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

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Abstract

India, like many countries, has attempted to reform its electricity sector by dismantling electricity utilities into separate generation, transmission and distribution companies. In 1995, all state government owned generation capacity was operated by vertically-integrated state electricity boards (SEBs). By 2009, 85 percent of the coal-based capacity owned by the state government was operated by unbundled state generation companies. This paper examines the impact of unbundling reforms on the operating efficiency of coal-fired power plants in India. Using information collected by India's Central Electricity Authority, I construct a panel dataset of electricity generating units (EGUs) for the years 1988–2009. I estimate the impact of reforms using difference-in-difference models that exploit the variation in the timing of reforms across states. I also estimate a triple-difference model that uses central government owned power plants, which were not directly impacted by restructuring, as an additional control group.

I estimate the impact of restructuring reforms on operating availability, forced outages, capacity utilization and thermal efficiency. My results suggest that the unbundling reforms significantly improved average annual plant availability by about 6 percentage points and reduced forced outages by 4.9 percentage points in states that unbundled before the electricity act of 2003. This represents a 25% decline in forced outages relative to 1995 levels. Restructuring has not, however, increased capacity utilization or improved plant thermal efficiency. The limited impacts may be due to the fact that unbundling has not yet attracted independent power producers into the market to the extent that it has in the United States.

JEL Codes: O13, O25, Q4, L43, L94
Key Words: Indian power sector; electricity reform, vertical disintegration, coal power.

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1 Introduction

Beginning with Chile in 1982 the last two decades of the 20th century were marked by the restructuring of the electricity sector in countries throughout the world. Utilities that were functioning as vertically-integrated monopolies were unbundled and privatized in an attempt to increase competition and lower costs. Electricity deregulation paved the way for the entry of independent power producers and the creation of wholesale electricity markets. The resulting gains in operating efficiency and reduction in costs have been documented using plant-level data for the US (Davis and Wolfram 2011, Fabrizio et al. 2007, Hiebert 2002) and cross-country data for developing countries (Khanna and Rao 2009; Jamasb et al, 2005). This paper adds to this literature by estimating the effects of electricity sector restructuring in India on the performance of state-owned thermal power plants.

In developing countries (Bacon and Besant-Jones 2001) electricity sector reforms usually begin with regulatory reform: creating agencies separate from the government that can regulate the power sector and promote transparency in regulatory reform. This is followed by the unbundling of vertically integrated utilities: separating generation from transmission and distribution. This is a necessary prerequisite to the development of competitive wholesale power markets, but can also lead to efficiencies in generation if companies are "corporatized" and faced with hard budget constraints. Unbundling may also improve efficiency by reducing diseconomies of scope—allowing managers to focus on decisions related solely to generation. This could result in improved plant maintenance, which would increase plant availability and reduce forced outages. Unbundling also facilitates the entry of independent power producers into electricity generation and the development of wholesale power markets. Eventually, divestiture of state ownership may occur.

The ultimate goal of electricity reforms is to improve both technical and allocative efficiency in electricity generation and to pass these savings onto consumers. The key policy question is whether reforms have been successful and, more importantly, what type of reforms yield what type of efficiency benefits. Fabrizio et al. (2007) suggest that, in the short term, the restructuring of electricity markets did not improve technical efficiency at thermal power plants in the US; however, it did reduce expenditure per kWh on non-fuel inputs. Davis and Wolfram (2012) examine the impacts of electricity deregulation on the US nuclear power industry. They find that, in spite of increased concentration of ownership, deregulation led to a 10 percentage point decrease in forced outages at nuclear power plants.

The question I address is whether electricity reform in India has improved operating efficiency at coal-fired power plants. Has it improved the thermal efficiency of plants (e.g., reduced the coal burned per kWh) and/or improved plant performance? Specifically, has it increased plant availability and reduced forced outages? The answer may well differ from what has been found in the US, where vertically integrated generating capacity was unbundled and sold to private operators. In India, State Electricity Boards (SEBs) in India were unbundled but not privatized—they were "corporatized." The question is what impact this reorganization, in the absence of ownership change, has had on power plant performance.

I investigate the impact of unbundling using a panel data set of thermal power plants for the years 1988–2009, using 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, I estimate difference-in-difference models for plant availability, forced outages, operating heat rate, and coal burned per kWh. These models compare the performance of plants in states that unbundled with plants in states that had not yet unbundled. In order to control for state-year shocks that may affect estimates of average treatment effects, I also estimate triple-difference models that use plants operated by the central government, which were not the target of restructuring, as an additional control group.

