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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 unbundling of generation from transmission and distribution on the operating efficiency of state-owned thermal power plantsin India. Using information collected by India's Central Electricity Authority we construct a panel dataset 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 same extent as has occurred in the US.

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

1. Introduction

In the decades following independence, the Indian power sector, like the power sector in 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 nationalization of the power sector in 1956, most generating capacity was government-owned.

The first steps towards 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 macro-economic liberalization and privatization agenda. However, it failed to substantially increase private sector entry into electricity generation and, in 1998, 60% of generation capacity and approximately 85% 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 were commonplace and resulted in large operating losses and the inability to invest in maintenance and upgrading of existing infrastructure. Transmission and distribution losses were high—over 30% of electricity produced—and tariffs covered less than 70% of costs. In addition, the lack of transparency and autonomy in operations resulted in inefficiently operated SEB-owned power plants: average thermal efficiency was below 30% and average plant load factor below 55%.The first SEB reform initiative 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 led to the creation of a central (national) electricity regulatory commission – the CERC, and

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

similar regulatory bodies at the state level – the 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 generators. Though there has been 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) distribution companies and taken steps towards tariff restructuring.

Despite more than a decade having passed since the first restructuring reforms, there has been no comprehensive study of their impacts on the plants targeted by the reform 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 examine how far individual plants (or generating units) are from the production frontier (Knittel 2002, Shanmugam and Kulshreshtha 2005, Singh 1991), or, they examine variation across plants in various performance measures, such as operating heat rate (energy used per kWh) and plant availability (percent of the time that the plant is available to generate electricity) (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 kWh of electricity—and by deviation of operating from design heat rate. Plant reliability is measured by the percent 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 responsiveness to price incentives and greater efficiency of resource allocation within a plant. Finally, unbundling thermal power plants may improve efficiency by reducing dis-economies of scope—managers can now 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 dataset 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 generating units in the plant, as well as state-level time trends, and plant and year fixed effects.

The results from these models suggest that unbundling significantly improved average annual plant availability and reduced forced outages in state-owned plants across India. Unbundling appears, on average, to have had little impact on operating heat rate. The magnitude of these impacts, however, varies significantly across states.The biggest improvements following unbundling have occurred primarily in the states in that were among the first to unbundle, i.e., those states that unbundled generation from transmission and distribution before the Electricity Reform Act of 2003. On average, plant availability increased by approximately 400 hours a 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 over 75% of the electricity generated in India. Ninety percent of the coal-fired generating units in India are sub-critical, with a maximum thermal efficiency of 35-38%. In 1998 the average thermal efficiency of these plants was below 30%, due in part to technical factors—the high ash and low heat content of Indian coal—and in part to inefficiencies in management. The use of coal with low heat content or high ash content raises the heat input needed to produce electricity. The heat content of coal used in Indian plants in 1990 averaged 4,000 kcal/kg, down from 6,000 kcal/kg in 1960, with ash content between 25 and 45% (Khanna and Zilberman 1999). This was domestic coal, transported from mines in central and east India. Imports of coal with a higher heat and lower ash content were effectively prohibited by high tariffs (the tariff on imported coal in 1993 was 85%). Facilities to wash coal to reduce its ash content were not widely available in the early 1990s.

In 1990, 63% of thermal generating capacity was owned by State Electricity Boards (SEBs).[2] 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. 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 had 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 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, independent power producers were allowed to invest in generating capacity. They were guaranteed a fair rate of return on their investment, with tariffs regulated by the Central Electricity Authority. The Electricity Regulatory Commissions Act of 1998 made it possible for the states to create state electricity regulatory commissions 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

[2]Thirty-three percent of capacity was owned by the central government and 4 percent by private companies. In2006, 51% of thermal generating capacity was owned by SEBs, 37% by the central government and 12% by private companies (CEA 2007).

distribution losses, and other benefits. The Electricity Act of 2003 made the establishment of state electricity regulatory commissions (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.[3]

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 guidelines of the Central Electricity Regulatory Commission (CERC) 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. In addition, an Availability Based Tariff 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%. Beginning in 2001, the use of coal with ash content exceeding 34 per cent was prohibited in any thermal power plant located more than 1000 km from the pithead, or in urban or sensitive or critically polluted areas. The question is what impact these reforms, together with the reforms under the Electricity Regulatory Commissions Act of 1998 and the Electricity Act of 2003, have had on power plant performance.

