforms on PLF, gross generation and transmission, and distribution losses.[15] Specifically, they explain the three performance measures as functions of six regulatory dummy variables and state and year fixed effects.[16] They find that the unbundling and tariff order dummy variables show a strong positive effect on PLF, as does the ratio of industrial to agricultural electricity prices. They also find that the SERC, unbundling, and privatization dummies have increased transmission and distribution losses, possibly due to the reduced ability to hide existing losses after reform.

In contrast to the state-level approach of Sen and Jamasb (2010), we use data at the plant level to examine the effect of unbundling on the performance of state-owned power plants. This allows us to control for plant fixed effects, state time trends, and year fixed effects. We argue that, conditional on these (and other) controls, the unbundling of generation from transmission and distribution can reasonably be regarded as exogenous. We also run falsification tests to see whether reforms designed to improve the efficiency of state plants also affected centrally owned coal-fired power plants.

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[15] The analysis reported is for 245 observations across 18 states and 17 years. Variables are defined at the state level, so the analysis measures the impact of reforms on all power plants—state-owned, privately owned, and centrally owned—within a state.

[16] The regulatory dummies are: presence of independent power producers, establishment of a SERC, unbundling of generation from transmission and distribution, passing of a tariff order, open access to transmission facilities, and privatization of distribution.

4. Methodology and Questions Addressed

4.1 Questions Addressed

We examine the unbundling of the vertically-integrated SEBs into specialized generation, transmission and distribution companies. Unbundling entails "corporatizing" the sector, which should promote greater autonomy and accountability and increase the efficiency with which plants are run. We ask whether unbundling increased the availability of plants (e.g., by improving plant maintenance) and reduced operating heat rate (e.g., by increasing imports of high-quality coal). We also ask whether the effects of unbundling depend on the amount of time that has elapsed since unbundling.

Economic theory predicts that, in the presence of well-functioning markets, increased specialization and autonomy should lead to an increase in efficiency through incentives created by greater exposure to market forces and reduced scope of decision-making. We expect that unbundling of the SEB would increase the transparency and independence in the functioning of each newly created entity. Generation efficiency may increase as plants will not need to reduce production in response to frequent load variations in transmission or distribution networks.[17] Delinking generation from distribution is also likely to improve the financial situation of generating plants[18]. This would probably lead to an increased investment in maintenance and upgrades of equipment, resulting in better operating efficiency. Fragmentation of the industry may also expose the newly created entities to the disciplining forces of the market and price signals which would create pressure to reduce costs. In addition, a vertically integrated SEB may suffer from diseconomies of scope: managerial decisions require consideration of factors affecting the system as a whole. The information required for this may be prohibitively costly to acquire and difficult to process. In contrast, an unbundled generation company would reduce the scope of managerial decisions and therefore allow for a focus on efficient generation.

We test these theoretical predictions using data on the performance of state-owned thermal power plants. Specifically, we examine whether plants in states that have restructured their electricity sectors operate more efficiently than plants in states that have not restructured.

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[17] After reducing output, increased oil input is required to get the boiler back to the temperature required to produce electricity. Increased input use and suboptimal temperature during the cycling up reduces average generation efficiency.

[18] The distribution function was the biggest drain on SEB resources due to subsidized consumer tariffs.

We use two sets of variables to measure the performance of generating plants. The first set measure the thermal efficiency of a plant. These measure the plant's efficiency in the use of its coal input--specific coal consumption[19], operating heat rate[20] and the deviation of operating heat rate from design heat rate. The second set of performance measures includes the percentage of time a plant is available to generate electricity (plant availability) and the percentage of time a plant is used to generate electricity (PLF). In addition to measuring plant availability, we measure the percentage of time a plant is unavailable for use because of forced outages or planned maintenance.[21] A final measure of plant efficiency is auxiliary electricity consumption—the percentage of gross generation consumed by the plant itself.

4.2 Models Estimated

The variation across states in the timing of reforms allows us to estimate the impact of the reforms on the performance of thermal power generators using difference-in-differences estimation. To estimate the average effect of the state-level unbundling reform variable on generating plant efficiency, we use a panel difference-in-differences model with year and plant-level fixed effects, as well as state time trends. The average treatment model takes the following form

$$Y_{ijt} = \theta_{\{i\}} + \tau_{\{t\}} + X_{ijt}\beta + \gamma\, UNB_{\{jt\}} + \sum \varphi_j TREND_{jt} + \varepsilon_{ijt} \qquad (1)$$

where Y_{ijt} is the plant-level performance measure for plant *i* in state *j* at time *t*. X_{ijt} is a vector of plant-level control variables that measure equipment characteristics (e.g., age and capacity). $UNB_{\{jt\}}$ is the unbundling dummy that takes a value of 1 starting the year after state *j* unbundles its SEB, $\theta_{\{i\}}$ is the plant-level fixed effect, $\tau_{\{t\}}$ is the year fixed effect, and $TREND_{jt}$ is the time trend in state *j*. Standard errors are clustered at the plant level. Inclusion of plant fixed effects also controls for time-invariant plant-level unobservables that affect the generation

[19] This is the coal consumption per unit electricity produced (kilograms per kilowatt-hour).

[20] This is defined as specific coal consumption × heating value of coal + specific oil consumption × heating value of oil.

[21] Note that percentage of time available, percentage of time unavailable because of forced outages, and percentage of time unavailable because of planned maintenance sum to 100 percent, by definition.

performance of each plant, whereas time dummies control for the nationwide macroeconomic conditions or shocks that may affect electricity generation.[22]

We argue that, by conditioning on plant fixed effects, state time trends, and year dummies, it is appropriate to treat the timing of unbundling as exogenous. We cannot, however, control for state–year shocks. To test whether unbundling could be picking up the effects of state-specific shocks, we run equation (1), including central government–owned power plants, and define an unbundled dummy for these plants = 1 if the state in which the centrally owned plant was located had unbundled in the year in question. We also estimate equation (1) using only centrally owned coal-fired power plants as a falsification test.

