The Impact of Electricity Sector Restructuring on Coal-fired Power Plants in India

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February 2013

Abstract

We examine the impact of electricity sector restructuring on the operating efficiency of coal-fired power plants in India. Between 1995 and 2009, 85 percent of coal-based generation capacity owned by state governments was unbundled from vertically integrated State Electricity Boards into state generating companies. We find that generating units in states that unbundled before the Electricity Act of 2003 experienced reductions in forced outages of about 25% and improvements in availability of about 10%, with the largest results occurring 3-5 years after restructuring. We find no evidence of improvements in thermal efficiency at state-owned power plants due to reform.

JEL O13, O25, Q4, L25, L43, L94, L98
Key Words: Indian power sector, electricity sector restructuring

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Acknowledgements: This research was supported by grants from the World Bank and Resources for the Future.

1 Introduction

During the past 30 years, over two dozen countries, including the US, have attempted to reform their electricity sectors. Vertically integrated monopolies have been broken into companies that generate electricity and those that distribute it, in an attempt to attract independent power producers into the industry and promote competition. Cost-of-service regulation has been replaced by incentive-based regulation and, in some cases, by competitive wholesale power markets. The ultimate goal of these reforms is to improve both technical and allocative efficiency in electricity generation and to pass these savings onto consumers.

This paper examines the impact of electricity sector restructuring on the operating efficiency of thermal power plants in India. Between 1996 and 2009, 85 percent of the coal-based generation capacity owned by state governments was unbundled from vertically-integrated State Electricity Boards (SEBs) into newly created state generation companies. The restructuring sought to expand generation capacity and reduce costs by encouraging the entry of independent power producers and by "corporatizing" unbundled generation companies. Although government owned, these companies were granted formal autonomy in technical, financial and managerial decisions. We examine whether greater managerial discretion and specialization in generation increased operating reliability and thermal efficiency at unbundled power plants.

A growing literature has documented the impacts of restructuring on the performance of power plants in the United States.[1] Fabrizio et al. (2007) find that,

[1]A related empirical literature evaluates the impact of reforms on plant dispatch order (Douglas 2006) and competitive behavior in wholesale power markets (Borentstein, Bushnell,and Wolak 2002; and Hortacsu, and Puller 2011).

in the short term, the restructuring did not improve technical efficiency at thermal power plants, but did reduce expenditure per kWh on non-fuel inputs. Knittel (2002) suggests that power plants facing compensation schemes with performance incentives were more efficient than plants compensated on a traditional cost-plus basis. Davis and Wolfram (2012) find that the selling of nuclear reactors to independent power producers led to a decrease in forced outages at nuclear power plants and a corresponding increase in electricity production.

To investigate the impact of reforms in the Indian electricity sector we construct a panel data set of coal-based electricity generating units (EGUs) for the years 1988–2009. The variation in the timing of reforms across states allows us to estimate the impact of unbundling on EGU reliability and plant thermal efficiency. Our difference-in-difference specification assumes that conditional on control variables—EGU/plant characteristics, EGU and year fixed effects, and state-specific linear time trends—the assignment of the timing of reforms (including not to reform) is exogenous. Under this assumption, these models identify the effect of reforms from a comparison of the performance of plants in states that unbundled with plants in states that had not yet unbundled.

To eliminate the possibility of state-year shocks affecting our estimates of average treatment effects, we also present results from a triple-difference specification that uses EGUs operated by central government owned generation companies as an additional control group. These companies operate outside the purview of state governments and thus were not directly affected by the reorganization of the SEBs.

Our results suggest that the gains from unbundling of generation from transmission and distribution were limited to the states that reformed before the Electricity Act of 2003. In these states, on average, EGUs at state-owned plants experienced a 5 percentage point reduction in forced outages as result of unbundling—roughly a 25 percent reduction compared to the 1995 average. The decrease in forced outages was accompanied by a 6 percentage point increase in availability. These results are driven largely by the improvements in operating reliability at EGUs with lower nameplate capacity. Our results are not driven by the decommissioning of old and inefficient EGUs or a commissioning of new more efficient ones, thus representing an improvement at existing capacity. This is an important distinction as increasing reliability at existing units can likely be achieved more cheaply than by installing new capital equipment.[2]

On average, there is no evidence of an improvement in capacity utilization due to restructuring, although the results suggest a statistically significant increase at some EGUs. For states that unbundled prior to 2003, we find that unbundling led to a significant improvement in electricity generation at smaller generating units—a 9.4 percentage point increase in capacity utilization at 110/120 MW units. Importantly, our results show no evidence that unbundling of SEBs led to the improvement in thermal efficiency at state-owned power plants.

In summary, our analysis points to modest gains from reform. Operating reliability increased at EGUs in states that unbundled prior to 2003; but there is no evidence of an improvement in thermal efficiency. Our failure to find a larger impact from restructuring than reported in the US may also reflect the path that reform has taken in India thus far. In the United States unbundling resulted in independent power producers (IPPs) entering the market for generation. This has not yet occurred on a large scale in India.

The rest of the paper is organized as follows. Section 2 provides background on the Indian power sector and the nature of reforms. Section 3

[2] We cannot state this with certainty as we do not have data on operating costs for power plants.

describes the empirical approach taken. In section 4, we discuss econometric issues. Section 5 describes the data used in the study and section 6 our results. Section 7 concludes.

2 Background

2.1 Overview of the Indian Power Sector

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

Our analysis focuses on coal-fired power plants, which have, for the past two decades, provided approximately 70% of the electricity generated in India.[3] Coal-fired power plants in India are, in general, less efficient than their counterparts in the US. Over the period 1988-1995 the average operating heat rate—the heat input (in kcal) required to produce a kWh of electricity—of state-

[3] In 2009-10 (CEA 2010) 53% of installed capacity connected to the grid was coal-fired, 11% fired by natural gas, 23% hydro, 3% nuclear and the remainder renewables; however 70% of electricity was generated by coal-fired power plants.

owned plants was 30 percent higher than the average operating heat rate of comparable plants in the United States during the period 1960–1980 (Joskow and Schmalensee 1987).[4]

The higher average operating heat rates of Indian plants are due in part to the poor quality of Indian coal, but also to inefficiencies in management. The design heat rate of generating units that use coal with high moisture and/or high ash content is higher than for units with low moisture and ash content (MIT 2007). The ash content of Indian coal is between 30 and 50% (Khanna and Zilberman 1999). This implies that Indian plants will require more energy to produce a kWh of electricity than comparable plants in the US. The operating heat rate of the plant may be higher than the design heat rate if the plant is poorly maintained or experiences frequent outages.[5] Pre-reform, operating heat rates at state-owned plants were, on average, 31% higher than design heat rates (Cropper et al. 2011).

State plants have, historically, been operated less efficiently than plants owned by the central government: they have had higher forced outages and lower capacity utilization. Figure 1 illustrates trends in the average percent of time state and central plants were available to generate electricity (plant availability), the average percent of time plants were shut down due to forced outages, and the average percent of time the plant was used to generate electricity (capacity utilization). State power plants have, on average, had lower availability and capacity utilization than central-government-owned plants and higher forced outages throughout the 1988-2009 period.

[4] See Table 3B. We focus on the operating heat rate of state-owned plants, as data on operating heat rate of central-government-owned plants are often not reported in the Central Electricity Authority's Thermal Power Reports (various years).

[5] Whenever a plant is started up after an outage, more coal is burned than during the normal operation of the plant.

2.2 History of Power Sector Reforms

Electricity sector reforms in India were prompted by the poor performance of state-owned power plants, by large transmission and distribution losses, and by problems with the SEBs' tariff structure. The tariff structure, which sold electricity cheaply to households and farmers and compensated by charging higher prices to industry, 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 Central Electricity Authority. The Electricity Regulatory Commissions Act of 1998 made it possible for the states to create State Electricity Regulatory Commissions (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).

There were two distinct waves of unbundling reforms in India.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.[6] The first wave, between 1996 and 2002, took place prior to the Electricity Reform Act of 2003. The second wave began in 2004 and continued through the end of our sample period (2009).[7] We refer to these as Phase 1 (unbundling prior to 2003) and Phase 2 (unbundling between 2004 and 2009) states. The remaining states (Phase 3 states) unbundled either outside of our sample period or have not unbundled as of 2012.

Why did certain states restructure their electricity sectors before others? A plot of Table 1 on a map suggests that there is no particular geographic pattern to unbundling. Whether a state restructured its electricity sector is also unrelated to the financial losses it was suffering prior to reform or to its electricity deficit—the difference between electricity supply and peak electricity demand. Figure 2 plots states that unbundled before and after the 2003 Electricity Act (i.e., Phase 1 v. Phase 2 and 3 states) against various factors that might have influenced the timing of unbundling. Panels A and B of Figure 2 show that there is no evidence of a relationship between either the electricity deficit in the state, pre-reform or the losses suffered by the SEB (the ratio of revenues to costs) and the timing of unbundling. Panel C suggests that states with a higher proportion of renewable electricity generation did unbundle earlier. Renewable capacity is largely hydro power and is thus determined by exogenous geographical features. Panel D shows

[6] Table 1 lists only those states containing thermal power plants. Our study focuses on coal- and lignite-fueled plants.
[7] Assam unbundled in 2004, but its only coal-fired power plant was decommissioned in 2001-02. We retain Assam in the dataset; however, for Phase 2 plants, the first year of unbundling is, effectively, 2005, the year in which Maharashtra unbundled.

that states with lower subsidies to agricultural consumers (a higher ratio of agricultural to industrial tariffs) were also more likely to unbundle earlier.[8]

2.3 Impacts of Electricity Sector Reforms

It is important to ask how unbundling reforms might affect the operating reliability of plants or their thermal efficiency. The separation of generation from transmission and distribution services could improve generation efficiency in several ways. Unbundling may result in an increase in generator efficiency from "corporatization"—plant managers being given greater discretionary powers to minimize costs and having to face hard budget constraints. Unbundling may also improve efficiency by reducing diseconomies of scope—allowing managers to focus on decisions related solely to generation. This may result in more timely maintenance decisions and lead to increase generator reliability through reduced breakdowns and forced outages.