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

3. Literature Review

3.1 Studies ofthe Productive Efficiency of Thermal Power Plants

There is a large literature measuring the productive efficiency of thermal power plants.[4] 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 (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).[5]

Other studies focus on the thermal efficiency of the plant—the amount of fuel used to produce a kWh of electricity[6]—and other measures of how efficiently a plant is operated. The latter include auxiliary consumption—the amount of electricity used for plant operations (i.e., the difference between gross and net generation), the percent of time that a plant is available for use (plant availability), or the percent of time the plant is actually generating electricity (plant load factor). Variation in these measures across plants is often explainedas 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 from 1986-87 to estimate the technical efficiency of state-owned coal-fired power plants. The range of technical efficiency across plants is wide, varying from 0.40 to 1.00. When plants are grouped by power sector region (see Table

[4] Our review focuses on measures of productive, as opposed to allocative, efficiency.
[5] 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).
[6] Operating heat rate is defined as the fuel input (in kcal or btu) per kWh of electricity produced. Thermal efficiency is proportional to the power output of the plant, divided by the heating value of the fuel.

2), plants in the South are, on average, more efficient than plants in other regions; however, the importance of region disappears in a multiple regression.[7] Plants with higher load factors 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 technical efficiency of 56 coal-based power plants for the period 1994-2001. Using panel data methods, they test whether technical efficiency parameters changed during the period of their analysis.Their results suggest that technical efficiency levels did not vary during this period; however, there is considerable variation in technical efficiency across plants (from 0.96 to 0.46). When technical efficiency is regressed on plant age and region dummies, technical efficiency decreases with age and is lower for plants located in the North than in other power regions.

Khanna and Zilberman (1999) use data (1987-88 to 1990-91) for 63 coal-fired power plants to analyze the contribution of regulatory and technical factors to plant efficiency. They measure efficiency by the heat input required to produce a net kWh 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 plant load factor. Khanna and Zilberman find that energy efficiency increased with the use of coal with higher heat content and was lower at plants operated by State Electricity Boards 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

[7] Singh regresses measures of technical efficiency from two linear programming approaches on region dummies, plant load factor and plant size (MW of installed capacity).

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 use washed coal, and 18 percent, imported coal. These proportions change to 52 percent and 34 percent when the tariff on imported coal is reduced to zero. Since 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 OECD countries and over 70 developing countries have taken steps to reform their electricity sectors (Bacon and Besant-Jones 2001; Khanna and Rao 2009). There is a large literature using cross-country data that examines 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 use either stochastic frontier or DEA methods. Jamasb et al. (2005) summarize and critique four such studies in developing countries.[8] In the US, Knittel (2002) and Hiebert (2002) have used 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.[9] He finds greater production efficiency for plants that operate under

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

[9] 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.

programs that provide direct incentives for increased efficiency by compensating generators based on heat-rate and plant availability (v. 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 US data for the period 1988-97. 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 introduced unbundling of 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 non-fuel input use as compared to similar utilities in non-restructuring states and cooperatively or publicly owned generators that were insulated from the reforms. Due to the nature of the restructuring process in the United States, their restructuring measure combines the effect of unbundling of generation from transmission and distribution withopening 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 7 states during the period of analysis.

Although the literature examining the impact of reforms in the Indian electricity 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 plant load factor (PLF), gross generation and transmission and distribution losses.[10] Specifically, they explain the three performance measures as functions of six regulatory dummy variables and state and year fixed effects.[11] They find that the unbundling and tariff order dummy variables show a strong positive effect on PLF as does the ratio ofindustrial to agricultural electricity prices. They also find that the State Electricity Regulatory Commission (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.

4. Methodology and Questions Addressed

4.1 Questions Addressed

Our goal is to estimate the impact of unbundling of generation, transmission and distribution services on generation efficiency at state-owned power plants. Unbundling entails corporatizing the sector, which should promote greater autonomy and accountability and increase the efficiency with which plants are run. We ask whether this increased the availability of plants (e.g., by improving plant maintenance) and also reduced operating heat rate (e.g., by increasing imports of high-quality coal). It is also of interest to know whether the effects of unbundling are affected by the amount of time that has elapsed since unbundling.

[10] 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.

[11] 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.

We expect that unbundling of the SEB would increase the transparency and independence in the functioning of each newly created entity. Generation efficiency is likely to increase as plants will not need to reduce production in response to frequent load variations in transmission or distribution networks.[12] Delinking generation from distribution is also likely to improve the financial situation of generating plants. This would likely lead to an increased investment in maintenance and upgrades of equipment, resulting in better operating efficiency. In addition, a vertically integrated SEB may suffer from diseconomies of scope: managerial decisions require considering factors affecting the system as a whole. In contrast, an unbundled generation company would reduce the scope of managerial decisions and therefore allow focus on efficient generation.