Equation (1) estimates the average effect of unbundling reform across all states, including states that unbundled early (e.g., before 2003) and ones that unbundled later. It is, however, likely that the impacts of unbundling take time to occur. To allow for the length of time since unbundling to affect various performance measures, we group states into three categories according to when unbundling occurred. The first group of states—Andhra Pradesh, Delhi, Haryana, Karnataka, Madhya Pradesh, Orissa, Rajasthan, and Uttar Pradesh—had unbundled by 2002; that is, before the Electricity Reform Act of 2003, which required all states to unbundle. The second group of states (Assam, Gujarat, Maharashtra, and West Bengal) unbundled between 2004 and 2007. The last group of states (Bihar, Punjab, Tamil Nadu, Chhattisgarh, and Jharkhand) unbundled only in 2008 or later.

To estimate the impact of duration of treatment (length of time since unbundling) on our performance measures, we interact the unbundled variables with dummy variables that indicate when a state unbundled

$$Y_{ijt} = \theta_{\{i\}} + \tau_{\{t\}} + X_{ijt}\beta + \sum \delta_k UNB_{\{jt\}} * \pi_{kj} + \sum \varphi_j TREND_j + \varepsilon_{ijt} \qquad (2)$$

In equation (2), $\boldsymbol{\delta_k}$ represents the impact of unbundling at time *k* (*k* = unbundled first, unbundled second) relative to not having unbundled within the time frame of our panel. Equation

[22] Aghion et al. (2008) use a similar procedure to estimate the impact of the dismantling of the licensing regime in India on manufacturing output. They take advantage of state and industry variation in industrial policy to estimate a difference-in-differences model of the incidence of delicensing on output. Besley and Burgess (2004) conduct a state-level panel analysis estimating the effect of labor regulation on state output per capita.

(2) is also estimated with central plants added as controls and an unbundling dummy added for central plants.[23]

4.3 Data

Data on the operating characteristics of thermal power plants were obtained from publicly available documents published by CEA.[24] We used these reports to construct an unbalanced panel of 82 thermal power plants, located in 17 states, for the years 1994–2008.[25] The data set includes 59 state-owned and 23 central government–owned plants. The plants in our data set constitute 75 percent of the total installed generation capacity in the country in the year 2007–2008.[26] The dates of establishment of the SERCs and of the unbundling of state utilities were obtained from the websites of the individual SERCs.

Table 3 presents summary statistics on key variables for state and central plants at the beginning (1994–1998) and at the end (2006–2008) of our panel.[27] Variable means are reported, both weighted and unweighted by plant capacity. Central plants are, on average, larger than state plants. Over the years 1994–1998, the average PLF at centrally owned plants was significantly higher than at state plants, although we found no statistically significant difference between central and state plants in average plant availability or in coal consumption per kilowatt-hour.[28] A comparison of operating heat rate between state and central plants is difficult, as data are often missing for plants operated by the National Thermal Power Corporation (NTPC). To put the thermal efficiency of state plants in perspective, the average operating heat rate of state plants in 1994–1998 (2,864 kcal/kWh, capacity-weighted) was 20 percent higher than the average

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[23] Because of the smaller number of central plants (23 plants) we do not distinguish central plants by the time period during which the state in which they were located unbundled.

[24] CEA annually publishes the *Thermal Power Review*, which describes the operating characteristics of all state-operated thermal power plants in India, and provides some data on central government–owned and privately owned plants.

[25] All years in our data set are Indian fiscal years. Thus, 1994 refers to the time period April 1, 1994, through March 30, 1995.

[26] Our data set includes all state-owned plants, but not all privately owned and central government–owned plants.

[27] Central plants are plants operated by the central government, including National Thermal Power Corporation plants.

[28] Means tests are based on unweighted means. Operating heat rate data are frequently missing for central plants; however, operating heat rate does not differ significantly between state and central plants based on reported data.

operating heat rate of subcritical plants in the United States during the period 1960–1980 (Joskow and Schmalensee 1987).

Between 1994 and 2008, both state and central plants improved in reliability (plant availability and PLF) and thermal efficiency; however, the average reduction in coal usage per kilowatt-hour at state-owned plants was not statistically significant, whereas it was at central plants. Table 3 indicates that both sets of plants have experienced large gains in PLFs (an average increase of 16 and percentage points for central and 12 percentage points for state plants, capacity-weighted) and smaller, but significant gains in plant availability (an average increase of 6.4 percentage points for central and 5.8 percentage points for state plants, capacity-weighted).[29] Average coal consumption per kilowatt-hour remained approximately constant for state plants (from 0.78 to 0.77 kg/kWh, capacity-weighted), but decreased at central plants (from 0.73 to 0.70 kg/kWh).[30]

Table 4 presents more detailed information on state-owned plants, grouped by when reforms occurred. In the period between 1994 and 1998, plants in states that unbundled before the Electricity Act of 2003 ("early" states) seemed to be performing slightly worse than those in states that unbundled between 2004 and 2007 ("middle" states). The former had higher time lost due to forced outages, lower availability and higher (worse) operating heat rate and specific coal consumption. The average age[31] of the plants were the similar for both states in terms of age, but the "early" states had higher design heat rates and lower average unit size. By 2006-2008, the states that unbundled early had started out performing the states that were just beginning to unbundle their SEBs. Table 4 shows lower forced outages, higher availability and PLF and much lower (better) heat rate for the "early" states as compared to the "middle" states. It is also interesting to note that there is a significant drop in the average design heat rate of the plants in the "early" states, which implies that at least a part of the gains in average measures of performance are due to an increased in the share of generation from newer and more efficient units.

[29] The unweighted means show much larger gains for central plants than for state plants: 20 percent vs. 10 percent for PLF, and 9 percent vs. 3.3 percent for plant availability.

[30] The changes in unweighted means are 0.79 to 0.71 kg/kWh for central plants and 0.81 to 0.79 kg/kWh for state plants.

[31] The averages referred to are the capacity-weighted averages.

4.4 Trends in Plant Performance and Thermal Efficiency

Before turning to our econometric results, we discuss trends in performance measures and in the thermal efficiency of plants in states that unbundled. Figure 1 shows how plant availability, forced outage, and planned maintenance changed before and after unbundling at state-owned plants in states that unbundled. In Panel A of Figure 1, both plant availability and forced outages show no apparent trends prior to unbundling; however, availability increased and forced outages decreased following unbundling. In contrast, planned maintenance shows no apparent trend prior to unbundling and a downward, but highly volatile pattern, after unbundling.