My results suggest that the reorganization of the SEBs has improved average annual plant availability by reducing forced outages. However, the unbundling of SEBs appears, on average, to have had little impact on the thermal efficiency of state-owned power plants. My results show considerable variation in the magnitude of these impacts across states. The biggest improvements following unbundling have occurred in the states that were among the first to unbundle—that is, those states that unbundled generation from transmission and distribution before the Electricity Act of 2003. On average, plant availability in those states increased by about 6 percentage points and forced outages decreased by 4.9 percentage points, a 30 percent decline in forced outages relative to 1996 levels. This could represent a duration-of-treatment effect: the impacts of reform take time to be realized.[1] When I estimate a flexible duration model, the results suggest that it took between 3 and 6 years for significant reductions in forced outages to occur in states that unbundled before the Electricity Act of 2003.

An important result of the paper is that, although unbundling appears to have increased plant availability by reducing forced outages, it did not increase capacity utilization. There were significant increases in plant load factors at both state-owned and central-owned plants between 1996 and 2009, but there is no evidence that these were the result of unbundling.

The paper is organized as follows. Section 2 provides background on the Indian power sector and the nature of reforms. Section 3 describes the empirical approach taken. In section 4 I discuss econometric issues. Section 5 describes the data used in the study and the following section the results. Section 7 concludes.

2 Background

a. History of Reforms in the Indian Power Sector

In the decades following independence, the Indian power sector, like those of many developing countries, was characterized by inadequate generating capacity, frequent blackouts, and high transmission and distribution losses. The thermal efficiency of Indian power plants was low compared to similar plants in high-income countries.[2] Electricity pricing was characterized by direct government subsidies, with high tariffs to industry cross-subsidizing low tariffs for residential and agricultural consumers. Following the nationalization of the power sector in 1956, most generating capacity was government owned.

[1] In my dataset 10 years have elapsed, on average, since the first group of states unbundled. The corresponding figure is 2.5 years for states that unbundled after the 2003 Electricity Act.

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

In 1990, 63 percent of thermal generating capacity was owned by SEBs,[3] which operated on soft budgets, with revenue shortfalls made up by state governments. Electricity tariffs set by SEBs failed to cover costs, generating capacity expanded slowly in the 1960s and 1970s, and blackouts were common. 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 CEA. The Electricity Regulatory Commissions Act of 1998 made it possible for the states to create SERCs to set electricity tariffs. States were to sign memoranda of understanding with the federal government, agreeing to set up SERCs and receiving, in return, technical assistance to reduce transmission and distribution losses and other benefits. The Electricity Act of 2003 made the establishment of SERCs mandatory and required the unbundling of generation, transmission, and distribution (Singh 2006). Table 1 shows the year in which the SERC became operational in each state and the year in which generation, transmission, and distribution were unbundled.[4]

Another objective of the 2003 Electricity Act was to reform the electricity tariff structure—both for end users and for generators. SERCs are to follow the CERC's guidelines in compensating generators. The CERC compensates the power plants under its jurisdiction based on performance. Compensation for energy used in generation is paid based on scheduled generation and depends on operating heat rate. Compensation for fixed costs (depreciation,

[3] In 1990, 33 percent of capacity was owned by the central government and 4 percent by private companies. In 2006, 51 percent of thermal generating capacity was owned by SEBs, 37 percent by the central government, and 12 percent by private companies (CEA 2007).
[4] Table 1 lists only those states containing thermal power plants. My study focuses on coal- and lignite-fueled plants.

interest on loans and finance charges, return on equity, operation and maintenance expenses, interest on working capital, and taxes) is based on plant availability. In addition, an availability-based tariff (ABT) was instituted in 2002 to regulate the supply of power to the grid. If a generator deviates from scheduled generation, the ABT imposes a tariff that depends on system frequency (Chikkatur et al. 2007).

b. Studies of Electricity Sector Reforms

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

Most of the studies that have examined the impact of reforms on generation efficiency using plant-level data employ either stochastic frontier or data envelopment analysis methods. In the United States, Knittel (2002) and Hiebert (2002) use stochastic frontier analysis to study the impact of reforms on generation efficiency. Knittel (2002) estimates a stochastic production frontier that allows the mean of the efficiency component of the error term to depend on the compensation program that the generator faces.[5] He finds greater production efficiency for plants that operate under programs that provide direct incentives for increased efficiency by compensating generators based on heat rate and plant availability (compared with plants compensated on a cost-plus basis).