We use two sets of variables to measure the performance of generating plants. The first set measures the thermal efficiency of a plant—the heat input required to produce a kWh of electricity. We measure this using operating heat rate (kcal of oil and coal per kWh) and also the deviation of operating heat rate from design heat rate.We also use coal consumption in kg per kWh.[13] The second set of performance measures includes the percent of time a plant is available to generate electricity (plant availability) and the percent of time a plant is used to generate electricity (plant load factor). In addition to measuring plant availability, we measure the percent of time a plant is unavailable for use due to forced outages and the percent of time it is unavailable due to planned maintenance.[14] A final measure of plant efficiency is auxiliary electricity consumption—the percent of gross generation consumed by the plant itself.

4.1 Models Estimated

The variation across states in the timing of the reforms allows us to estimate their impact on the performance of thermal power generators using difference-in-differences methods. To estimate the average effect of the state-level unbundling reform variable on generating plant

[12] 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.

[13] This differs from operating heat rate, defined as coal consumption*heating value of coal + oil consumption*heating value of oil.

[14] Note that percentage of time available, percentage of time unavailable due to force outages and percentage of time unavailable due to planned maintenance sum to 100 percent, by definition.

efficiency, weuse a panel difference-in-differences modelwith year and plant-level fixed effects, as well as state time trends. The average treatment model takes the following form:

$$\boldsymbol{Y_{ijt}} = \boldsymbol{\theta}_{\{i\}} + \boldsymbol{\tau}_{\{t\}} + \boldsymbol{X_{ijt}\beta} + \boldsymbol{\gamma}\ \boldsymbol{UNB}_{\{jt\}} + \sum \boldsymbol{\varphi_j TREND_{jt}} + \boldsymbol{\varepsilon_{ijt}} \quad (1)$$

where, $\boldsymbol{Y_{ijt}}$ is the plant level performance measure for plant *i* in state *j* at time *t*. $\boldsymbol{X_{ijt}}$ is a vector of plant level control variables that measure equipment characteristics (e.g., age, capacity). $\boldsymbol{UNB}_{\{jt\}}$ is the unbundling dummy that takes a value of 1 starting in the year after state *j* unbundles its SEB, $\boldsymbol{\theta}_{\{i\}}$ is the plant-level fixed effect, $\boldsymbol{\tau}_{\{t\}}$ is the year fixed effect and $\boldsymbol{TREND_{jt}}$ 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 performance of each plant while time dummies control for the nation-wide macro-economic conditions or shocks that may affect electricity generation.[15]

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 center-owned plant was located had unbundled in the year in question. We also estimate equation (1) using only center-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 the year 2002; i.e.,before the Electricity Reform Act of 2003 which required all states to

[15]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/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.

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 dummyvariables that indicate when a state unbundled,

$$\boldsymbol{Y_{ijt}} = \boldsymbol{\theta}_{\{i\}} + \boldsymbol{\tau}_{\{t\}} + \boldsymbol{X_{ijt}\beta} + \sum \boldsymbol{\delta_k UNB}_{\{jt\}} * \boldsymbol{\pi_{kj}} + \sum \boldsymbol{\varphi_j TREND_j} + \boldsymbol{\varepsilon_{ijt}}. \qquad (2)$$

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 timeframe of our panel. Equation (2) is also estimated with central plants added as controls and an unbundling dummy added for central plants.[16]

4.3 Data

Data on the operating characteristics of thermal power plants were obtainedfrom publicly available documents published by the Central Electricity Authority of India (CEA).[17] We used these reports to construct an unbalanced panel of 82 thermal power plants, located in 17 states, for the years 1994-2008.[18] The dataset includes 59 state-owned and 23 central-government-owned plants. The plants in our dataset constitute75 per cent of the total installed generation capacity in the country in the year 2007-08.[19] 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 center-owned plants at the beginning (1994-98) and at the end of our panel (2006-08).[20] Variable means are reported

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[16] Due to 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.

[17] The 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.

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

[19] Our dataset includes all state-owned plants, but not all private and central government owned plants.

[20] Central plants are plants operated by the central government, including National Thermal Power Corporation (NTPC) plants.

both weighted and unweighted by plant capacity. Central plants are, on average, larger than state plants. Over the years 1994-98, the average plant load factor at center-owned plants was significantly higher than at state plants, although there is no statistically significant difference in average plant availability or in coal consumption per kWh.[21] Comparison of operating heat rate between state and center 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 1994-98 (2864 kcal/kWh, capacity weighted) was 20% higher than the average operating heat rate of subcritical plants in the US during the period 1960-1980 (Joskow and Schmalensee 1987).