Panel B indicates that the plants in states that unbundled before 2003 exhibit similar patterns in availability and forced outages following unbundling. Further, the graphs—especially the graphs of availability—also suggest that improvements materialized a few years after unbundling. Because we have, at most, three years of data available for states that unbundled after 2003, we cannot capture improvements that may have occurred in subsequent years. Figure 2, showing corresponding trends at centrally owned power plants, suggests that availability increased and forced outages decreased at centrally owned plants before the states in which they were located unbundled. These trends continued after unbundling, suggesting that unbundling had no effect on centrally owned plants.

The two measures of thermal efficiency pictured in Figure 3 for state-owned plants that unbundled—operating heat rate and auxiliary power consumption—present a mixed picture. Auxiliary power consumption does not appear to have improved following unbundling in either Panel A (which shows results for all power plants) or Panel B, which distinguishes plants by the timing of unbundling. Plants that unbundled before 2003 have experienced lower operating heat rates since unbundling; however, attributing this effect to unbundling requires that we control for state time trends and compare the behavior of plants in states that unbundled with that of plants in states that did not.

5. Results

Our empirical results reflect two sets of comparisons. The basic difference-in-differences specification compares state plants in states that did and did not unbundle. Next, we include central plants as an additional comparison group to estimate a specification similar to a triple difference estimation (difference in difference in differences, DDD. We also report results from an estimation of equation (1) using only central plants as a falsification test because unbundling was designed to affect only state-owned plants.

5.1 Impact of Unbundling on Thermal Efficiency

To examine the impact of unbundling on thermal efficiency, we estimate equations to explain the logarithm of operating heat rate, the deviation of operating heat rate from design heat rate, and the logarithm of coal consumption per kilowatt-hour. At the level of the EGU, the amount of fuel required to produce a kilowatt-hour 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 kilowatt-hour than units with lower design heat rates, and coal with a higher heating value can be burned more efficiently than coal with a lower heating value. 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 the amount of coal required per kilowatt-hour, up to some point. And units with higher PLFs and fewer forced outages will burn less coal because they need to be shut down and started up less often.[32] We control for all of these variables in the coal consumption per kilowatt-hour and operating heat rate equations, and we control for all factors except design heat rate in the equation to explain the deviation of operating from design heat rate.[33]

Table 5 presents least squares estimates of equations (1) and (2) for the three thermal efficiency variables.[34] As expected, thermal efficiency declines with plant age and is higher at plants with larger EGUs. Plants with higher PLFs have lower (better) operating heat rates and lower deviations of operating from design heat rates. The use of coal of lower heating value increases the amount of coal that must be burned to generate a kilowatt-hour of electricity. Operating heat rate increases with the heating value of coal, implying that the reduction (in kilograms) of the amount of coal used does not fully offset the increased heating value of the coal.

In contrast to Figure 3, Table 5 suggests that after controlling for plant characteristics and state-level trends, there is no evidence to support the hypothesis that unbundling improved the thermal efficiency of state-owned power plants. Average treatment effects in models (1)–(3) show no significant impact of unbundling. In models (4)–(6), which distinguish effects by the

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[32] Clearly, PLF and coal consumption are jointly determined but, as noted by Joskow and Schmalensee (1987), PLF is the best proxy for the way a unit is operated to increase thermal efficiency.

[33] Because our models are estimated at the plant level, variables measured at the level of the EGU (such as age) have been aggregated to the plant level by weighting each unit by its nameplate capacity.

[34] Standard errors are clustered at the plant level. Robust *p*-values are reported based on clustered standard errors.

length of time unbundled, we find no impact of unbundling on thermal efficiency for plants in states that unbundled before the Electricity Reform Act of 2003. For plants that unbundled between 2004 and 2007, thermal efficiency actually decreased after unbundling. The states that were in the middle group of reformers include Assam, Gujarat, Maharashtra, and West Bengal. Based on raw data, coal consumption per kilowatt-hour increased in Gujarat, Maharashtra, and West Bengal between 1994 and 2008.[35] These increases persist in Table 5. One possible explanation for these results is the presence of newly installed, unstabilized units, resulting from expansion of capacity in these states.

As a result of missing data on thermal efficiency for centrally owned power plants, we do not present the triple-differences estimations or falsification tests for the models in Table 5. As noted above, data on operating heat rates are often missing for NTPC plants.

5.2 Impact of Unbundling on Other Performance Measures

Table 6 reports least squares estimates of models for other performance measures—plant availability, PLF, forced outage, planned maintenance, and gross consumption of electricity by the plant (gross auxiliary consumption). These models control for plant age, plant age squared, and average unit capacity, as well as state time trends and plant and year fixed effects.

The average treatment effects of unbundling (models [1]–[5]) suggest that unbundling is associated with a small, statistically significant effect on plant availability. Models (6)–(10) suggest that this occurred primarily in the states that unbundled before the Electricity Reform Act of 2003. Model (6) indicates that availability increased, on average, by 4.6 percentage points (400 hours) at plants in those states. Forced outages decreased by 2.9 percentage points (250 hours), although this effect is significant at only the 10 percent level.

The impact of unbundling on plant availability persists when we add central plants as an additional control group in our estimations. The models in Table 7 estimate the average impact of unbundling on state plants, including an unbundling dummy for central plants in the years after the state in which the plant is located unbundled. We expected to see no impact of unbundling on centrally owned plants: a significant coefficient on the unbundled dummy for

[35] Data for Assam are missing after 2004.

central plants suggests that unbundling might be capturing the effect of state–year shocks rather than the effect of restructuring per se.[36]

The impact of unbundling on state plants in early unbundling states is unaffected by the inclusion of central plants in the models. For states that unbundled before 2003, unbundling is associated with 4.2 percentage point increase in plant availability (360 hours) and a 2.8 percentage point decrease in forced outages (models [6] and [8] of Table 7a). In these models, however, unbundling by state plants is associated with a decrease in forced outages at central plants and an increase in planned maintenance (models [8] and [9]).