The scope for such performance improvements is illustrated by comparing management practices at state and central government owned power plants (ESMAP 2009). The differences in plant availability and capacity utilization at central-government owned plants pre-reform (Table 3A) are due to greater forced outages and more time spent on planned maintenance at state plants, although capital equipment at both sets of plants is, on average, of the same age. Time spent on planned maintenance can be reduced by better scheduling of maintenance and better inventory management. Better management of

[8] We also check whether state economic well-being (per capita income and electricity consumption) drives reform. We find no evidence to suggest that either of these determined the timing of unbundling reforms.

information can help address and avoid technical problems that result in forced outages.[9]

Differences in fuel efficiency can also be driven by factors related to manpower. At the plant-level, Bushnell and Wolfram (2007) document differences in plant operator skill and effort levels that lead to significant differences in plant efficiency. While some processes are automated, activities such as controlling the rate at which pulverized coal is fed to burners, adjusting the mix of air and fuel in the mills, and operating soot blowers in boilers crucially depend on the plant operator's skill and effort levels.

The incentives for improving fuel efficiency and maintaining equipment to prevent breakdowns depends on how plants are compensated. Under the 2003 Electricity Act SERCs are to follow the Central Electricity Regulatory Commission's (CERC's) guidelines in compensating generators. The CERC compensates the power plants under its jurisdiction based on performance. Compensation for energy used in generation is paid based on scheduled generation and depends on operating heat rate. Compensation for fixed costs (depreciation, interest on loans and finance charges, return on equity, operation and maintenance expenses, interest on working capital, and taxes) is based on plant availability.

How have SERCs actually compensated power plants? There is evidence that SERCs have set compensation for fuel use based on very high estimates of operating heat rate, suggesting that this may not provide much of an incentive for plants to improve thermal efficiency (Crisil Ltd. 2010). Compensation for fixed costs based on availability has occurred and is meant to prevent plants from

[9] The main technical problems at state plants identified by ESMAP (2009) include poor condition of boiler pressure parts due to overheating and external corrosion, poor water chemistry, poor performance of air pre-heaters and poor performance of the milling system.

supplying excess electricity to the grid, as was the case historically when plants were compensated based on capacity utilization.

Another avenue through which reforms could influence plant reliability and thermal efficiency is through investment in new equipment. Between 1995 and 2009 coal-fired generation capacity in India increased by 31 percent. It increased by 45% in Phase 1 states, by 30% in Phase 2 states and by 5% in Phase 3 states. An important policy question is the extent to which reforms improved the performance of EGUs installed pre-reform versus impacts that occurred through the installation of new equipment. We test this by estimating models using only EGUs in operation pre-reform as well as using all EGUs.

3 Empirical Strategy

To examine the impact of restructuring on the operating efficiency of state owned power plants, we use EGU-level data on measures of operating reliability and plant-level data on thermal efficiency as outcome variables. Operating reliability is measured by the percentage of time in a year an EGU is available to generate electricity (unit availability), and the percentage of time a unit is forced to shut down due to equipment failures (forced outage).[10] Thermal efficiency is measured by coal consumption per kWh and by operating heat rate. We also estimate the impact of reform on the capacity utilization of the EGU (percent of time the EGU generates electricity).

The time variation in restructuring across states allows us to use a difference-in-difference (DD) estimator. Figure 3 shows the proportion of EUGs in states that have restructured, by year. With data at the EGU-level, we estimate the impact of unbundling on generation efficiency controlling for time-invariant

[10] The percentage of time a unit is available equals the 100 percent minus the percent of time spent on planned maintenance and the percent of time lost due to forced outages.

characteristics of EGUs, year fixed effects and linear time trends specific to each state. The baseline model is estimated using the following specification,

$$Y_{ist} = \emptyset 1[Unbundled]_{st} + X_{ist}\beta + \sum \mu_s TREND_{st} + \tau_t + \theta_i + \varepsilon_{ist} \quad \ldots (1)$$

where Y_{ist} is the measure of generation efficiency for EGU *i* in state *s* in year *t*. In the thermal efficiency models, i refers to the plant, as data for operating heat rate and specific coal consumption are available only at the plant level. The variable of interest is $1[Unbundled]_{st}$, a policy indicator that takes a value of 1 starting in the year after state *s* unbundles its SEB; $\emptyset$ thus estimates the average effect of the policy. A positive and statistically significant estimate of $\emptyset$ for unit availability and capacity utilization and a significant negative estimate for forced outage, specific coal consumption and heat rate is evidence of an average improvement in the efficiency of generation as a result of reform.

All baseline specifications estimate the impact of reforms controlling for EGU/plant fixed effects, θ_i, and year fixed effects, τ_t. The inclusion of fixed effects controls for all time-invariant characteristics that affect the generation performance of an EGU or plant. The inclusion of year dummies captures macroeconomic conditions and changes in electricity sector policy that affect generation in the country as a whole.[11] The upward trend in operating reliability at both state and central plants throughout the sample period (see Figure 1) implies that without year fixed effects estimates of the impact of unbundling would be overestimated. Estimates of the effects of unbundling may also be biased due to

[11] In 2003 an Unscheduled Interchange charge was instituted throughout the country to compensate (penalize) plants supplying unscheduled electricity to the grid when there is excess demand (supply).

differing pre-reform trends between states that restructured their SEBs and those that did not. To control for this, the baseline specifications include state-specific time trends, $TREND_{st}$.

The estimated models also control for EGU and plant level characteristics that directly affect generation performance. The EGU models include a quadratic age term.[12] The thermal efficiency regressions include average unit capacity in the plant, the heating content of coal (gross calorific value per kg), the average design heat rate and a quadratic term in average plant age.

To examine whether the impact of unbundling varies with the phase of unbundling, we estimate a variant of (1) that interacts the unbundled variable with indicators for Phase 1 and Phase 2 states,

$$Y_{ist} = \sum_{k=1,2} \emptyset_k . 1[PhaseUnb]_{kst} + X_{ist}\beta + \sum \mu_s TREND_j + \tau_t + \theta_i + \varepsilon_{ist} \qquad \ldots (2)$$

$1[PhaseUnb]_{kst}$ takes the value of 1 after unbundling of the SEB in state s belonging to group k (k = Phase 1, Phase 2) and $\emptyset_k$ is the estimate of the impact of unbundling for state-group k relative to the counterfactual of not having unbundled by 2009—the last year of the data.

In addition to examining heterogeneous treatment effects, we test for persistence in reform impacts over time. To do this, we interact the unbundled variable with a set of biennial dummy variables post reform; these measure the impact of reform 1-2 years after reform, 3-4 years after reform, and so on. Estimation of dynamic duration effects is of interest for two reasons. First, it is

[12] Other characteristics such as capacity, vintage and make of boiler/EGU also impact generation performance, but are time-invariant and thus subsumed by the EGU fixed-effects.

important to check whether reforms result in a persistent change in operating efficiency at unbundled power plants. A temporary increase in efficiency followed by a reversion to the mean may still yield a positive, significant average treatment effect in the short-term.

Second, Wolfers (2006) points out the potential for bias in estimating average treatment effects when panel-specific trends are included in a difference-in-difference analysis. Since the average treatment effect captures the average deviation from trends in the post-treatment period, incorrectly estimated pre-treatment trends cause the estimate to be biased. This problem is most severe when the estimation sample contains a relatively short pre-treatment period. In this case, a reversal of the trend in the post-treatment period would have a disproportionate effect on estimates of the trend coefficients. Allowing full flexibility in post treatment impacts enables the trend slope coefficients to be determined by the pre-treatment period trends and allows us to examine the evolution of efficiency increases after unbundling reform.

The estimate of dynamic effects of reform relies on the following specification,

$$Y_{ist} = \sum_{t=1,3,5,..} \sum_{k=1,2} \emptyset_k^t 1[PhaseUnb]_{kst} D_t^{t+1} + X_{ist}\beta + \sum_{s=1}^{17} \mu_s TREND_j + \tau_t + \theta_i + \varepsilon_{ist} \quad \ldots (3)$$

In equation (3) the unbundling variable is multiplied by a set of indicator variables that represent the number of years since the reform. $D_t^{t+1} = 1$ if between t and $(t+1)$ years have elapsed since the reform and $\emptyset_k^t$ estimates the average impact for the same time period.

4 Econometric Issues and Identification

An obvious concern in estimating the impacts of reform is that the adoption of reforms across states may be endogenous, thus biasing estimated impacts. Endogeneity may result from state officials explicitly considering potential efficiency improvements in deciding when to implement reforms, or from unobserved heterogeneity across states that drives both the decision to reform and improvements in power plant performance. If states where power plants were likely to gain most from reform were more likely to reform first, the estimated coefficient on the reform dummy would be biased upward. Alternatively, states with greater institutional capacity may be quicker to reform and more likely to benefit from it—also resulting in a positive bias. Although it is impossible to rule out all sources of bias, our estimation strategy and the institutional context of power sector reforms in India should reduce endogeneity concerns.

First, the inclusion of EGU fixed effects controls for any time-invariant differences across EGUs, including factors such as state location (vis-à-vis coal mines and the transmission grid) and institutional capacity (which may be regarded as fixed over the sample period). The inclusion of state-specific time trends controls for any linear time-varying unobserved differences across states and addresses the concern that adoption of reform may be associated with pre-existing trends in power plant performance.

Second, the adoption of reform was a decision taken at the state level by bureaucrats and politicians. It is more likely that political factors determined the decision to restructure state electric utilities than beliefs about generation efficiency. Tongia (2003) cites opposition from the agricultural sector as a factor that delayed the adoption of reforms by some states, given that one objective of reforms was to reduce subsidies to agricultural consumers. The political importance of agricultural constituencies may have delayed the adoption of even the initial stages of reform (i.e., unbundling);[13] however, this is unlikely to bias estimates of generation efficiency.