Between 1994 and 2008 both state and central plants improved in reliability (plant availability and plant load factor) and thermal efficiency; however, the average reduction in coal usage per kWh at state-owned plants was not statistically significant, whereas it was at central plants. Table 3 indicates that both sets of plants have experience large gains in plant load factors (an average increase of 16 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).[22]Average coal consumption per kWh remained approximately constant for state plants (from 0.78 to 0.77 kg/kWh, capacity-weighted) while decreasing at central plants (from 0.73 to 0.70 kg/kWh).[23]

Table 4 presents more detailed information on state-owned plants, grouped by when reforms occurred. Plants that unbundled before the Electricity Act of 2003 are not significantly different from states that unbundled between 2004 and 2007 in terms of plant availability and plant load factor during the 1994-98 period. They are, however, less thermally efficient than plants that unbundled later, both in terms of coal consumption per kWh and operating heat rate. Plants in states that unbundled first have (on average) significantly greater availability and load

[21] 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.
[22] The unweighted means show much larger gains for central plants than for state plants: 20 percentage points v. 10 points for plant load factor and 9 v. 3.3 points for plant availability.
[23] 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.

factors than plants in states that unbundled in 2008 or later. There is, however, no significant difference in operating heat rates or coal consumption per kWh between the two sets of plants.

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 also suggest that improvements materialize a few years after unbundling (especially the graphs for availability). Since we have, at most, 3 years of data available for states that unbundled after 2003 we cannot capture improvements that may occur in subsequent years. Figure 2, showing corresponding trends at center-owned power plants, suggests that availability increased and forced outages decreased at center-owned plants before the states in which they were located unbundled. These trends continued after unbundling, suggesting that unbundling had no effect on center-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 when unbundling occurred. 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 plants in states than did not.

5. Results

Our empirical results reflect two sets of comparisons: First, we compare state plants in states that unbundled with state plants in states that did not unbundle (equations (1) and (2)). Second, we compare state plants in states that unbundled with state plants in states that did not unbundle *and* with central plants. In the second case a dummy variable is included if a central plant is located in an unbundled state. We also estimate equation (1) using data for only central plants as a falsification test, since 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 kWh. At the generating unit level the amount of fuel 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 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 coal required per kWh, up to some point. Also, 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.[24] We control for all of these variables in the coal consumption per kWh and operating heat rate equations, and control for all factors except design heat rate in the equation to explain the deviation of operating from design heat rate.[25]

Table 5 presents least squares estimates of equations (1) and (2) for the three thermal efficiency variables.[26] As expected, thermal efficiency declines with plant age and is higher at

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

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

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

plants with larger generating units. Plants with higher load factors have lower operating heat rates and lower deviations of operating from design heat rate. Coal of lower heating value increases the amount of coal burned to generate a kWh of electricity. Operating heat rate increases with the heating value of coal, implying that the reduction in kg of coal used does not fully offset the increased heating value of the coal.

In contrast to Figure 3, Table 5 suggests that unbundling did not improve the thermal efficiency of power plants. Average treatment effects in models (1) – (3) show no significant impact of unbundling. In models (4) – (6), which distinguish effects by length of time unbundled, there is 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 kWh increased in Gujarat, Maharashtra and West Bengal between 1994 and 2008.[27] These increases persist in Table 5. One possible explanation for these results is the presence of newly installed, unstabilized units, due to expansion of capacity in these states.

Due to missing data on thermal efficiency for center-owned power plants, we do not present falsification tests for the models in Table 5. As noted above, data on operating heat rate 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, plant load factor, 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

[27] Data for Assam are missing after 2004.

Act of 2003. Model (6) indicates that availability increased, on average, by 4.6 percentage points (400 hours) at plants in those states. Forced outage 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 state plants are compared with central plants, as well as with state plants that did not unbundle during our panel. The models in Table 7 estimate the average impact of unbundling on state plants, including an unbundling dummy for center plants in years after the state in which the plant is located unbundled. We expect to see no impact of unbundling on center-owned plants: A significant coefficient on the unbundled dummy for center plants suggests that unbundling might be capturing the effect of state-year shocks rather than the effect of restructuring per se[28].

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

Similar results occur in Tables 8a and 8b, which present equation (1) for only center-owned plants. The apparent impact of unbundling on the performance of center-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.

[28] It is possible that there are indirect effects of systemic changes due to unbundling in state electricity markets on the operation of center-owned power plants. This is something we leave for future research.