Hiebert (2002) estimates a stochastic frontier cost function to examine the efficiency impacts of unbundling and open access to transmission and generation using U.S. data for the period 1988–1997. As in Knittel (2002), he jointly estimates the parameters of the stochastic frontier

[5] 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.

and the factors determining the efficiency component of the error term. His analysis shows that investor-owned utilities and cooperatively owned plants are more efficient than publicly owned municipal plants. Hiebert adds dummy variables for states that unbundled generation from transmission and distribution in 1996 and 1997. The results indicate efficiency gains in 1996 (but not 1997) for coal-fired plants that were operating in states that implemented reforms.

Fabrizio, Rose, and Wolfram (2007) study the impact of electricity restructuring on generation efficiency in the United States using a difference-in-differences approach to measuring efficient input use. Using a plant-level panel (1981–1999) of gas- and coal-fired thermal power plants, the authors estimate cost-minimizing input demands as a function of plant characteristics while controlling for the regulatory regime. They show that privately owned utilities in restructuring states experienced greater gains in efficiency of nonfuel input use compared to similar utilities in non-restructuring states and cooperatively or publicly owned generators that were insulated from the reforms. Because of the nature of the restructuring process in the United States, their restructuring measure combines the effect of unbundling of generation from transmission and distribution with opening the generation sector to retail competition. The authors, however, attribute most of their impact to the unbundling of generation, as retail competition was limited to only seven states during the period of analysis.

Although the literature examining the impact of reforms in the Indian electricity sector is growing (e.g., Thakur et al. 2006; Singh 2006; Chikkatur et al. 2007), the only econometric study that attempts to estimate ex-post generation efficiency gains is Sen and Jamasb (2012). The authors use panel data at the state level for the period 1990–2007 to test the impact of reforms on capacity utilization (plant load factor), gross generation and transmission, and distribution losses.[6] Specifically, they explain the three performance measures as functions of six regulatory dummy variables and state and year fixed effects.[7] They find that the unbundling and tariff order dummy variables show a strong positive effect on capacity utilization, as does the ratio of industrial to agricultural electricity prices. They also find that the SERC, unbundling, and

[6] The analysis reported is for 245 observations across 18 states and 17 years.

[7] 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.

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 (2012), I use data at the plant level to examine the effect of unbundling on the performance of state-owned power plants. This allows me to control for plant fixed effects, state time trends, and year fixed effects. I argue that, conditional on these (and other) controls, the unbundling of generation from transmission and distribution can reasonably be regarded as exogenous.

3 Empirical Strategy

To examine the impact of restructuring on operating efficiency of state government owned generation plants, I 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).[8] Thermal efficiency is measured by coal consumption per kWh and by operating heat rate. Specific coal consumption measures the quantity of coal used to produce a unit of electricity (kg/kWh). Operating heat rate measures the heat energy—from coal and oil (secondary fuel)—required to produce a unit of electricity (kcal/kWh). I also estimate the impact of reform on the capacity utilization factor[9] of the EGU. Conditional on EGU characteristics, this measures the electricity that the unit produces in a year.

The time variation in the policy change across states in India allows the use of a quasi-experimental difference-in-difference (DD) estimator (see Figure 1). With data at the EGU-level, I estimate the impact of unbundling on generation efficiency controlling for time-invariant characteristics of EGUs, year-specific effects and linear time trends specific to each state. The baseline model is estimated using the following specification,[10]

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[8] The percentage of time available will be directly affected by the percentage of time that the unit is under shutdown due to forced outages. Availability is also reduced due to routine maintenance.

[9] The capacity utilization factor is referred to as the plant load factor (PLF) in official Indian electricity sector reports. I use the terms interchangeably here.