A third econometric concern is that the coefficient on unbundling may be capturing non-linear time-varying factors that are specific to the state but not related to unbundling. To account for this possibility we take advantage of the presence of power plants owned by the central government that operate in many states across the country. These power plants are owned and operated by the National Thermal Power Corporation (NTPC) and the Damodar Valley Corporation (DVC). They operate outside the structure of the SEBs and are thus not directly affected by restructuring.[14]

To account for state-specific non-linear year shocks, we employ a triple-difference (DDD) specification that includes central power plants and uses state-year dummy variables,

$$Y_{iost} = \emptyset\, 1[Unbundled]_{sot} + X_{ist}\beta + \theta_{\{ot\}} + \psi_{\{st\}} + \nu_i + \epsilon_{\{ist\}} \qquad \text{... (4)}$$

In equation (4), $Y_{\{isot\}}$is the outcome at EGU i in state s under ownership o in year t. $\theta_{\{ot\}}$ represents the full set of ownership (state/central) year effects and $\psi_{\{st\}}$ represents the full set of state-year effects. The specification thus controls for time effects in each state and time effects for each ownership type. The

[13] It is not surprising that Orissa was the first state to reform, given the (un)importance of farming in the state.

[14] To confirm this, we conduct a falsification test to estimate the impact of state SEB unbundling on operating reliability of central EGUs using equations (1) and (2). The impact is statistically indistinguishable from zero.

estimate of the impact of unbundling, $\emptyset$, is identified by the variation in ownership-state-year (as compared to state-year variation that identifies the estimate in the DD specification).

The DDD estimate takes the following form,

$$\emptyset^{\{DDD\}} = \left[\Delta^t Y_{\{U\}} - \Delta^t Y_{\{B\}}\right]_{\{state\}} - \left[\Delta^t Y_{\{U\}} - \Delta^t Y_{\{B\}}\right]_{\{center\}} \qquad \ldots (5)$$

where $\Delta^t Y_{\{U\}}$ is the change in the outcome post reform for states that unbundle and $\Delta^t Y_{\{B\}}$ is the corresponding change for non-reforming states. The difference of these values for center-owned EGUs is subtracted from the difference for state-owned EGUs to obtain the estimate of the impact of unbundling reform.

5 Data

We use data from the Central Electricity Authority of India's Performance Review of Thermal Power Stations (CEA various years) to construct an unbalanced panel of 385 EGUs for the years 1988–2009.[15] Of the 385 EGUs, 270 operate in 60 state-owned generation plants and 115 are in 23 central-government-owned plants. The units in the dataset constitute 83 percent of the total installed coal-fired generation capacity in the country in the year 2009–2010.[16] Additional information on the date that the SERCs were established, the date of the unbundling reforms for each state and ownership information for each power plant was obtained from the websites of the individual SERCs and the CEA.

[15] The CEA reports are not available for the years 1992 and 1993. These years are thus omitted from our data. A year in the dataset is an Indian fiscal year. Thus, 1994 refers to the time period April 1, 1994, through March 30, 1995.
[16] Nine percent of coal-fired generation capacity in 2009-10 was privately owned.

Tables 2A and 2B present summary statistics that compare state EGUs (Table 2A) and plants (Table 2B) by phase of reform in the period prior to restructuring (1988–1995) and at the end of the sample period (2006–2009). Tables 3A and 3B present similar comparisons between state and central EGUs (Table 3A) and plants (Table 3B).

Prior to the first unbundling reforms in 1996, Phase 1 states were performing slightly worse than other states. The EGUs in these states were older, smaller, had higher forced outages, slightly lower availability and lower thermal efficiency compared to Phase 2 states. This pattern was reversed by 2006-09: Phase 1 states were now statistically indistinguishable in terms of performance measures—forced outages, availability, capacity utilization—from Phase 2 states.[17] Operating heat rate at plants in Phase 1 states was also slightly below operating heat rate in Phase 2 states by 2006-09, although the difference is not statistically distinguishable. This suggests that between 1996 and 2006 the states that unbundled early (Phase 1 states) outperformed the states that were just beginning to unbundle their SEBs in 2004 (Phase 2 states). The tables also show a drop in the average design heat rate of plants in Phase 1 states, which implies that at least a part of the gains in average performance measures are due to the addition of newer and more efficient units.

The comparison between state and central plants In Tables 3A and 3B confirms that central plants were significantly more efficient than state plants throughout the sample period. Over the years 1988–1995, the average capacity utilization of state EGUs was about 10 percentage points lower than EGUs at centrally owned plants. Coal consumption per kWh was about 7 percent higher at state plants. A comparison of operating heat rates at state and central plants is

[17] Average forced outage was lower in Phase 1 states compared to Phase 2 in the period 2006-09; however, the difference in means is not statistically significant.

more difficult, as data are often missing for plants operated by the National Thermal Power Corporation (NTPC).

During the sample period, both state and central plants improved in reliability, but showed little improvement in thermal efficiency. Table 3 indicates that EGUs in both sets of plants have experienced large gains in capacity utilization (an average increase of 19 percentage points for state and 25 percentage points for central plants) and smaller gains in plant availability (an average increase of 13 percentage points for both central and state plants). Forced outages also decreased substantially at both sets of plants. There was, in contrast, little change in coal consumption per kWh.

6 Results

6.1 Difference-in-Difference Results for Thermal Efficiency

We measure the impacts of unbundling on thermal efficiency using both specific coal consumption (kg/kWh) and operating heat rate (kcal/kWh). The models are estimated using plant-level data. Plants owned by the central government cannot be used as controls since data on thermal efficiency are often missing for these plants.

Coal burned per kWh depends on the design heat rate of the boiler (e.g., boilers designed to burn high-ash coal have higher design heat rates and thus require more coal), the heating value of the coal burned, and the age and capacity of the boiler (Joskow and Schmalensee 1987). Coal consumption per kWh should decrease with the heating value of the coal and capacity of the boiler and should increase with boiler age.[18] In estimating models of coal consumption we treat the heating value of the coal as exogenous to the plant. Given the structure of the Indian coal market, plant managers cannot choose coal quality. Power plants are linked to coal mines by a central government committee and thus have little leeway in determining the quality of the coal received.[19]

Operating heat rate (OPHR) is the sum of coal burned per kWh, multiplied by the heating value of the coal, plus oil burned per kWh, multiplied by the heating value of the oil. Although OPHR captures oil as well as coal usage, we expect the impact of unbundling on operating heat rate to be similar to its impact on coal consumption per kWh.[20] One way in which restructuring could reduce coal consumption and operating heat rate are through the purchase of newer generating equipment. This should improve thermal efficiency because boilers generally deteriorate as they age and, new boilers embody technical improvements. It is also possible to improve thermal efficiency by pulverizing coal before it is burned and by performing regular maintenance of boilers. By holding equipment age constant in our thermal efficiency models we focus on the change in efficiency due to managerial factors.

Table 4 indicates that after controlling for plant characteristics, year dummy variables and state-level trends, there is no evidence to support the hypothesis that unbundling improved the thermal efficiency of state-owned power plants. Plant characteristics have the expected signs; however, average treatment

[18] 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. The average nameplate capacity is a simple average of EGU capacity in the plant.
[19] The use of washed (beneficiated) coal, which has a higher heating value, is also mandated through regulation and not determined by plant managers.
[20] Because coal constitutes most of the kcal used to generate electricity, OPHR $\approx$ (Coal per kWh)*(Heating Value of Coal). It follows that the coefficient of ln(Heating Value of Coal) in the ln(OPHR) equation should approximately equal 1 plus the coefficient of ln(Heating Value of Coal) in the ln(Coal Consumption per kWh) equation. Our results confirm this.

effects in columns [1] and [2] show no significant impact of unbundling on operating heat rate and a significant positive impact on specific coal consumption. Examining the heterogeneous impacts in column [3] and [4] reveals that plants in Phase 2 states experience a statistically significant worsening in thermal efficiency post unbundling reforms—this is also what drives the average impact of specific coal consumption in column [2]. This result is consistent with large increases in specific coal consumption observed in Gujarat and Maharashtra beginning in 2005. These increase could be due to idiosyncratic shocks to the quality of coal (e.g., to its ash and moisture content) for which we do not have data.

Our results, which show no significant improvement in thermal efficiency as a result of restructuring, are consistent with the results of Hiebert (2002) and Fabrizio et al. (2007). Hiebert find mixed effects of restructuring on the technical efficiency of coal-fired power plants in US states that restructured their electricity sectors (improvements in 1996 but not in 1997). Fabrizio et al. (2007) find no improvement in fuel input usage at plants in states that restructured their electricity sectors. It should, however, be noted that both studies look at the impacts of restructuring shortly after states separated generation from distribution. Our panel follows plants in Phase 1 states for an average of 10 years after unbundling.

6.2 Difference-in-Difference Results for Operating Reliability

Columns [1] and [2] of Table 5 show the average effect of unbundling of SEBs on unit availability and forced outage. Availability is the percentage of hours in a year that the EGU is available to produce electricity; forced outage is the percentage of time that the EGU is forced to shut down due to breakdowns and mechanical failures. The results in Column [1] and [2] indicate that the average impact of unbundling on state EGUs is statistically insignificant from zero.

Columns [3] and [4], however, show that states that unbundled prior to the Electricity Act of 2003 experienced a statistically significant improvement in operating reliability: average EGU availability increased by 6.8 percentage points. This increase represents a 10 percent increase over 1995 levels. The improvements in availability were largely driven by a reduction in forced outages. The unbundling of generation resulted in a 5.1 percentage point reduction in the time lost from breakdowns, a 25 percent reduction from average forced outage for these states in 1995.