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—i.e., states that unbundled between 1996 and 2002. Whether these improvement are due to reductions in forced outages is less clear, although reductions in forced outage are statistically significant in some models. We find improvements in availability when we compare plants in states that unbundled with plants in states that did not unbundle, and also when we compare them to plants operated by the central government. 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 U.S., but differ from those of Sen and Jamasb (2010). Fabrizio et al. (2007) do not find significant impacts of restructuring in the U.S. on the thermal efficiency of plants, although they do find significant impacts on labor demand. Sen and Jamasb (2010) find that unbundling increased average plant load factors by 26 percentage points in states that unbundled—an extremely large effect. Raw data plots similar to those in Figures 1-3 show that plant load factors increased after unbundling at both state and center-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 above 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 in order to make generation profitable. Although tariff reform has begun, in 2006 only 3 of the 10 states that had unbundled before this date were making positive profits (TERI 2009, Table 1.80). One way in which unbundling is likely to encourage competition is by encouraging independent power producers to enter the market. This followed restructuring of the electricity sector in the U.S., but has not yet taken hold on a large scale in India.

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

	SERC operational	SEB unbundled
ANDHRA PRADESH	1999	1998
ASSAM	2001	2004
BIHAR	2005	*
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	*
JHARKHAND	2003	*

*Reform not implemented by 2008

Table 2: Indian Power Sector Regions Prior to Reform

NORTH	EAST	WEST	SOUTH	NORTH-EAST
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, Center and State Plants

	CENTER				STATE			
	1994-1998				1994-1998			
	N	Mean (w.)	Mean	Std. dev.	Obs.	Mean (w.)	Mean	Std. dev.
# of operating units	93		4.53	2.12	251		4.05	2.18
net generation* (GWH)	92		5270	4629	242		2927	2679
derated capacity *(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* (%)	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* (%)	93	69.0	61.4	21.2	251	59.6	54.5	20.0
design heat rate (KCal/KWH)	12	2532	2520	148	89	2414	2472	183
operating heat rate (KCal/KWH)	14	3133	3283	496	88	2864	3106	659
specific coal cons. (Kg/KWH)	76	0.731	0.795	0.359	226	0.779	0.809	0.201
aux. cons.* (% 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* (MW)	96	262	219	120	253	175	138	71
	2006-2008				2006-2008			
# of operating units*	64		5.03	2.13	166		4.07	2.20
net generation* (GWH)	64		8977	6641	166		3994	3426
derated capacity* (MW)	65		1295	843	169		687	494
forced outage* (%)	65	6.7	9.2	16.1	169	10.1	14.2	16.5
planned maintenance* (%)	65	5.6	5.6	3.1	169	8.5	9.7	15.5
availability* (%)	65	87.8	85.1	15.4	169	81.4	76.2	22.6
plant load factor* (%)	65	85.1	81.1	18.1	169	71.5	64.8	24.9
design heat rate* (KCal/KWH)	17	2523	2504	140	111	2357	2408	179
operating heat rate* (KCal/KWH)	17	3127	3159	397	111	2752	2878	460
specific coal cons.* (Kg/KWH)	55	0.700	0.710	0.067	135	0.773	0.791	0.124
aux. cons.* (% gross gen.)	64	6.81	7.59	1.67	166	8.71	9.39	2.09
net thermal efficiency*	17	0.253	0.251	0.030	111	0.291	0.278	0.043
age*	65	15.5	17.8	10.8	169	20.4	22.0	10.8
average unit capacity* (MW)	65	318	263	135	168	187	154	70

* different at the 5% level between STATE and CENTER according to a two-sample t-test w. 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.
# of operating units	119		3.88	2.60	85		4.18	1.70	47		4.23	1.72
net generation (GWH)	113		2657	2742	85		3281	2715.76	44		2937	2411
derated capacity* (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*^ (KCal/KWH)	44	2469	2521	209	31	2374	2430	153.58	14	2371	2412	107
operating heat rate* (KCal/KWH)	42	2969	3247	683	32	2763	2932	543.43	14	2861	3079	771
specific coal cons.* (Kg/KWH)	99	0.815	0.858	0.262	80	0.736	0.732	0.09	47	0.791	0.837	0.143
aux. cons.* (% 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*	42	0.273	0.251	0.050	32	0.290	0.274	0.04	14	0.283	0.267	0.052
age^	119	13.21	16.17	9.17	85	13.65	14.96	7.22	49	12.32	12.71	7.33
average unit capacity*^ (MW)	119	168	126	76.3	85	187	147.8	65.89	49	166	150	60.1
	2006-2008				2006-2008				2006-2008			
# of operating units^	65		4.46	2.65	58		4.17	1.97	43		3.35	1.53
net generation (GWH)	65		4426	3797	58		4045	3433.07	43		3275	2705
derated capacity^ (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*^ (%)	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	2349	2403	185	45	2371	2438	203.77	26	2348	2363	100
operating heat rate (KCal/KWH)	41	2717	2902	631	44	2840	2954	309.04	26	2668	2710	300
specific coal cons.* (Kg/KWH)	57	0.779	0.819	0.127	45	0.776	0.772	0.09	33	0.756	0.770	0.154
aux. cons.*^ (% 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