[10] Aghion et al. (2008) use a similar procedure to estimate the impact of the dismantling of the licensing regime in India on manufacturing output. They take advantage of state and industry variation in industrial policy to estimate a

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

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 $[Unbundled]_{st}$, 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 the baseline specifications estimate the impact of reforms controlling for a full set of 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 each unit 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. The strong upward trend in efficiency measures at both state and central plants throughout the sample period shown in Figure 2 implies that without year fixed effects estimates of the impact of unbundling would be vastly overestimated. Estimates of the effects of unbundling may also be biased due to differences in 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[11] and the thermal efficiency regressions include the average unit capacity in the plant, the heating content of coal

difference-in-difference 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.

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

(gross calorific value per kg), the average design heat rate and a quadratic term for average plant age.[12]

There were two distinct waves of unbundling reforms in India. The first wave, between 1996 and 2002, took place prior to the Electricity Reform Act of 2003. The second wave began in 2005 and continues through the end of my sample period (2009).[13] To test whether reforms had differential impacts for each phase of reform, I allow the coefficients on reform impacts to vary between states that unbundled before and after the Electricity Reform Act of 2003. Table 1 lists the states based on the timing of unbundling reforms. I refer to these as Phase 1 (unbundling prior to 2003) and Phase 2 (unbundling between 2004 and 2009) states. The remaining states unbundled either outside of my sample period or have not unbundled as of 2012.

To estimate the heterogeneous impact of unbundling equation (1) is estimated with interactions between the unbundled variable and indicators for Phase 1 and Phase 2 states.

$$Y_{ist} = \sum_{k=1,2} \emptyset_k (UNB_{st} * \pi_{ks}) + X_{ist}\beta + \sum_{s=1}^{17} \mu_s TREND_j + \tau_t + \theta_i + \varepsilon_{ist} \qquad (2)$$

In equation (2), π_{ks} is the indicator variable for state s belonging to group k (k = Phase1/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, I test for persistence in reform impacts over time. To do this, I include 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 important to check whether reforms result in a permanent change in operational 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.

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

[12] The average plant age is calculated as the capacity-weighted average of the age of EGUs within the plant. Unlike the quadratic age variable in the EGU regressions, the average age could decrease from one year to the next with the installation of a new EGU in the plant.
[13] Assam unbundled in 2004, but its only coal-fired power plant was decommissioned in 2001-02.

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[14]. Allowing full flexibility in post treatment impacts enables the trend slope coefficients to be determined by the pre-treatment period trends and allows me to examine the evolution of efficiency increases after unbundling reform. The estimate of dynamic effects of reform relies on the following specification,

$$Y_{ist} = \sum_{t=1,3,5,..}\sum_{k=1,2} \emptyset_k^t(UNB_{st} * \pi_{ks} * D_t^{t+1}) + X_{ist}\beta + \sum_{s=1}^{17}\mu_s TREND_j + \tau_t + \theta_i + \varepsilon_{ist} \quad \dots (3)$$

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 having 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 was endogenous, thus biasing estimated impacts. Endogeneity may result because state officials explicitly considered 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, my estimation strategy and the institutional context of power sector reforms in India should reduce endogeneity concerns.

[14] This is unlikely to be a serious problem in this analysis as I have adequate data prior to unbundling.

First, the inclusion of EGU fixed effects controls for any time-invariant differences across EGUs. The fixed effects also control for constant state-level factors such as state location (vis-à-vis coal mines and the transmissions 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);[15] however, this is unlikely to bias estimates of generation efficiency.

Although the small number of states with coal-fired power plants (17) makes formal econometric modeling of the timing of adoption infeasible, graphical evidence suggests that the timing of reforms was unrelated to generation efficiency. Panels A-D of Figure 3 show that there is no evidence of a relationship between the timing of unbundling and pre-reform measures of average power plant performance in the state (measured by availability and capacity utilization), the shortage of power supply (deficit as a proportion of peak demand), or financial viability and size of SEBs.[16] Panel E suggests that states with a higher proportion of renewable electricity generation unbundled earlier. Renewable capacity is largely hydro power and thus determined by exogenous geographical features. Finally, panel F shows that states with lower subsidies to agricultural consumers (a higher ratio of agricultural to industrial tariffs) were more likely to unbundle earlier; however, subsidies to agriculture are uncorrelated with generation efficiency.[17]

[15] It is not surprising that Orissa was the first state to reform, given the (un)importance of farming in the state.
[16] The size of labor force of the SEBs is one of the possible explanations of delayed reform. Labor unions in overstaffed SEBs would likely oppose reform due to the possibility of layoffs. However, the graph shows that this was not a decisive factor in delaying unbundling reforms.
[17] I also check for presence of geographical sorting (if reform took place in geographical clusters) and whether state economic well-being (per capita income and electricity consumption) drives reform. I find no evidence to suggest that either of these determined the timing of unbundling reform.