Column [3] shows a decline in EGU availability in Phase 2 states due to unbundling that is significant at the 10 percent level, but no statistically significant impact on forced outages. Because plant availability, forced outages and planned maintenance must sum to 100 percent, this implies that the reduction in availability is due to increased plant maintenance. This is a very different outcome than an increase in forced outages and need not represent a decline in efficiency.

Table 6 presents robustness checks for the operating reliability models. These indicate that the reduction in forced outages in Phase 1 states is robust to sample specification and representation of time trends. For Phase 1 states the increase in EGU availability and reduction in forced outages is affected only slightly by dropping Phase 2 states from the models (i.e., to using only states that did not restructure during the sample period as a control group). This is also the case when state time trends are replaced by time trends for the three phases of unbundling.

Table 6 also investigates the impact of the decommissioning and commissioning of EGUs on our results. Columns [5] and [6] re-estimate the models dropping observations for the EGUs that were shut down during the sample period. This eliminates the possibility that units that were shut down are driving the results in Table 5. This slightly reduces the impact of unbundling on forced outages and plant availability, to -3.7 and 4.9 percentage points, respectively. To test whether it is new EGUs that are driving the results we estimate the models using EGUs that were installed pre-reform and remain in the dataset through 2009 (columns [7] and [8]). Columns [7] and [8] suggest that unbundling significantly improved the performance of existing equipment in Phase 1 states, reducing forced outages by about 5 percentage points and increasing availability by about 6 percentage points.

As is the case for Phase 1 states, results for Phase 2 states are also robust to choice of sample. The reduction in availability at Phase 2 plants remains statistically significant and is associated with increased restoration and maintenance of EGUs, rather than an increase in forced outages.

6.3 Triple-difference Estimates of Operating Reliability

The triple-difference (DDD) specifications include EGUs at central power plants as an additional control group. The validity of central power plants as a control group rests partly on SEB reforms having no impact on the operating reliability of these plants. To test this, we estimate a model of the impacts of SEB restructuring on EGUs at central power plants. The results, presented in the Appendix, show that there is no evidence of unbundling reforms on operating availability or forced outages at central EGUs—the magnitude of the coefficients is small and the standard errors are large.

Table 7 presents the results from the DDD estimation of the impact of unbundling, by phase. The results in Table 7 are qualitatively similar to those in Table 5 for the DD specification. The coefficient estimates in columns [1] and [2] show a statistically significant increase in availability of 6 percentage points—equivalent to an additional 700 MW becoming available for electricity production—and a decrease in forced outage for EGUs in Phase 1 states of 5 percentage points. These results are robust to dropping from the sample units that were shut down (columns [3] and [4]). Results for Phase 2 states, although qualitatively similar to Table 5, are no longer statistically significant. When the DDD model is estimated using EGUs that were installed pre-reform and remain in the dataset through 2009, the impact of unbundling on forced outages is unaffected, suggesting that reforms improved existing cacpity; however, the impact on availability is estimated less precisely.

6.4 Dynamic Effects of the Impact of Unbundling

The average treatment effects for units in Phase 1 states could reflect an initial impact of restructuring that declined over time. Our analysis of the dynamic impacts of restructuring suggests that this is not the case. Using equation (3), we estimate the impact of unbundling by interacting a series of biennial dummy variables with the unbundling variables. Figures 4A to 4D plot the estimated coefficients of time dummy variables that represent two-year intervals after reform for Phase 1 states.[21]

Figures 4A and 4B show a similar pattern of the impact on forced outage for both DD (Figure 4A) and DDD (Figure 4B) specifications. The DD

[21] The dummy year categories are 1-2 years, 3-4 years, 5-6 years, 6-7 years and 9+ years since unbundling. The last category captures up to 13 years after unbundling in the case of Orissa. We combine years greater than 9 into one dummy because the number of observations is too low to estimate finer categories.

coefficients are, however, less precisely estimated. The DDD estimates in Figure 4B suggest a lag in the reduction of forced outages after unbundling for Phase 1 states. The impact is significant starting 3 years after unbundling, and is largest 3, 5 and 9 (or more) years after reform.

Figures 4C and 4D plot the results from a more flexible specification of the DDD model. Here, we allow both the pre- and post-reform time effects for state-owned EGUs to vary non-parametrically.[22] Figure 4C shows that the flexible estimation of the pre-reform trend in forced outage at state-owned EGUs yields a flat trend, conditional on covariates. The evolution of the impact after unbundling is the same as in figure 4B above. Figure 4D indicates that the significant reform impacts on availability for Phase 1 states persist for the duration of the sample.

6.5 Impacts on Capacity Utilization

Did the reductions in forced outages and increases in availability at EGUs in Phase 1 states result in greater electricity production? Table 8 suggests that, on average, increases in availability were not reflected in increased capacity utilization of state-owned EGUs. Column [1] and column [2] report the impacts, by phase, from the DD and DDD specifications. We find no evidence to suggest that, on average, unbundling generation from transmission and distribution led to an increase in capacity utilization at state EGUs.

This result is at variance with the results of Sen and Jamasb (2012) who, using state-level data, find that unbundling resulted in a 26 percentage point increase in capacity utilization at state-owned power plants. Interestingly, average capacity utilization at state-owned EGUs increased by roughly 25

[22] This is similar to an event study specification.

percentage points from 1991 to 2009 (see Figure 1C). However, once we control for plant and year fixed effects and state time trends, this result is unrelated to unbundling.

One reason why increases in availability did not result in greater electricity generation may be that they occurred at higher cost plants. If these plants were not able to underbid lower cost plants in the merit dispatch order, increased availability would not necessarily result in increased capacity utilization. Alternatively, it could also be that there was heterogeneity in the impacts of unbundling on capacity utilization which caused the average effect to be estimated noisily. We note that the sign of the impact of unbundling on average capacity utilization in Table 8 is positive but insignificant for Phase 1 states, suggesting this possibility.[23] We examine the nature of heterogeneity in the impact of reforms by estimating models that allow for differential impacts by EGU size.

Table 9 presents difference-in-difference models which interact the Phase-specific unbundling variable with categorical variables for 4 EGU size categories—EGUs less than 100 MW, 110/120 MW, 210/220/250 and 500 MW.[24] The results show that 110/120 MW units experienced a significant positive increase in operating reliability in Phase 1 states: operating availability increases by about 12 percentage points, largely driven by a 9 percentage point reduction in time lost due to forced outages. The increase in operating availability translated into a roughly 9 percentage point increase in capacity utilization at these EGUs.

[23] The magnitude of the average term may be reduced due to gains in capacity utilization (or reliability) at some generators and possible deterioration at others—e.g. due to adjustment costs of restructuring.
[24] We define each group based on a range of nameplate capacities that is largely composed of these capacities.

Indeed, the results in Tables 5-8 appear to be driven by reductions in forced outages at small (100 MW and 110/120 MW) plants.

The estimates for Phase 2 states suggest that the impact of unbundling was to decrease EGU reliability. There is a statistically significant decline in availability which leads to a decline in capacity utilization. The estimates also show that the deterioration associated with reforms at EGUs in Phase 2 states is not due to an increase in forced outage. Thus an increase in maintenance is driving the observed decreases in availability and capacity utilization. As argued above, it is questionable whether this captures a reduction in efficiency due to reform.

7 Conclusions

This paper examines the impact of reforms in the Indian electricity sector on the generation performance of state-owned power plants. Our results show that unbundling resulted in a statistically significant increase in the average availability of EGUs in states that restructured their SEBs prior to the Electricity Act of 2003. We find that the increase in availability at these EGUs is mainly driven by a corresponding reduction in forced outages. There is no evidence of an impact of restructuring on average capacity utilization or improvements in thermal efficiency. In fact, the results show a statistically significant increase in coal consumption per kWh and in operating heat rate at state plants in states that unbundled between 2005 and 2009.

Results from a triple difference specification suggest a 5.9 percentage point increase in average unit availability and a 4.9 percentage point reduction in forced outages in Phase 1 states. The reduction in forced outages represents a 25 percent reduction from the mean for these states in 1995. Examination of the duration of reform impacts, using a full set of pre and post time dummies, shows that the improvements in generation reliability are not reversed in the short to medium term. Robustness checks confirm that our baseline results are not sensitive to changes in model and sample specifications.

The estimation of the average impact of unbundling hides the considerable heterogeneity in the impact of reform by EGU characteristics. Smaller EGUs experienced a significant increase in operating reliability due to reform in Phase 1 states. In Phase 1 states, 110/120 MW EGUs experienced a 9.4 percentage point increase in capacity utilization driven largely by a reduction in the time lost due to forced outage. The increase in capacity utilization represents a 24 percent increase above the 1995 average (39 percent) at 110/120 MW EGUs and implies an additional 2083 GWh of electricity production per year from these units.[25]

For Phase 2 states, our results suggest that the initials years following reforms were associated with a reduction in availability and capacity utilization, especially at 110/120 MW EGUs, and a decrease in thermal efficiency. The estimated coefficients are unstable and often insignificant, but suggest a worsening in generation performance across various specifications. The estimated deterioration in performance may be due to initial adjustment costs to restructuring in the states that were forced to unbundle. It should also be noted that the reductions in availability at EGUs are due to increases in planned maintenance rather than increases in forced outages.

The offsetting deterioration in Phase 2 states implies that, on average, the impact of reforms has been modest in magnitude. It is safe to say that the gains from unbundling reforms have thus far been limited to an improvement in

[25] State-owned thermal power plants generated 240.8 TWh (10^3 GWh) of electricity in 2005 (CEA 2006). This figure includes gas-fired plants.

operating reliability and capacity utilization for the most inefficient plants in the states that unbundled prior to 2003.