* different at the 5% level between MIDDLE and EARLY according to a two-sample t-test w. unequal variances; ^ different between LATE and EARLY

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, CHATTISGARH and JHARKHAND

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)
Unbundled	0.0101	0.0146	0.0201			
	(0.545)	(0.249)	(0.104)			
Unbundled before 2003				-0.0173	-0.00378	0.00127
				(0.573)	(0.863)	(0.952)
Unbundled after 2003				0.0452*	0.0381*	0.0441**
				(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

Robust pval 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

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 and Center 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	3.261**	-0.185	-1.671	-1.590*	0.361					
(State plants)	(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	1.531	3.057	-5.137*	3.606*	-0.0187	2.025	3.441	-5.693*	3.667*	0.0299
(Center plants)	(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

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 and Center Owned Coal-fired Power Plants (w/o 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	3.110**	-0.186	-1.424	-1.686*	0.365					
(State plants)	(0.0456)	(0.925)	(0.261)	(0.0776)	(0.145)					
Unbundled						4.123**	0.795	-2.489	-1.634	0.456
before 2003						(0.0417)	(0.753)	(0.133)	(0.299)	(0.199)
Unbundled						1.572	-1.676	0.193	-1.764	0.229
after 2003						(0.602)	(0.608)	(0.943)	(0.368)	(0.553)
Unbundled	-0.264	1.178	-3.130	3.394	-0.118	0.290	1.714	-3.713	3.422	-0.0692
(Center plants)	(0.934)	(0.751)	(0.254)	(0.136)	(0.601)	(0.924)	(0.631)	(0.171)	(0.152)	(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

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 8a:Impact of Unbundling on Performance Measures: Center Owned Coal-fired Power Plants

	(1) Plant Availability	(2) Plant Load Factor	(3) Forced Outage	(4) Planned Maintenance	(5) Gross Auxiliary Consumption
Unbundled (Center 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

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 8b:Impact of Unbundling on Performance Measures: Center Owned Coal-fired Power Plants (w/o Orissa)

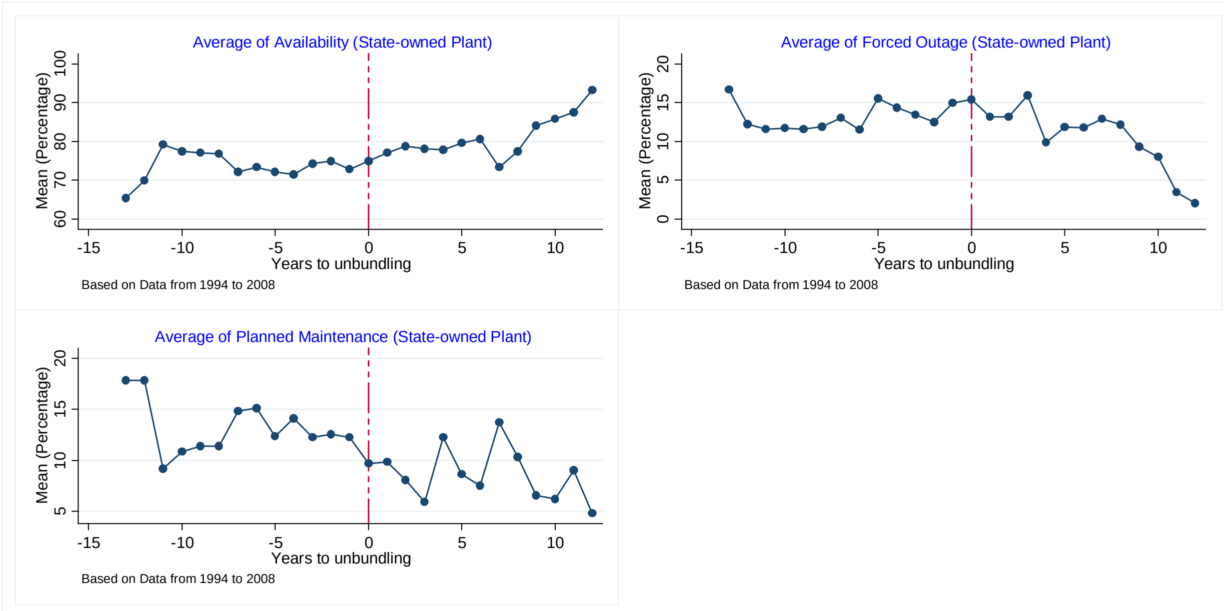
	(1) Plant Availability	(2) Plant Load Factor	(3) Forced Outage	(4) Planned Maintenance	(5) Gross Auxiliary Consumption
Unbundled (Center plants)	1.195	-1.614	-2.293	1.098	0.515
	(0.598)	(0.653)	(0.346)	(0.542)	(0.143)
Observations	272	272	272	272	271
R-squared	0.801	0.865	0.768	0.357	0.671