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 I 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.[18] To account for state-specific non-linear year shocks, I employ a triple-difference (DDD) specification that includes central power plants and uses state-year dummy variables,

$$Y_{\{isot\}} = \alpha + \beta * Reform_{\{sot\}} + \theta * Controls_{\{isot\}} + \phi_{\{ot\}} + \psi_{\{st\}} + \nu_i + \epsilon_{\{ist\}} \quad \text{... (4)}$$

In equation (4), $Y_{\{isot\}}$is the outcome at EGU i in state s under ownership o in year t. $\phi_{\{ot\}}$ represents the full set of ownership (state/central) year effects and $\psi_{\{st\}}$ represents the full set of state-year effects. The specification thus non-parametrically controls for time effects in each state and time effects for each ownership type. The estimate of the impact of unbundling, β, is identified by the variation ownership-state-year (as compared to state-year variation that identifies the estimate in the DD specification). The DD estimate takes the following form,

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

In equation (5), $\Delta^t \mathrm{Y}_{\{\mathrm{U}\}}$ 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.

[18] To confirm this, I 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.

5 Data

My primary source of data is the "Performance Review of Thermal Power Stations" published annually by the Central Electricity Authority of India. These reports contain performance characteristics for all state and central government owned coal and lignite[19] fired EGUs in the country that are above 25W and sell electricity commercially[20, 21]. The coverage of private power plants is incomplete and thus they are left out of the analysis.

I use these reports to construct an unbalanced panel of 385 EGUs that operate in state and central coal-fired power plants, for the years 1988–2009.[22] Of the 385 EGUs, 270 operate in 60 state-owned generation plants and 115 are in 23 central-government-owned plants. The plants in the dataset constitute 75 percent of the total installed coal-fired generation capacity in the country in the year 2007–2008.

The information in the reports is based on the data that thermal power plants submit to the CEA. The reports contain data on nameplate capacity, manufacturer, unit availability, forced outage, capacity utilization and electricity generation at the EGU level. All operating parameters are measured in percentage terms; e.g., availability is the percent of time that an EGU is available for the production of electricity in a year. The reports also contain plant-level data on specific coal consumption, secondary fuel oil consumption,[23] operating heat rate and its deviation from design heat rate. The operating heat rate captures the heat input (from both coal and secondary fuel oil) that is required to produce a unit of electricity (kcal/kWh).

[19] There are 4 lignite based power plants in the dataset. Although there are differences in the nature of these plants they are captured by the EGU/plant fixed effects. The management and operations of lignite based plants are broadly similar to that of a coal-based plant and thus I do not drop them from the data. However, these plants are left out of the thermal efficiency equations as they do not have data on coal consumption and quality. Any reference to coal plants implies coal and lignite plants unless otherwise stated.

[20] Captive power plants, owned and operated by private companies to supply electricity to their own factories are not included.

[21] Newly commissioned EGUs may also be left out from the report if they have not "synchronized" for an adequate amount of time prior to the collection of data. Synchronization with the power grid is necessary before the EGU can begin commercial operations.

[22] The CEA reports are not available for the years 1992 and 1993. These years are thus omitted from my 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.

[23] Secondary fuel oil is used during ramping up of the EGU. Oil is used to stabilize the flame in the boiler before coal is injected.

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.

Tables 3A and B present summary statistics that compare state EGUs (Table 3A) and plants (table 3B) by phase of reform in the period prior to restructuring (1988–1995) [24] and at the end of the sample period (2006–2009). Tables 4A and B present similar comparisons between state and central EGUs (Table 4A) and plants (Table 4B). Both capacity-weighted and un-weighted variable means are reported. Several points are worth noting.

First, 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 outage, availability, capacity utilization—from Phase 2 states.[25] Specific coal consumption and operating heat rate at EGUs in Phase 1 states were also slightly below other states by 2006-09, though 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 significant 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.

Second, the comparison between state and central plants 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 10 percent higher at state plants, although the difference is not statistically significant.[26] A comparison of operating heat rates at state and central plants is difficult, as data are often missing for plants operated by

[24] Due to missing data, this period does not include the years 1992 and 1993.
[25] 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.
[26] The difference in the mean specific coal consumption remains roughly the same for 2006-09, but now becomes statistically significant.