To the extent that we find modest impacts of restructuring on operating reliability due to a reduction in forced outages—and no improvements in thermal efficiency—our results are comparable to those of Fabrizio et al. (2007) and Davis and Wolfram (2011) for the US. Fabrizio et al. (2007) do not find evidence of the impact of restructuring on the thermal efficiency of power plants, although they do find significant reductions in non-fuel expenditures. Davis and Wolfram (2011) find that deregulation and consolidation in ownership led to a 10 percentage point increase in operating efficiency nuclear power plants—driven largely by reductions in forced outages.

Our results disagree with those of Sen and Jamasb (2012) who, using state-level data for India, find that unbundling increased average capacity utilization by 26 percentage points—an extremely large effect. One possible explanation for the difference is that the Sen and Jamasb (2012) may not adequately control for the strong upward trend in the capacity utilization at Indian power plants during the period of their study (see Figure 1C).

The failure to find more widespread impacts from restructuring may reflect the nature and progress of electricity reform in India thus far. Ruet (2005) argues that unbundling and subsequent corporatization has failed to increase the technical and financial autonomy of power plant managers to the extent envisaged at the start of reforms. Executive orders from state governments continue to drive some of the important decisions of generation companies, which may be contrary to cost-minimization objectives.

Bacon and Besant-Jones (2001) emphasize that 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). Another way in which unbundling may increase generation efficiency is through increased competitive pressure from the entry of IPPs into the electricity market. Such an effect followed the restructuring of the US electricity sector, but has not yet occurred 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

Unbundling Phase	State	SERC operational	SEB unbundled
Phase 1	Orissa	1995	1996
	Andhra Pradesh	1999	1998
	Haryana	1998	1998
	Karnataka	1999	1999
	Uttar Pradesh	1999	1999
	Rajasthan	2000	2000
	Delhi	1999	2002
	Madhya Pradesh	1998	2002
Phase 2	Assam	2001	2004
	Maharashtra	1999	2005
	Gujarat	1998	2006
	West Bengal	1999	2007
	Chhattisgarh	2000	2008
Phase 3	Punjab	1999	2010
	Tamil Nadu	1999	2010
	Bihar	2005	[a]
	Jharkhand	2003	[a]

[a] Reform not implemented by 2012.

Table 2A. Variable Means, State-owned EGUs, by Unbundling Phase (EGU Data)

	Phase-I		Phase-II		Phase-III			
	1988 - 1995		1988 - 1995		1988 - 1995			
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Diff. in means	
	[1]	[2]	[3]	[4]	[5]	[6]	[1]-[3]	[1]-[5]
Nameplate capacity (MW)	117	73	146	74	131	60	-29***	-14***
Generation (GWh)	534	489	686	498	561	465	-152***	-27
Age (yrs.)	14.8	8.0	13.5	8.2	12.9	7.5	1.3**	1.8***
Forced outages (%)	21.5	20.4	16.8	20.4	17.6	17.2	4.6***	3.9**
Planned maintenance (%)	12.2	18.7	14.2	18.7	18.3	27.4	-2	-6.1***
Availability (%)	66.3	23.4	69.0	23.8	64.1	26.4	-2.6*	2.2
Capacity utilization (%)	50.0	21.2	49.8	20.7	46.0	24.0	0.2	3.9**
	2006 - 2009		2006 - 2009		2006 - 2009			
Nameplate capacity (MW)	164	91	172	86	159	61	-8	4
Generation (GWh)	1062	750	1052	656	1038	664	10	24
Age (yrs.)	23.0	12.2	24.6	11.7	24.7	9.3	-1.6*	-1.7*
Forced outages (%)	10.8	14.7	12.6	16.3	13.3	18.4	-1.8	-2.5
Planned maintenance (%)	8.2	15.6	6.1	9.8	12.6	23.1	2.1**	-4.4**
Availability (%)	81.0	19.8	81.4	18.0	74.2	27.6	-0.3	6.9***
Capacity utilization (%)	69.1	23.7	68.1	20.1	66.1	30.0	1	3

Notes: Phase 1 (pre-2003): Andhra Pradesh, Haryana, Karnataka, Orissa, Rajasthan, Uttar Pradesh, Delhi, and Madhya Pradesh. Phase 2 (post-2003): Gujarat, Maharashtra, West Bengal, Chhattisgarh and Assam. Phase 3 (out-of-sample): Bihar, Punjab, Tamil Nadu and Jharkhand. GWh, gigawatt-hours; MW, megawatts. 1988-1995 does not contain data for 1992 and 1993. Difference in means according to a two-sample *t*-test with unequal variances*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Number of observations (1988-1995): Phase 1- 466, Phase 2- 461, Phase 3- 217. Number of observations (2006-2009): Phase 1- 399, Phase 2- 370, Phase 3- 155.

Table 2B. Variable Means, State-owned Plants, by Unbundling Phase (Plant Data)

	Phase-I			Phase-II			Phase-III				
	1988-1995			1988-1995			1988-1995				
	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Diff. in means	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[2]-[5]	[2]-[8]
No. of operating units	117	3.98	3.03	118	3.91	1.67	50	4.34	2.41	0.08	-0.36
Nameplate capacity (MW)	115	473	421	117	574	383	49	580	285	-100*	-107*
Heating value of coal (kcal/kg)	58	4203	617	67	4307	604	32	3809	380	-104	394***
Design heat rate (kcal/kWh)	36	2633	194	41	2438	148	12	2486	70	195***	147***
Operating heat rate (kcal/kWh)	59	3478	950	69	3135	537	32	3210	664	342**	268
Specific coal cons. (kg/kWh)	98	0.83	0.15	103	0.72	0.12	49	0.82	0.13	0.11***	0.01
	2006-2009			2006-2009			2006-2009				
No. of operating units	86	4.64	2.76	93	3.98	1.90	44	3.52	1.73	0.66*	1.12***
Nameplate capacity (MW)	86	760	551	93	685	509	44	561	347	74.4	199**
Heating value of coal (kcal/kg)	48	3547	386	45	3673	493	29	3773	334	-125	-226***
Design heat rate (kcal/kWh)	53	2405	177	66	2423	201	29	2383	110	-18.2	21.9
Operating heat rate (kcal/kWh)	53	2901	642	65	2932	323	29	2777	456	-31.9	123
Specific coal cons. (kg/kWh)	76	0.82	0.13	63	0.78	0.09	41	0.78	0.15	0.04**	0.04

Notes: Phase 1 (pre-2003): Andhra Pradesh, Haryana, Karnataka, Orissa, Rajasthan, Uttar Pradesh, Delhi, and Madhya Pradesh. Phase 2 (post-2003): Gujarat, Maharashtra, West Bengal, Chhattisgarh and Assam. Phase 3 (out-of-sample): Bihar, Punjab, Tamil Nadu and Jharkhand. GWh, gigawatt-hours; MW, megawatts; kcal/kWh, kilo-calories/kilowatt-hours. 1988-1995 does not contain data for 1992 and 1993. Difference in means according to a two-sample t-test with unequal variances*** p<0.01, ** p<0.05, * p<0.1.

Table 3A. Variable Means, by Sector (EGU Data)

	CENTER 1988 - 1995		STATE 1988 - 1995		
	Mean	St Dev	Mean	St Dev	Diff. in means
	[1]	[2]	[3]	[4]	[1]-[3]
Nameplate capacity (MW)	194	132	131	72	62.80***
Generation (GWh)	1046	917	602	493	443.6***
Age (yrs.)	13.5	10.7	13.9	8.0	-0.36
Forced outages (%)	14.9	16.8	18.7	19.7	-3.82***
Planned maintenance (%)	9.4	13.9	14.2	20.7	-4.79***
Availability (%)	75.7	19.9	67.1	24.1	8.623***
Capacity utilization (%)	59.5	21.1	49.2	21.5	10.23***
	2006 - 2009		2006 - 2009		
Nameplate capacity (MW)	259	155	166	85	93.01***
Generation (GWh)	1928	1281	1054	699	873.4***
Age (yrs.)	20.2	12.2	23.9	11.6	-3.72***
Forced outages (%)	5.6	9.6	11.9	16.0	-6.36***
Planned maintenance (%)	5.8	5.5	8.1	15.4	-2.28***
Availability (%)	88.7	10.5	80.0	20.8	8.642***
Capacity utilization (%)	84.7	14.2	68.2	23.6	16.49***

Notes: GWh, gigawatt-hours; MW, megawatts. 1988-1995 does not contain data for 1992 and 1993. Difference in means between State and Central plants according to a two-sample *t*-test with unequal variances*** p<0.01, ** p<0.05, * p<0.1. Number of observations (1988-1995): Center- 404, State- 1141. Number of observations (2006-2009): Center- 435, State- 924.