Robust p-values in parentheses; *** p<0.01, ** p<0.05, * p<0.1

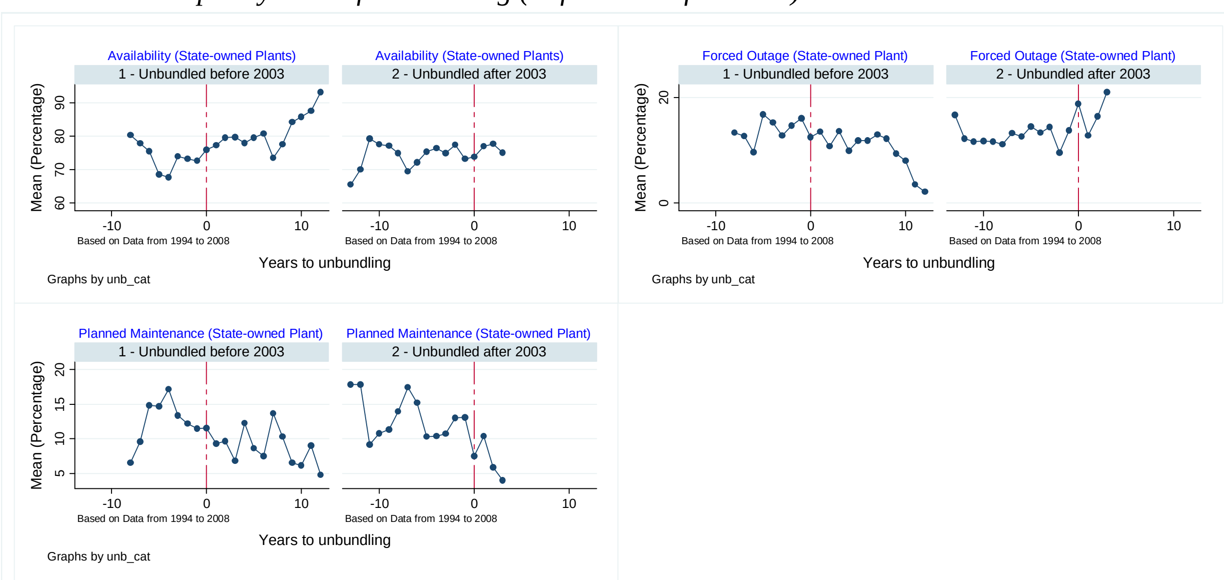
All equations control for plant age, plant age squared, average capacity, year and plant fixed effects and state time trends.

Figure 1: Trends in Performance Measures at State-Owned Plants in States that Unbundled

Panel A: All States that unbundled



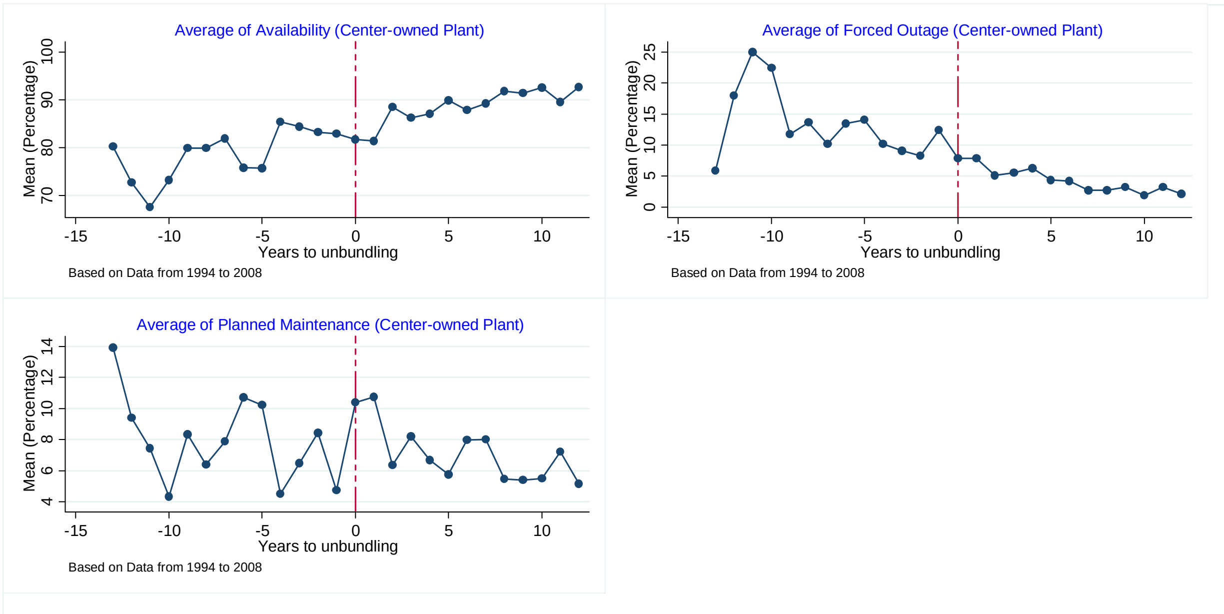
Panel B: States Split by Year of Unbundling (Before and After 2003)