The apparent impact of unbundling on centrally owned plants is due entirely to the opening of the Talcher STPS plant in Orissa in 1996. This plant, an extremely efficient plant that opened the year in which Orissa unbundled, makes it appear that centrally owned plants became more efficient after unbundling. When the one state-owned and two centrally owned plants in Orissa are dropped from our sample (see Table 7b), unbundling has no statistically significant effect on the performance of centrally owned plants.

Similar results are shown in Tables 8a and 8b, which present equation (1) only for centrally owned plants. The apparent impact of unbundling on the performance of centrally owned plants in Table 8a disappears once plants in Orissa are dropped. We therefore conclude that, as expected, the unbundling of state-owned plants did not affect the efficiency with which central plants were operated.

6. Conclusions

Our results suggest that the unbundling of generation from transmission and distribution at state power plants in India resulted in modest but significant gains in plant availability. These effects are more pronounced among the first group of states to unbundle—that is, states that unbundled between 1996 and 2002. Whether these improvements are due to reductions in time lost due to forced outages is less clear, although such reductions are statistically significant in some models. We find improvements in availability among plants in states that unbundled compared to plants in states that did not unbundle and plants operated by the central government.

[36] Systemic changes due to unbundling in state electricity markets may have indirect effects on the operation of centrally owned power plants. This is something that is an interesting subject for further research, but out of the scope of our current analysis.

The magnitude of increases in plant availability range from 2.8 to 4.7 percentage points (258 to 411 hours per year). We do not find statistically significant improvements in the thermal efficiency of plants in states that unbundled.

Our results are consistent with results obtained by Fabrizio et al. (2007) in a study of the impact of restructuring on generation efficiency in the United States, but differ from those of Sen and Jamasb (2010). Fabrizio et al. (2007) do not find significant impacts of restructuring in the United States on the thermal efficiency of plants, although they do find significant impacts on labor demand. Sen and Jamasb (2010) find that unbundling increased average PLF by 26 percentage points in states that unbundled—an extremely large effect. Raw data plots similar to those in Figures 1–3 show that PLFs increased after unbundling in both state-owned and centrally owned plants; however, these impacts are not statistically significant once we control for time fixed effects and state time trends.

Our failure to find a larger impact from restructuring than reported elsewhere may reflect the path that reform has taken in India thus far. As Bacon and Besant-Jones (2001) emphasize, separating generation from transmission and distribution is likely to be most successful when it is accompanied by tariff reform and when it induces competition in generation. Tariff reform that promotes cost recovery in the electricity sector is needed to make generation profitable. Although tariff reform has begun, in 2006 only 3 of the 10 states that had unbundled were making positive profits (The Energy and Resources Institute 2009, Table 1.80). One way in which unbundling is likely to encourage competition is by encouraging IPPs to enter the market. Such an effect followed the restructuring of the U.S. electricity sector, but has not yet taken hold on a large scale in India.

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Tables and Figures

Table 1. Timeline of Reforms by States under the 1998 and 2003 Electricity Reform Acts

State	SERC operational	SEB unbundled
Andhra Pradesh	1999	1998
Assam	2001	2004
Bihar	2005	[a]
Delhi	1999	2002
Gujarat	1998	2006
Haryana	1998	1998
Karnataka	1999	1999
Madhya Pradesh	1998	2002
Maharashtra	1999	2005
Orissa	1995	1996
Punjab	1999	2010
Rajasthan	2000	2000
Tamil Nadu	1999	2008
Uttar Pradesh	1999	1999
West Bengal	1999	2007
Chattisgarh	2000	[a]
Jharkhand	2003	[a]

[a] Reform not implemented by 2008.

Table 2. Indian Power Sector Regions Prior to Reform

North	East	West	South	Northeast
Delhi	Bihar	Chhattisgarh	Andhra Pradesh	Assam
Haryana	Jharkhand	Gujarat	Karnataka	
Punjab	Orissa	Madhya Pradesh	Tamil Nadu	
Rajasthan	West Bengal	Maharashtra		
Uttar Pradesh				

Table 3. Variable Means, Central and State Plants

	Central				State			
	1994–1998				1994–1998			
Variables	*Obs.*	Mean (wt.)	Mean	Std. dev.	Obs.	Mean (wt.)	Mean	Std. dev.
No. of operating units	93		4.53	2.12	251		4.05	2.18
Net generation[a] (GWh)	92		5,270	4,629	242		2,927	2,679
Derated capacity[a] (MW)	96		922	613	253		601	447
Forced outage (%)	93	10.7	14.3	13.0	251	12.3	13.4	9.95
Planned maintenance[a] (%)	93	8.0	9.6	9.5	251	12.1	13.7	13.0
Availability (%)	93	81.4	76.1	16.2	251	75.7	72.9	17.9
Plant load factor[a] (%)	93	69.0	61.4	21.2	251	59.6	54.5	20.0
Design heat rate (kcal/kWh)	12	2,532	2,520	148	89	2414	2,472	183
Operating heat rate (kcal/kWh)	14	3,133	3,283	496	88	2864	3,106	659
Specific coal cons. (kg/kWh)	76	0.731	0.795	0.359	226	0.779	0.809	0.201
Auxiliary cons.[a] (% gross gen.)	92	7.92	8.33	1.22	242	8.76	9.21	1.32
Net thermal efficiency	14	0.256	0.243	0.037	88	0.282	0.262	0.049
Age	96	11.0	13.2	10.6	253	13.2	15.1	8.28
Average unit capacity[a] (MW)	96	262	219	120	253	175	138	71
	2006–2008				2006–2008			
No. of operating units[a]	64		5.03	2.13	166		4.07	2.20
Net generation[a] (GWh)	64		8,977	6,641	166		3,994	3426
Derated capacity[a] (MW)	65		1,295	843	169		687	494
Forced outage[a] (%)	65	6.7	9.2	16.1	169	10.1	14.2	16.5
Planned maintenance[a] (%)	65	5.6	5.6	3.1	169	8.5	9.7	15.5
Availability[a] (%)	65	87.8	85.1	15.4	169	81.4	76.2	22.6
Plant load factor[a] (%)	65	85.1	81.1	18.1	169	71.5	64.8	24.9
Design heat rate[a] (kcal/kWh)	17	2,523	2,504	140	111	2,357	2,408	179
Operating heat rate[a] (kcal/kWh)	17	3,127	3,159	397	111	2,752	2,878	460
Specific coal cons.[a] (kg/kWh)	55	0.700	0.710	0.067	135	0.773	0.791	0.124
Auxiliary cons.[a] (% gross gen.)	64	6.81	7.59	1.67	166	8.71	9.39	2.09
Net thermal efficiency[a]	17	0.253	0.251	0.030	111	0.291	0.278	0.043
Age[a]	65	15.5	17.8	10.8	169	20.4	22.0	10.8
Average unit capacity[a] (MW)	65	318	263	135	168	187	154	70

Notes: GWh, gigawatt-hours; MW, megawatts.