Table 3B. Variable Means, by Sector (Plant Data)

	CENTER			STATE			
	1988-1995			1988-1995			
	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Diff. in means
	[1]	[2]	[3]	[4]	[5]	[6]	[2]-[5]
No. of operating units	92	4.39	2.26	285	4.01	2.44	0.38
Nameplate capacity (MW)	90	872	601	281	534	386	338***
Heating value of coal (kcal/kg)	42	4092	543	157	4167	598	-75
Design heat rate (kcal/kWh)	12	2530	164	89	2523	185	6.73
Operating heat rate (kcal/kWh)	43	2984	387	160	3276	751	-293***
Specific coal cons. (kg/kWh)	67	0.73	0.12	250	0.78	0.14	-0.05***
	2006-2009			2006-2009			
No. of operating units	87	5.00	2.17	223	4.14	2.28	0.86***
Nameplate capacity (MW)	87	1297	854	223	689	502	608***
Heating value of coal (kcal/kg)	11	4323	267	122	3647	424	676***
Design heat rate (kcal/kWh)	23	2505	137	148	2409	178	96***
Operating heat rate (kcal/kWh)	23	3138	398	147	2890	486	247**
Specific coal cons. (kg/kWh)	74	0.71	0.07	180	0.80	0.12	-0.08***

Notes: GWh, gigawatt-hours; MW, megawatts; kcal/kWh, kilo-calories/kilowatt-hours. 1988-1995 does not contain data for 1992 and 1993. Difference in means between State and Central plants according to a two-sample *t*-test with unequal variances*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 4: Thermal Efficiency - Impact of Unbundling on State Plants

	[1] Log Heat rate	[2] Log Specific Coal Cn.	[3] Log Heat rate	[4] Log Specific Coal Cn.
[Unbundled]	0.0320	0.0356*		
	(0.0201)	(0.0189)		
[Phase-I*Unbundled]			-0.0183	-0.0107
			(0.0229)	(0.0179)
[Phase-II*Unbundled]			0.0820***	0.0818***
			(0.0223)	(0.0207)
ln(Design Heat Rate)	0.491***	0.483***	0.448***	0.444***
	(0.157)	(0.138)	(0.133)	(0.117)
ln(Heating value of Coal)	0.514***	-0.451***	0.508***	-0.457***
	(0.0890)	(0.0869)	(0.0834)	(0.0824)
Average Age	0.00578**	0.00786**	0.00711**	0.00908**
	(0.00261)	(0.00347)	(0.00259)	(0.00339)
Average Age^2	0.000139***	8.20e-05	0.000120**	6.46e-05
	(4.35e-05)	(5.04e-05)	(4.45e-05)	(4.91e-05)
Average Nameplate Capacity	-0.000953	-0.000572	-0.000872	-0.000498
	(0.000698)	(0.000677)	(0.000659)	(0.000644)
Time Trend	State	State	State	State
Plant FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	478	478	478	478

Notes: Std. errors in parentheses, clustered at state level. *** p<0.01, ** p<0.05, * p<0.1. All equations control for a quadratic for plant age, average capacity, design heat rate, heat content of coal, year and plant fixed effects and state time trends. Number of observations=478 (46 Plants).

Table 5: Operating Reliability - Impact of Unbundling on State EGUs

	[1]	[2]	[3]	[4]
	Average Impacts		Heterogeneous Impacts	
	Availability	Forced Outages	Availability	Forced Outages
[Unbundled]	0.743	-1.824		
	(1.885)	(1.352)		
[Phase-I*Unbundled]			6.793**	-5.110***
			(2.819)	(1.726)
[Phase-II*Unbundled]			-5.559*	1.599
			(2.993)	(2.467)
Time Trend	State	State	State	State
Unit FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes**:** Std. errors in parentheses, clustered at state level. *** p<0.01, ** p<0.05, * p<0.1. All equations control for a quadratic for EGU age, year and plant fixed effects and state time trends. Number of observations=4298 (270 Units).

Table 6: Robustness Checks - Impact of Unbundling on State EGUs

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	Drop Phase 2		**Phase Trends**		**Drop Shutdown**		**Drop Enter/Exit**	
	Availability	Forced Outages	Availability	Forced Outages	Availability	Forced Outages	Availability	Forced Outages
1[Phase-I*Unbundled]$_{it}$	5.983**	-3.885**	6.711**	-5.258***	4.943*	-3.698**	6.141*	-5.134**
	(2.512)	(1.447)	(2.870)	(1.740)	(2.359)	(1.421)	(3.163)	(2.047)
1[Phase-II*Unbundled]$_{it}$			-6.656**	1.754	-5.415*	0.987	-8.501**	1.434
			(3.097)	(2.350)	(2.949)	(2.583)	(3.013)	(2.378)
Time Trend	State	State	Phase	Phase	State	State	State	State
Observations	2,605	2,605	4,298	4,298	3,859	3,859	2,895	2,895
Number of id	166	166	270	270	236	236	147	147

Notes: Standard errors in parentheses clustered at state level**.** *** p<0.01, ** p<0.05, * p<0.1**.** All equations control for a quadratic for EGU age, and EGU and Year fixed effects. Columns [1]-[2] drop Phase 2 states from the estimation sample. Columns [3]-[4], substitute phase-wise trends instead of state-specific trends. Columns [5]-[6] drop units that were decommissioned during the sample period. Columns [9]-[10] drop units that were either commissioned or decommissioned during the sample period.

Table 7: Triple Difference Estimates (DDD) - Impact of Unbundling on State EGUs

	[1]	[2]	[3]	[4]	[5]	[6]
			Drop Shutdown		**Drop Enter/Exit**	
	Availability	Forced Outages	Availability	Forced	Availability	Forced
[Phase-I*Unbundled]	5.959*	-4.938**	6.284*	-4.435**	7.398	-5.088**
	(3.12)	(1.818)	(3.175)	(1.709)	(4.500)	(2.203)
[Phase-II*Unbundled]	-3.684	3.104	-3.620	2.711	-4.239	1.679
	(2.233)	(2.447)	(2.285)	(2.419)	(5.589)	(6.400)
Observations	6054	6054	5,541	5,541	4,024	4,024
Number of Units	385	385	344	344	203	203

Notes: Standard errors in parentheses clustered at state level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. All equations control for a quadratic for EGU age, and a full set of state×year, ownership×year and EGU fixed effects.

Table 8. Capacity Utilization Factor – Impact of Unbundling on EGUs

	[1]	[2]
	Capacity Utilization	
	DD	DDD
[Phase-I*Unbundled]	3.955	1.101
	(3.475)	(2.789)
[Phase-II*Unbundled]	-4.039	0.571
	(3.281)	(2.133)
Observations	4,298	6,054
Number of EGUs	270	385

Notes: Std. errors in parentheses, clustered at state level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.) Estimations in both column [1] and [2], respectively, control for all the same controls as the earlier estimations for DD and DDD.

Table 9: Operating Reliability by Size of EGU

	[1]	[2]	[3]
	Dependent Variable		
Interaction Variable	Availability	Forced Outages	Capacity Utilization
Phase-I			
[Phase-I*Unbundled] * Less than 100 MW	4.239	-5.564**	2.141
	(3.265)	(2.168)	(5.033)
[Phase-I*Unbundled] * 110/120 MW	12.26***	-9.313**	9.415**
	(3.041)	(3.518)	(4.214)
[Phase-I*Unbundled] * 200/210 MW	6.466	-2.913	2.812
	(4.279)	(1.748)	(4.049)
[Phase-I*Unbundled] *500 MW	1.169	-0.192	1.716
	(2.178)	(2.224)	(3.057)
Phase-II			
[Phase-II*Unbundled] * Less than 100 MW	-6.098	3.706	1.013
	(4.998)	(4.003)	(4.129)
[Phase-II*Unbundled] * 110/120 MW	-7.492**	2.764	-7.851**
	(3.275)	(4.793)	(3.482)
[Phase-II*Unbundled] * 200/210 MW	-4.396	0.325	-3.514
	(2.565)	(1.487)	(3.366)
[Phase-II*Unbundled] * 500 MW	-10.13***	4.658***	-14.57***
	(2.358)	(1.413)	(2.825)

Notes: Number of observations for all specifications=4298 (270 EGUs). Each column in Panel A and Panel B represents coefficients from a single DD estimation. Less than 100MW: all EGUs <100MW; 110/120MW: between 100MW and <150MW; 200/210/250MW: between 150MW and 300MW; and 500MW: 490 MW and above. All equations control for a quadratic for EGU age, year and EGU fixed effects and state time trends. Standard errors in parenthesis clustered at the state level. **. *** *p*<0.01, ** *p*<0.05, * *p*<0.1.**