Notes:

1. The X-axis represents year that have been normalized around the year in which unbundling law was enacted in that particular state.
2. 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 Center-Owned Plants

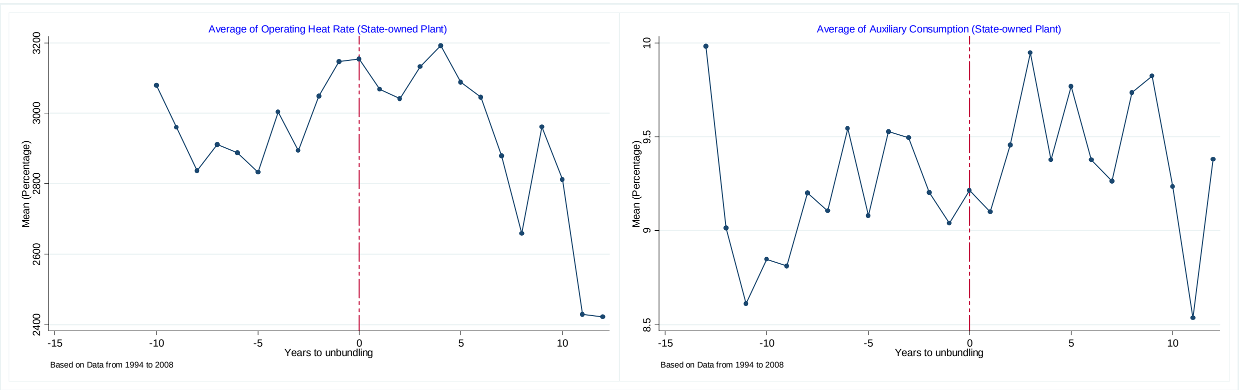


Notes:

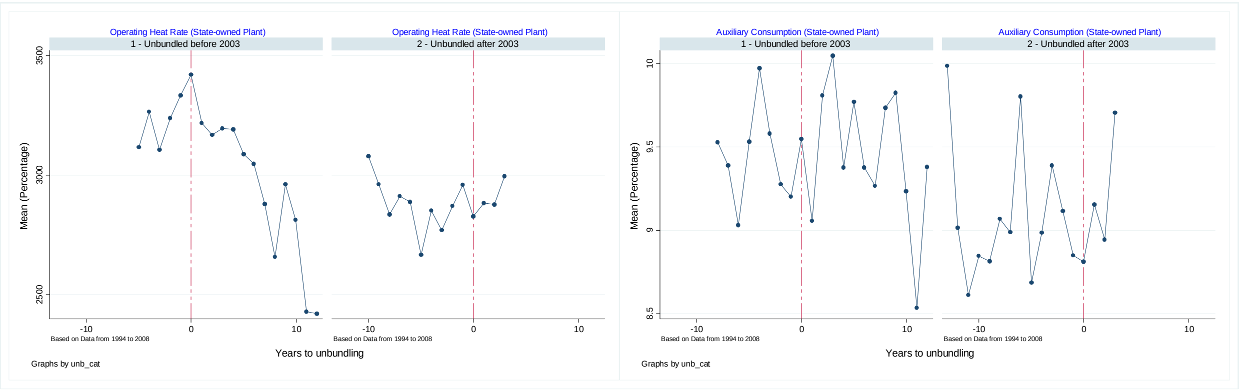
1. The X-axis has been normalized so that year 0 is the year in which unbundling occurred in each state.

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:

1. The X-axis has been normalized so that year 0 is the year in which unbundling occurred.
2. 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.