[a] Significant difference ($p \leq 0.05$) between State and Central according to a two-sample *t*-test with unequal variances.

Table 4. Variables Means, State Plants, by Time of Unbundling

	Early				Middle				Late			
	1994–1998				1994–1998				1994–1998			
	Obs.	Mean (w.)	Mean	Std. dev.	Obs.	Mean (w.)	Mean	Std. dev.	Obs.	Mean (w.)	Mean	Std. dev.
No. of operating units	119		3.88	2.60	85		4.18	1.70	47		4.23	1.72
Net generation (GWh)	113		2,657	2,742	85		3,281	2,715.76	44		2,937	2,411
Derated capacity[a] (MW)	119		531	457	85		686	475.59	49		622	340
Forced outage (%)	119	13.2	13.5	9.68	85	10.7	11.62	6.61	47	13.2	16.4	14.22
Planned maintenance (%)	119	12.0	13.3	12.8	85	10.5	12.8	12.25	47	15.1	16.5	14.6
Availability (%)	119	74.8	73.2	17.5	85	78.7	75.6	15.63	47	71.7	67.1	21.6
Plant load factor (%)	119	61.1	56.4	18.9	85	60.0	54.8	18.29	47	55.6	49.4	24.5
Design heat rate[a, b] (kcal/kWh)	44	2,469	2,521	209	31	2,374	2,430	153.58	14	2,371	2,412	107
Operating heat rate[a] (kcal/kWh)	42	2,969	3,247	683	32	2,763	2,932	543.43	14	2,861	3,079	771
Specific coal cons.[a] (kg/kWh)	99	0.815	0.858	0.262	80	0.736	0.732	0.09	47	0.791	0.837	0.143
Auxiliary cons.[a] (% gross gen.)	113	8.96	9.43	1.32	85	8.61	8.90	0.95	44	8.62	9.22	1.80
Net thermal efficiency[a]	42	0.273	0.251	0.050	32	0.290	0.274	0.04	14	0.283	0.267	0.052
Age[b]	119	13.21	16.17	9.17	85	13.65	14.96	7.22	49	12.32	12.71	7.33
Average unit capacity[a, b] (MW)	119	168	126	76.3	85	187	147.8	65.89	49	166	150	60.1
	2006–2008				2006–2008				2006–2008			
No. of operating units[b]	65		4.46	2.65	58		4.17	1.97	43		3.35	1.53
Net generation (GWh)	65		4,426	3,797	58		4,045	3,433.07	43		3,275	2,705
Derated capacity[b] (MW)	65		747	549	60		705	529.85	44		574	320
Forced outage (%)	65	7.94	12.8	12.81	60	12.3	17.36	20.88	44	10.5	11.7	14.11
Planned maintenance[a, b] (%)	65	7.48	7.94	7.14	60	6.19	5.51	4.30	44	14.4	17.9	27.3
Availability (%)	65	84.6	79.2	15.4	60	81.6	77.1	19.81	44	75.0	70.4	32.4
Plant load factor (%)	65	74.6	66.1	22.7	60	69.0	63.7	20.41	44	69.6	64.1	32.8
Design heat rate (kcal/kWh)	40	2,349	2,403	185	45	2,371	2,438	203.77	26	2,348	2,363	100
Operating heat rate (kcal/kWh)	41	2,717	2,902	631	44	2,840	2,954	309.04	26	2,668	2,710	300
Specific coal cons.[a] (kg/kWh)	57	0.779	0.819	0.127	45	0.776	0.772	0.09	33	0.756	0.770	0.154
Auxiliary cons.[a, b] (% gross gen.)	65	8.87	9.99	2.31	58	8.62	9.17	1.52	43	8.55	8.77	2.23
Net thermal efficiency	41	0.296	0.280	0.055	44	0.279	0.267	0.03	26	0.299	0.294	0.033
Age	65	18.45	21.81	11.25	60	21.54	21.46	11.00	44	22.13	22.96	9.82
Average unit capacity (MW)	65	187	148	76.0	59	196	160	69.5	44	173	156	63.8

Notes: Early (pre-2003): Andhra Pradesh, Haryana, Karnataka, Orissa, Rajasthan, Uttar Pradesh, Delhi, and Madhya Pradesh. Middle (post-2003): Gujarat, Maharashtra, West Bengal, and Assam. Late (out-of-sample): Bihar, Punjab, Tamil Nadu, Chhattisgarh, and Jharkhand. GWh, gigawatt-hours; MW, megawatts.

[a] Significant difference ($p \leq 0.05$) between Middle and Early according to a two-sample *t*-test with unequal variances. [b] Different between Late and Early.

Table 5. Impact of Unbundling on Thermal Efficiency of State-Owned Coal-Fired Power Plants