Figure 1: Trends in Outcome Variables

Figure 1A: Trend in Availability for State and Center Owned EGUs

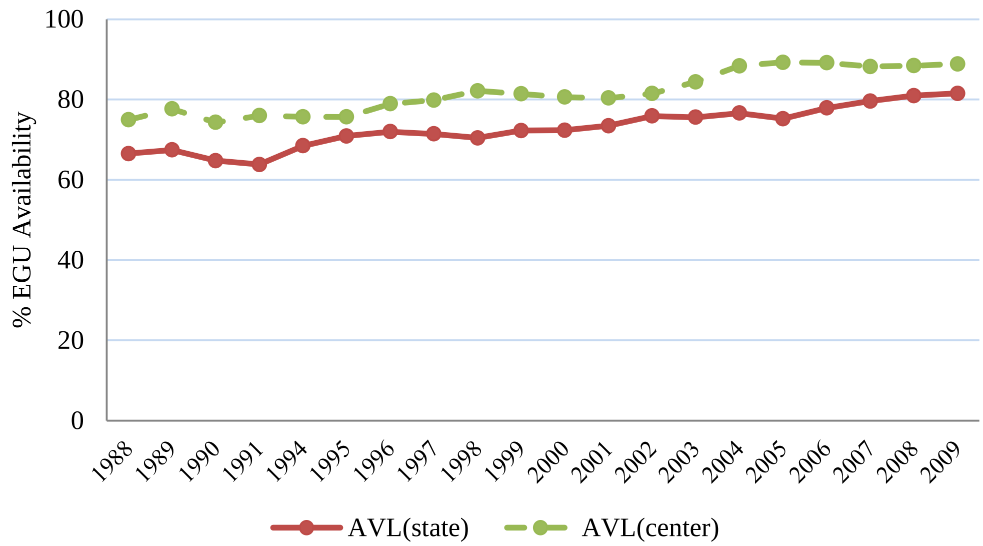


Figure 1B: Trend in Forced Outage for State and Center Owned EGUs

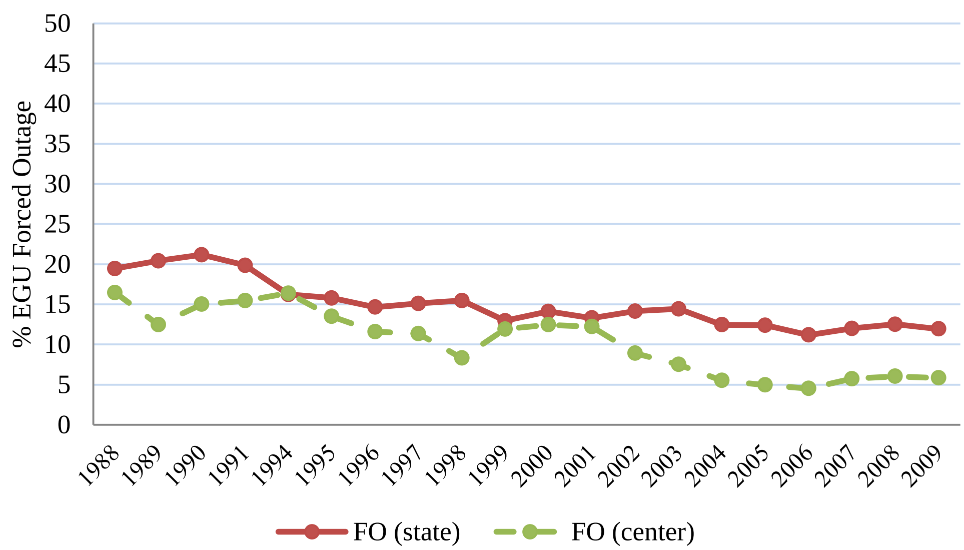


Figure 1C: Trend in Capacity Utilization for State and Center Owned EGUs

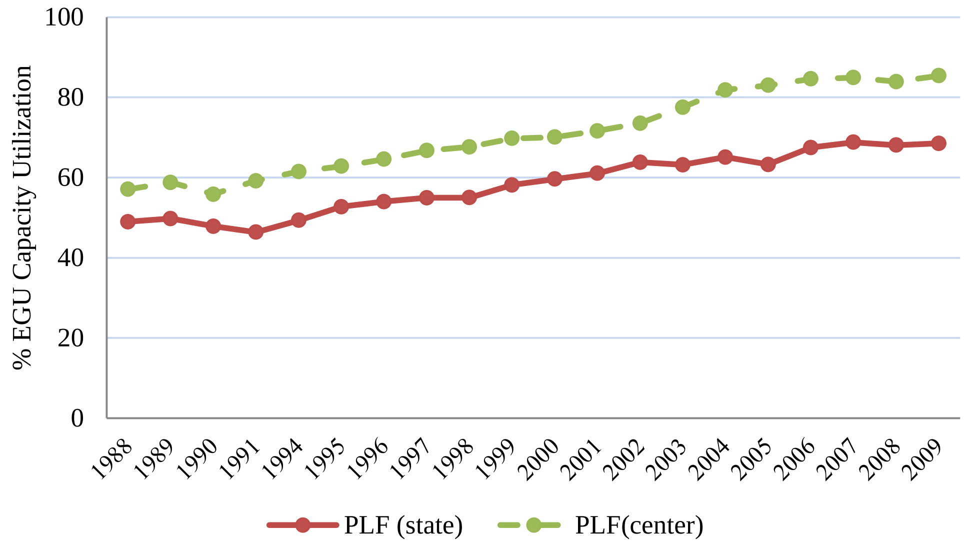
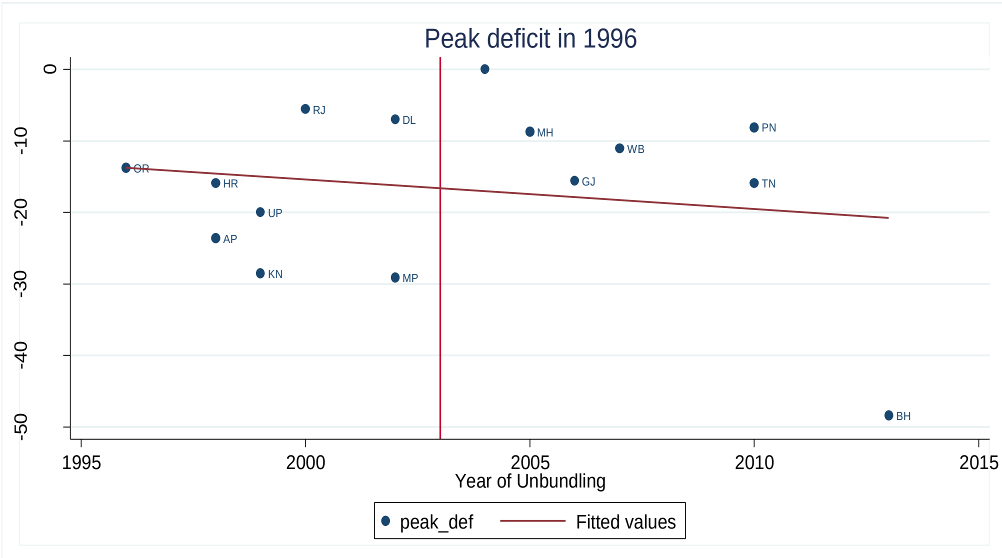
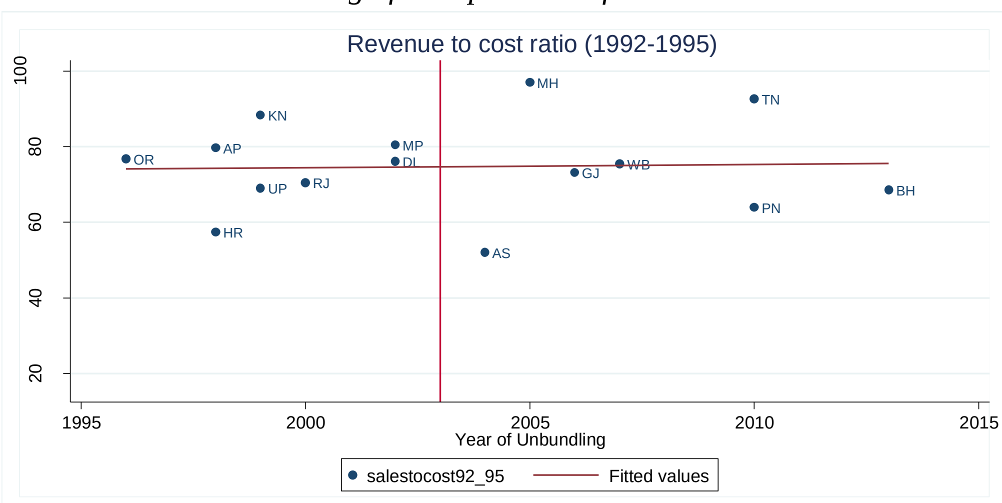


Figure 2: Correlates of the Year of Unbundling across States

Panel A: Energy deficit at peak demand in 1996



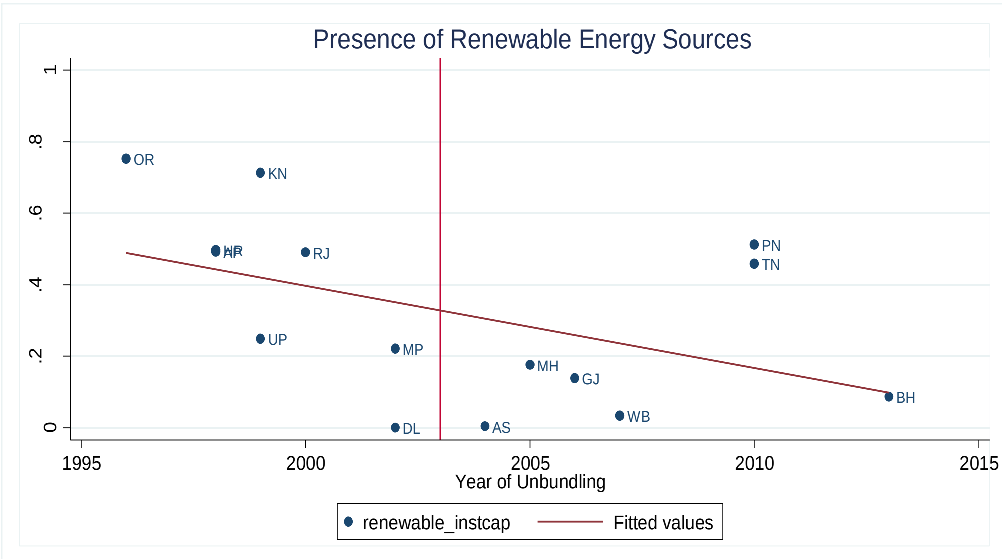
Panel B: Financial well-being of SEB prior to reform



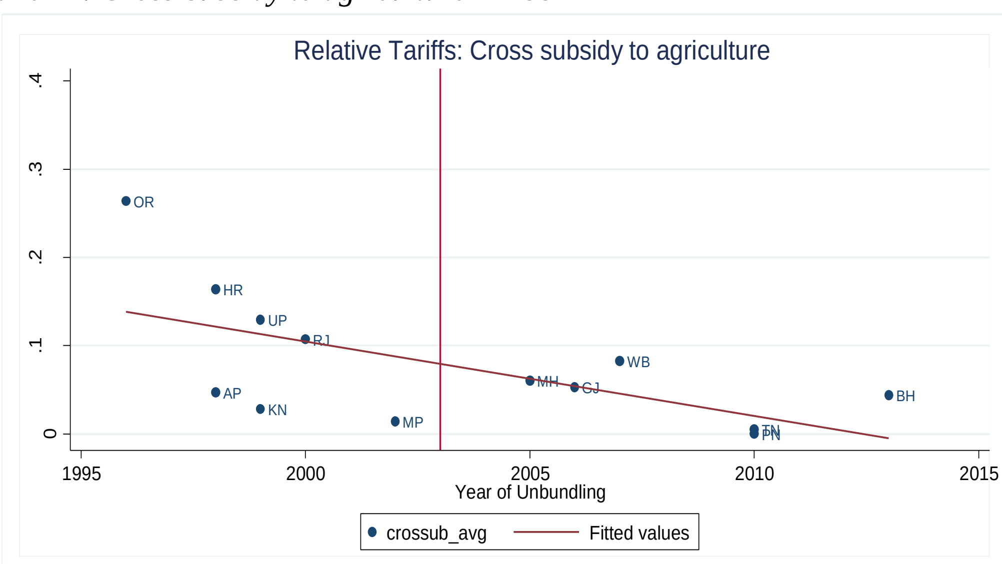
Note: 1. Jharkhand and Bihar have not unbundled as of 2012. We set 2013 as their arbitrary unbundling date to plot the averages.
2. The red line represents the Electricity Act of 2003 which divides the first and second phase of reforms.