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 1988–1995 (3,115 kcal/kWh, capacity-weighted) was 30 percent higher than the average operating heat rate of subcritical plants in the United States during the period 1960–1980 (Joskow and Schmalensee 1987).

During the sample period, both state and central plants improved in reliability, but showed little improvement in thermal efficiency. Table 4 indicates that EGUs in both sets of plants have experienced large gains in capacity utilization (an average increase of 18 percentage points for state and 24 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. The increase in the average reliability of EGUs for both state and central plants is also pictured in Figures 2A-2C.

6 Results

The impacts of unbundling using plants in states that have not yet unbundled as controls are summarized in Tables 5 and 6 and in Figure 4A. Table 5 presents estimates of the impact of unbundling reforms for thermal efficiency outcomes using plant-level data. Table 6 contains estimates of the impact of reforms on operating reliability (availability and forced outages) using unit-level (EGU) data. Columns [1] and [2] show the average treatment effects estimated using the baseline model in equation (1). Column [3] and [4] estimate the heterogeneous impacts using the specification in equation (2). The impacts of duration of treatment are pictured in Figures 4A and 4B.

This is followed by estimates of the impacts of unbundling using central plants, as well as plants in states that have not yet unbundled, as controls. Table 7 verifies that central plants are a valid control group by examining the impact of SEB restructuring on EGUs in central plants. Table 8 presents results from the triple-difference model specified in equation (4). Figures 4B through 4D display the post-unbundling impact duration estimates for Phase 1 states from a DDD specification similar to equation (3). Table 9 examines the impact of restructuring on capacity utilization, and Table 10 presents the results from a series of robustness checks that test the stability of the main results.

a. *Difference-in-difference Results for Thermal Efficiency*

Table 5 displays the impact of unbundling on thermal efficiency at state-owned power plants based on models for ln(specific coal consumption) and ln(operating heat rate). The models control for a quadratic term for age, heat content of coal, the design heat rate and the average nameplate capacity of units in the plant.[27]

For each EGU, the amount of fuel required to produce a kilowatt-hour of electricity should depend on the unit's design heat rate, the quality of coal used, and the age of the unit (Joskow and Schmalensee 1987). An increase in the heat content of coal, measured as the gross calorific value per kg of coal (kcal/kg) will, all else equal, lower the amount of coal needed to produce a unit of electricity. I control for heat content as plant managers have little opportunity to alter the heating value of the coal they receive, given the structure of the Indian coal market.[28] As long as an increase in the heat content of coal is not fully offset by a corresponding reduction in the quantity used to produce a unit of electricity, a higher heat content should raise operating heat rate.[29]

Units with higher design heat rates will burn more coal per kilowatt-hour than units with lower design heat rates, and usually, unit performance should deteriorate with age, although performance may actually improve after the first few years of operation. Increasing boiler size should reduce the amount of coal required per kilowatt-hour, up to some point. Although not reported in the table, the regression results confirm that thermal efficiency declines with plant age and is higher at plants with larger EGUs, although this effect is not significant at conventional levels.

Table 5 shows that after controlling for plant characteristics and state-level trends, there is no evidence to support the hypothesis that unbundling improved the thermal efficiency of

[27] Because my 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.

[28] 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.

[29] Because coal constitutes most of the kcal used to generate electricity, OPHR ≈ (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. My results confirm this.

state-owned power plants.[30] Average treatment 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. (The same is true, to a lesser extent, for operating heat rate.) These increase could be due to idiosyncratic shocks to the quality of coal (e.g., to its ash and moisture content) for which I do not have data.

b. Difference-in-Difference Results for Operating Reliability

Columns [1] and [2] of Table 6 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] 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 the operating reliability: average EGU availability increased by 6.8 percentage points. This increase represents a 10 percent increase in availability over 1995 levels. The improvements in availability were largely driven by a reduction in forced outage. The unbundling of generation resulted in a 5.1 percentage point reduction in the time lost from breakdowns, a 25 percent reduction from the 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. Robustness checks (discussed below) suggest that the impacts on units in Phase 2 states are quite unstable.

c. Triple-difference Estimates on Operating Reliability

[30] The use of plant-level data and missing observations for heat rate and coal quality restrict the estimation sample quite drastically compared to the operating reliability equations.