Variables	(1) Operating heat rate (deviation)	(2) Log (operating heat rate)	(3) Log (specific coal consumption)	(4) Operating heat rate (deviation)	(5) Log (operating heat rate)	(6) Log (specific coal consumption)
Log(design heat rate)		0.397*	0.412*		0.393*	0.407*
		(0.0907)	(0.0611)		(0.0872)	(0.0579)
Log(heating value of coal)	0.449***	0.343***	–0.634***	0.459***	0.350***	–0.626***
	(0.000212)	(5.73e–05)	(3.69e–10)	(0.000157)	(4.01e–05)	(4.62e–10)
Plant age	0.00879	0.00830*	0.0101**	0.00816	0.00789	0.00972**
	(0.174)	(0.0863)	(0.0293)	(0.210)	(0.105)	(0.0373)
Plant age squared	0.000140	9.79e–05	4.88e–05	0.000149	0.000103	5.45e–05
	(0.133)	(0.171)	(0.482)	(0.109)	(0.146)	(0.429)
Average unit capacity	–0.00191*	–0.00157*	–0.00157**	–0.00205*	–0.00167**	–0.00167**
	(0.0933)	(0.0589)	(0.0426)	(0.0740)	(0.0487)	(0.0351)
Forced outage	0.000469	6.68e–05	3.61e–05	0.000431	4.01e–05	8.86e–06
	(0.689)	(0.933)	(0.963)	(0.717)	(0.960)	(0.991)
Plant load factor	–0.00111*	–0.000988**	–0.000562	–0.00105	–0.000950**	–0.000524
	(0.0904)	(0.0419)	(0.206)	(0.105)	(0.0478)	(0.232)
	0.0101	0.0146	0.0201			
Unbundled	(0.545)	(0.249)	(0.104)			
				–0.0173	–0.00378	0.00127
Unbundled before 2003				(0.573)	(0.863)	(0.952)
				0.0452*	0.0381*	0.0441**
Unbundled after 2003				(0.0700)	(0.0557)	(0.0301)
Observations	376	376	376	376	376	376
R-squared	0.942	0.965	0.945	0.943	0.966	0.946

Notes: Robust *p*-values in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. All equations control for year and plant fixed effects and state time trends.

Table 6. Impact of Unbundling on Performance of State-Owned Coal-Fired Power Plants

	(1) Plant availability	(2) Plant load factor	(3) Forced outage	(4) Planned maintenance	(5) Gross auxiliary consumption	(6) Plant availability	(7) Plant load factor	(8) Forced outage	(9) Planned maintenance	(10) Gross auxiliary consumption
Unbundled	2.748*	0.861	−1.563	−1.185	0.157					
	(0.0806)	(0.657)	(0.242)	(0.249)	(0.558)					
Unbundled before 2003						4.588**	3.152	−2.894*	−1.696	0.203
						(0.0149)	(0.160)	(0.0920)	(0.405)	(0.615)
Unbundled after 2003						0.226	−2.279	0.261	−0.484	0.0952
						(0.946)	(0.507)	(0.930)	(0.853)	(0.817)
Observations	786	786	786	786	776	786	786	786	786	776
R-squared	0.801	0.877	0.656	0.518	0.500	0.802	0.878	0.657	0.518	0.500

Notes: Robust *p*-values in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. All equations control for plant age, plant age squared, average capacity, year and plant fixed effects, and state time trends.

Table 7a. Impact of Unbundling on Performance Measures: State-Owned and Centrally Owned Coal-Fired Power Plants

	(1) Plant availability	(2) Plant load factor	(3) Forced outage	(4) Planned maintenance	(5) Gross auxiliary consumption	(6) Plant availability	(7) Plant load factor	(8) Forced outage	(9) Planned maintenance	(10) Gross auxiliary consumption
Unbundled (state plants)	3.261**	–0.185	–1.671	–1.590*	0.361					
	(0.0330)	(0.92)	(0.180)	(0.0807)	(0.135)					
Unbundled before 2003						4.207**	0.550	–2.736*	–1.472	0.454
						(0.0312)	(0.818)	(0.0882)	(0.318)	(0.172)
Unbundled after 2003						1.739	–1.368	0.0415	–1.779	0.212
						(0.562)	(0.676)	(0.988)	(0.354)	(0.583)
Unbundled (central plants)	1.531	3.057	–5.137*	3.606*	–0.0187	2.025	3.441	–5.693*	3.667*	0.0299
	(0.629)	(0.404)	(0.0825)	(0.0839)	(0.932)	(0.511)	(0.330)	(0.0532)	(0.0945)	(0.906)
Observations	1,085	1,085	1,085	1,085	1,074	1,085	1,085	1,085	1,085	1,074
R-squared	0.792	0.870	0.679	0.492	0.549	0.793	0.870	0.679	0.492	0.549

Notes: Robust *p*-values in parentheses. ****p*<0.01, ** *p*<0.05, * *p*<0.1. All equations control for plant age, plant age squared, average capacity, year and plant fixed effects, and state time trends.

Table 7b. Impact of Unbundling on Performance Measures: State-Owned and Centrally Owned Coal-Fired Power Plants (Excluding Orissa)

	(1) Plant availability	(2) Plant load factor	(3) Forced outage	(4) Planned maintenance	(5) Gross auxiliary consumption	(6) Plant availability	(7) Plant load factor	(8) Forced outage	(9) Planned maintenance	(10) Gross auxiliary consumption
Unbundled (state plants)	3.110** (0.0456)	–0.186 (0.925)	–1.424 (0.261)	–1.686* (0.0776)	0.365 (0.145)					
Unbundled before 2003						4.123** (0.0417)	0.795 (0.753)	–2.489 (0.133)	–1.634 (0.299)	0.456 (0.199)
Unbundled after 2003						1.572 (0.602)	–1.676 (0.608)	0.193 (0.943)	–1.764 (0.368)	0.229 (0.553)
Unbundled (central plants)	–0.264 (0.934)	1.178 (0.751)	–3.130 (0.254)	3.394 (0.136)	–0.118 (0.601)	0.290 (0.924)	1.714 (0.631)	–3.713 (0.171)	3.422 (0.152)	–0.0692 (0.796)
Observations	1,044	1,044	1,044	1,044	1,033	1,044	1,044	1,044	1,044	1,033
R-squared	0.794	0.871	0.680	0.494	0.562	0.794	0.872	0.680	0.494	0.562

Notes: Robust *p*-values are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. All equations control for plant age, plant age squared, average capacity, year and plant fixed effects, and state time trends.

Table 8a. Impact of Unbundling on Performance Measures: Centrally Owned Coal-Fired Power Plants

	(1) Plant availability	(2) Plant load factor	(3) Forced outage	(4) Planned maintenance	(5) Gross auxiliary consumption
Unbundled (central plants)	3.379	0.704	–5.033*	1.654	0.542*
	(0.218)	(0.845)	(0.0961)	(0.245)	(0.0923)
Observations	299	299	299	299	298
R-squared	0.795	0.870	0.762	0.347	0.681

Notes: Robust *p*-values are in parentheses. *** *p*<0.01, ** *p*<0.05, * *p*<0.1. All equations control for plant age, plant age squared, average capacity, year and plant fixed effects, and state time trends.