Figure 2: Correlates of the Year of Unbundling across States

Panel C: Renewable energy capacity in 1997(Hydro and Wind)



Panel D: Cross-subsidy to agriculture in 1997



Note: 1. Jharkhand and Bihar have not unbundled as of 2012. We set 2013 as their arbitrary unbundling date to plot the averages.
2. The red line represents the Electricity Act of 2003 which divides the first and second phase of reforms.

Figure 3: Units Operating in Unbundled State-owned Generation Plants by Year

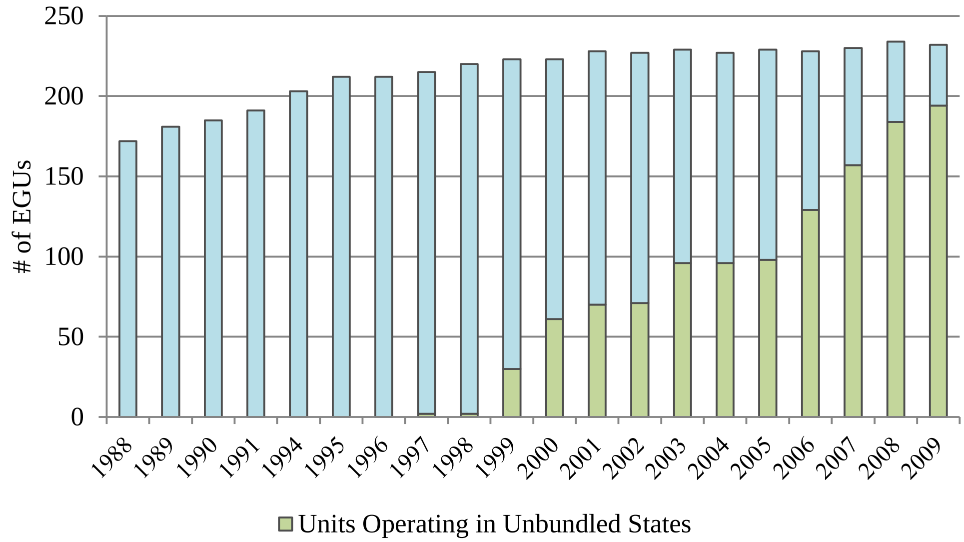


Figure 4A: Post Treatment Flexible Duration Estimates from DD Specification

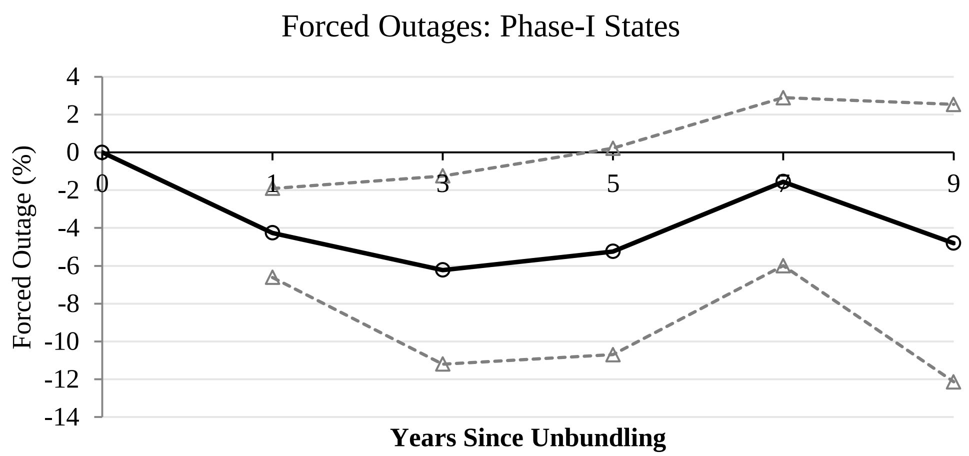


Figure 4B: Post Treatment Flexible Duration Estimates from DDD Specification

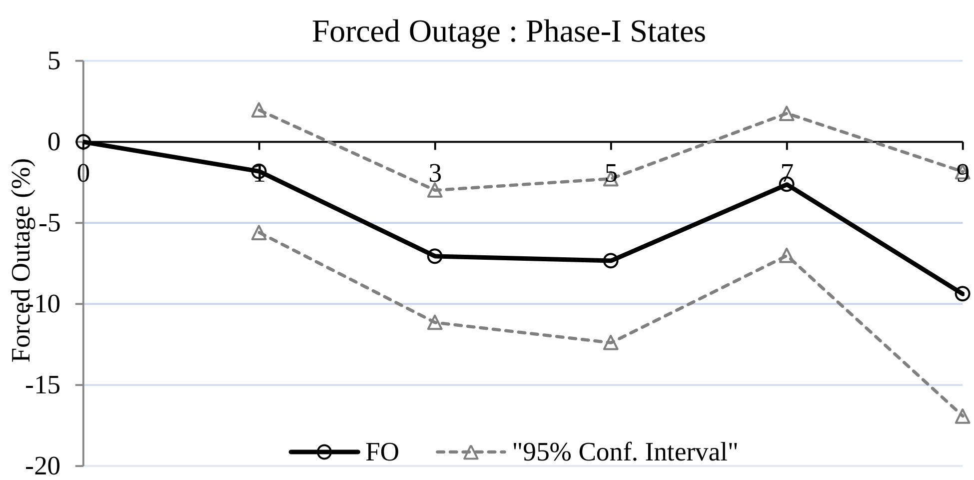


Figure 4C: Pre and Post Treatment Flexible Duration Estimates from DDD Specification

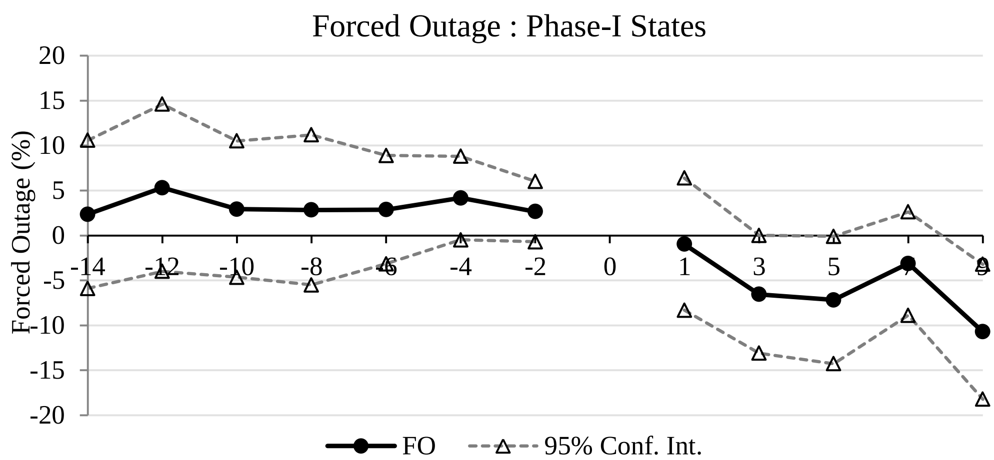
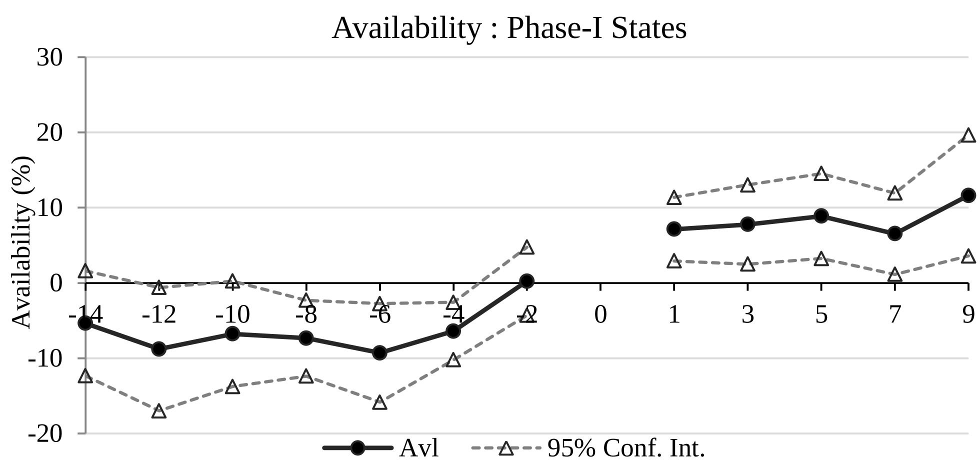


Figure 4D: Pre and Post Treatment Flexible Duration Estimates from DDD Specification



Appendix Table 1: Falsification - Impact of Unbundling on Central EGUs

	[1] Availability	[2] Forced Outages	[3] Availability	[4] Forced Outages
[Unbundled]	-1.516	-1.504		
	(2.276)	(2.407)		
[Phase-I*Unbundled]			-1.845	-2.175
			(3.306)	(3.193)
[Phase-II*Unbundled]			-0.681	0.196
			(2.104)	(2.515)
Time Trend	State	State	State	State
Unit FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes**:** Std. errors in parentheses, clustered at state level. *** p<0.01, ** p<0.05, * p<0.1. All equations control for a quadratic for EGU age, year and plant fixed effects and state time trends. Number of observations=1756 (119 Units).