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 central plants. To test this, I estimate a model of the impacts of SEB restructuring EGUs at central power plants. The results, presented in Table 7, 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 8 presents the results from the DDD estimation of the impact of unbundling, by phase. The results in Table 8 are qualitatively similar to those in Table 5 for the DD specification. The coefficient estimates show a statistically significant increase in availability and a decrease in forced outage for EGUs in Phase 1 states. Compared to DD estimates the estimated impact on availability is lower by 1 percentage point[31] and the impact on forced outage is very similar—0.2 percentage point lower in absolute value for the DDD estimate. The increased availability of 5.9 percentage points is equivalent to an additional 700 MW becoming available for the production of electricity[32] (the average EGU size in 2009 in the sample was 170 MW). The roughly 5 percentage point reduction in forced outage represents a 25 percent reduction from the mean for these states in 1995.

d. Dynamic Effects of the Impact of Unbundling

Figures 4A to 4D examine the dynamic impact of SEB restructuring for EGUs in Phase 1 states. Using the specification given in equation (3), I estimate the impact of unbundling by imposing minimal structure on its evolution over time. Figures 4A to 4D plot the estimated coefficients of time dummy variables that represent two year intervals after reform for Phase 1 states[33] (in figures 4C and 4D, the pre-reform time dummy variables are also plotted).

[31] The estimate is less significant—at the 10 percent level of significance as opposed to the 5 percent level in the DD estimates.
[32] The total installed capacity at state-owned coal-fired power plants in Phase 1 states is about 11766 MW in 1995. The size of the biggest unit in the dataset is 500 MW.
[33] 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. I combine years greater than 9 into one dummy because the number of observations is too low to estimate finer categories.

Figure 4A and 4B show a similar pattern of the impact on forced outage over time for both DD (figure 4A) and DDD (figure 4B) specifications. There is, however, a difference between the two specifications in the statistical significance of the estimates: the DD coefficients are less precisely estimated. The DDD estimates in figure 4B suggest a lag in the reduction of forced outage after unbundling for Phase 1 states. The impact is significant starting 3 years after unbundling, except for a temporary spike 7-8 years after reform.

Figures 4C and 4D plot the results from a more flexible specification of the DDD model. Here, I allow both the pre- and post-reform time effects for state-owned EGUs to vary non-parametrically.[34] Figure 4C shows that the flexible estimation of the pre-reform trend in forced outage at state-owned EGUs yields a flat trend.[35] The evolution of the impact after unbundling is the same as that presented in figure 4B above. Figure 4D shows that the significant reform impacts on availability for Phase 1 states persist for the duration of the sample[36].

e. Impacts on Capacity Utilization

Table 9 reports estimates of the impact of restructuring on the capacity utilization of state-owned EGUs. Column [1] and column [2] report the impacts, by phase, from the DD and DDD specifications. I find no evidence to suggest that unbundling generation from transmission and distribution led to an increase in the 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 plants. It is interesting to note that average capacity utilization at state-owned EGUs increased by roughly 25 percentage points from 1991 to 2009 (see Figure 2C). It is possible that Sen and Jamasb (2012) do not adequately control for this positive trend in their estimates.

[34] This is similar to an event study specification.
[35] Conditional on all the covariates included in the DDD estimation.
[36] A comparison of the trend coefficients between average treatment effects and dynamic effect specifications reveals that the incorrect estimation of the trends in the average effects estimation is not a serious problem in my analysis.

f. Robustness Checks

Table 10 tests the robustness of my main results to changes in the sample and to slight changes in equation specification. Columns [1] and [2] drop Phase 2 states from the sample. The estimated impact is thus a comparison between units in Phase 1 states and units in states that do not unbundle within the sample period. The coefficient estimates from the restricted sample are qualitatively similar to those from the DDD models in Table 8. Columns [3] and [4] test the robustness of the results to the inclusion of phase-wise trends (instead of state-specific trends). This causes the magnitude of impact to increase only slightly for both availability and forced outage in Phase 1 states.