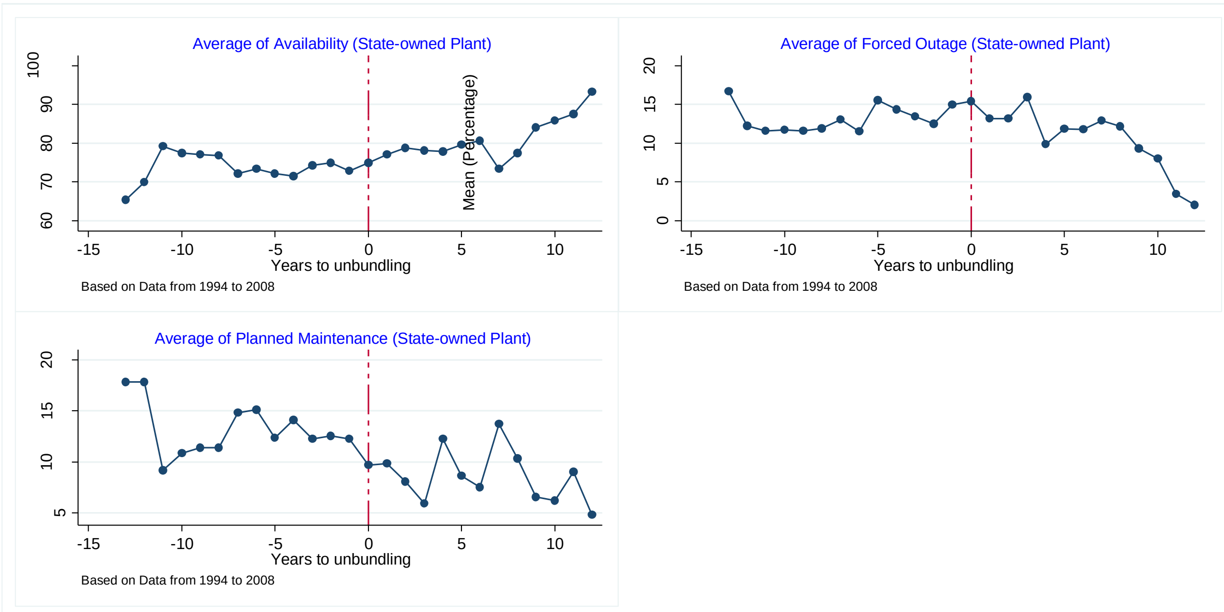
Table 8b. Impact of Unbundling on Performance Measures: Centrally Owned Coal-Fired Power Plants (Excluding Orissa)

	(1) Plant availability	(2) Plant load factor	(3) Forced outage	(4) Planned maintenance	(5) Gross auxiliary consumption
Unbundled (central plants)	1.195	–1.614	–2.293	1.098	0.515
	(0.598)	(0.653)	(0.346)	(0.542)	(0.143)
Observations	272	272	272	272	271
R-squared	0.801	0.865	0.768	0.357	0.671

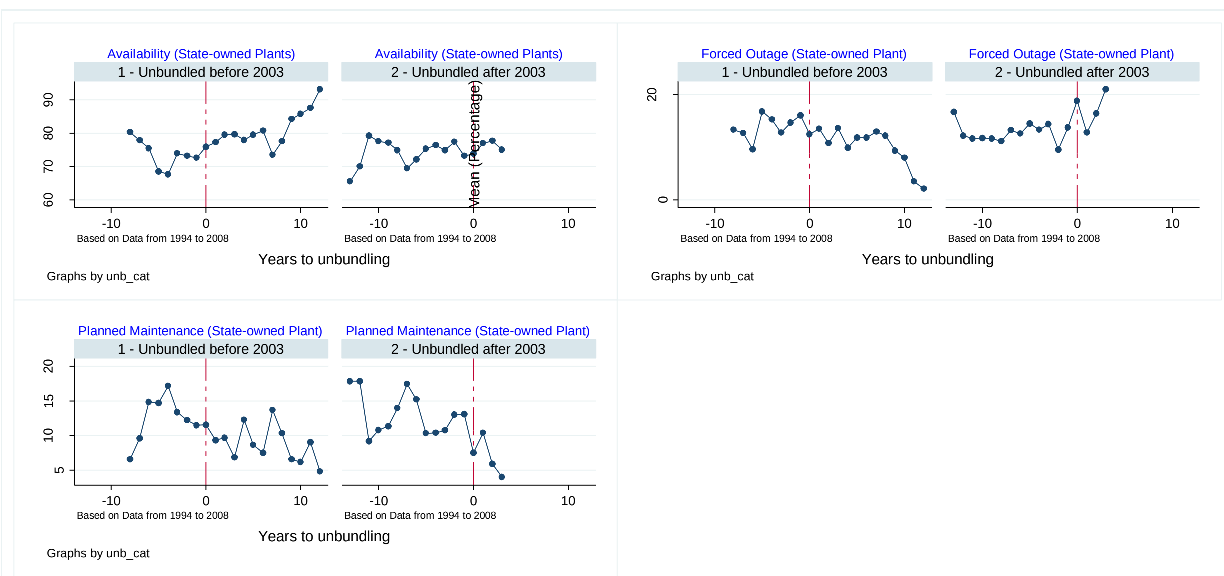
Notes: Robust *p*-values are in parentheses. *** *p*<0.01, ** *p*<0.05, * *p*<0.1. All equations control for plant age, plant age squared, average capacity, year and plant fixed effects, and state time trends.

Figure 1. Trends in Performance Measures at State-Owned Plants in States That Unbundled

Panel A: All States That Unbundled

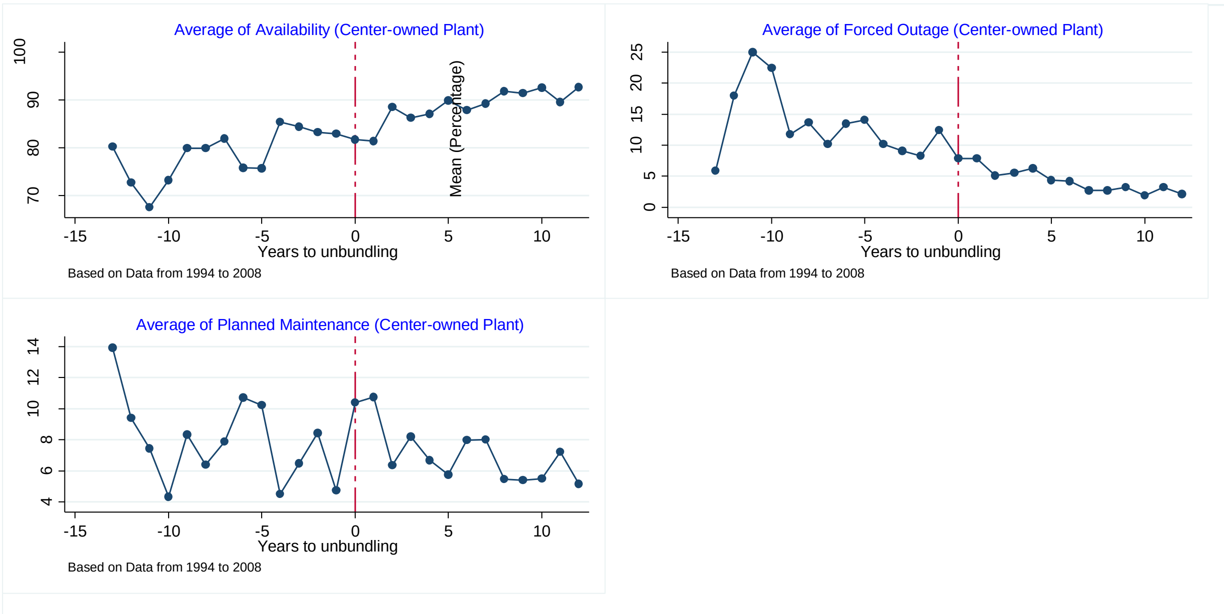


Panel B: States Split by Year of Unbundling (before and after 2003)



Notes: The x-axis has been normalized so that year 0 is the year in which unbundling occurred in each state. States that unbundled before 2003 are Andhra Pradesh, Haryana, Karnataka, Orissa, Rajasthan, Delhi, and Madhya Pradesh. States that unbundled after 2003 (within the sample period) are Gujarat, Maharashtra, West Bengal, and Assam.

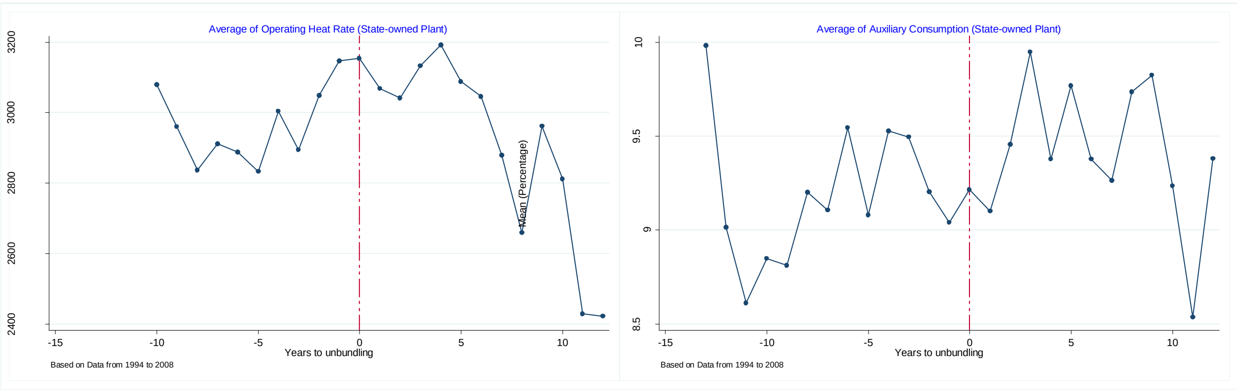
Figure 2. Trends in Performance Measures at Centrally Owned Plants



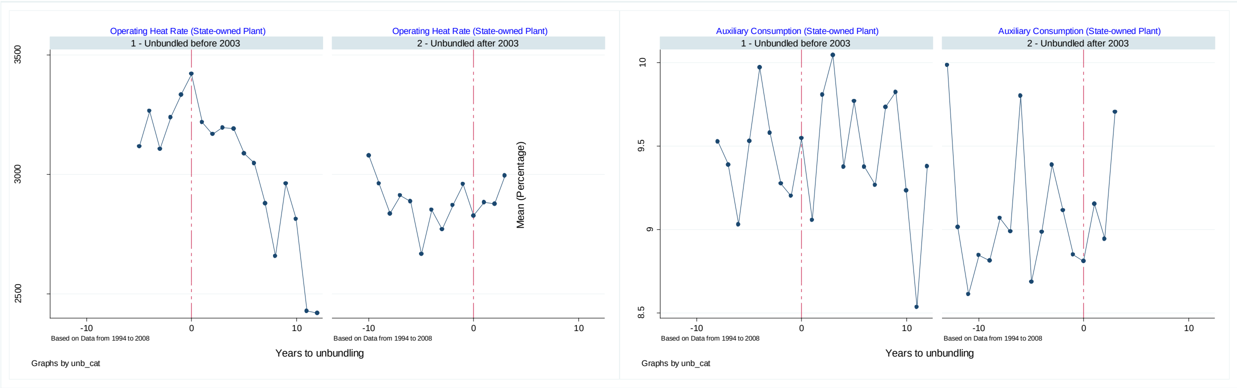
Notes: The x-axis has been normalized so that year 0 is the year in which unbundling occurred in each state.

Figure 3. Trends in Thermal Efficiency at State-Owned Plants in States That Unbundled

Panel A: All States That Unbundled



Panel B: States Split by Year of Unbundling (before and after 2003)



Notes: The x-axis has been normalized so that year 0 is the year in which unbundling occurred. States that unbundled before 2003 are Andhra Pradesh, Haryana, Karnataka, Orissa, Rajasthan, Delhi, and Madhya Pradesh. States that unbundled after 2003 (but within the sample period) are Gujarat, Maharashtra, West Bengal, and Assam.