Columns [5] through [8] drop any units with availability close to zero (units available less than 1 percent of the year) from the sample. This effectively removes units that have been shut down in estimating the impact of reforms. These coefficient estimates are very similar to the main results.[37]

Since the main results of the analysis are based on an unbalanced panel, an obvious concern is the effect of entry and exit of EGUs from the sample. As new units tend to be more efficient and exiting units are likely to be those that are less efficient, previous estimates confound changes in efficiency due to entry/exit with increases in efficiency at existing EGUs. Estimates in column [9] and [10] restrict the sample to EGUs that were not commissioned or decommissioned within the sample period. The results from the balanced sample are broadly similar to the estimates from the full sample—although the impact on availability becomes insignificant.

Overall, the estimated impact of unbundling on units in Phase 1 states is robust to changes in equation specification and sample composition.[38] The impact of unbundling on forced outage is slightly more robust (in terms of statistical significance) than that for availability. This is likely a result of the noise introduced in the measure of availability from time lost due to routine maintenance of the EGU. The robustness checks also show that impacts on Phase 2 states

[37] I drop all EGU-year observations with availability <1.

[38] I also estimate the DD and DDD specifications dropping one state at a time from the sample. The estimates remain reasonably stable.

are very imprecisely estimated and are sensitive to changes in sample and equation specifications.

7 Conclusions

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

The main results, from a triple difference specification, suggest a 5.9 percentage point increase in unit availability and a 4.9 percentage point reduction in forced outages in Phase 1 states. The increase in availability is equivalent to an additional 700 MW of installed capacity. 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 shows that the improvements in generation reliability are not reversed in the short to medium term. The magnitude of the average impacts is fairly robust to modifications in model and sample specifications.

My results are comparable to results obtained by Fabrizio et al. (2007) and Davis and Wolfram (2011) for the US but differ from those of Sen and Jamasb (2012) for India. Fabrizio et al. (2007) do not find significant impacts of restructuring on the thermal efficiency of plants, although they do find significant reductions in non-fuel expenditure. 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 the reduction in forced outages. Sen and Jamasb (2012) find that unbundling increased average capacity utilization by 26 percentage points in states that unbundled—an extremely large effect.

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

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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
	Punjab	1999	2010
	Tamil Nadu	1999	2010
	Bihar	2005	[a]
	Jharkhand	2003	[a]

[a] Reform not implemented by 2012.

Table 2. Indian Power Sector Regions Prior to Reform

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

Table 3A. Variables Means, State-owned EGUs, by Unbundling Phase (EGUs)

Comparison of means				Phase 1				Phase 2				Phase 3			
				1988-1995				1988-1995				1988-1995			
(Early v. mid)	(Early v. late)	(Mid v. late)		N	Wt. mean	Mean	Std. dev.	Obs.	Wt. mean	Mean	Std. dev.	N	Wt. mean	Mean	Std. dev.
***	***	*	Nameplate capacity (MW)	466		117	73	461		146	74	217		131	60
***			Generation (GWh)	466	800	534	489	461	913	686	498	217	733	561	465
**	***		Age	466	11.3	14.8	8.0	458	10.8	13.5	8.2	217	10.3	12.9	7.5
***	**		Forced outage (%)	466	18.5	21.5	20.4	461	13.9	16.8	20.4	217	15.3	17.6	17.2
	***	***	Planned maintenance (%)	466	11.0	12.2	18.7	461	12.5	14.2	18.7	217	16.2	18.3	27.4
*		***	Availability (%)	466	70.5	66.3	23.4	461	73.5	69.0	23.8	217	68.4	64.1	26.4
	**		Plant load factor (%)	466	54.7	50.0	21.2	461	55.1	49.8	20.7	217	50.9	46.0	24.0
						2006-2009				2006-2009				2006-2009	
		*	Nameplate capacity (MW)	399		164	91	370		172	86	155		159	61
			Generation (GWh)	399	1434	1062	750	370	1345	1052	656	155	1270	1038	664
*	*		Age	399	18.1	23.0	12.2	370	21.3	24.6	11.7	155	21.6	24.7	9.3
			Forced outage (%)	399	8.3	10.8	14.7	370	10.7	12.6	16.3	155	9.9	13.3	18.4
**	**	***	Planned maintenance (%)	399	6.6	8.2	15.6	370	6.1	6.1	9.8	155	9.5	12.6	23.1
	***	***	Availability (%)	399	85.0	81.0	19.8	370	83.2	81.4	18.0	155	80.6	74.2	27.6
			Plant load factor (%)	399	75.2	69.1	23.7	370	70.7	68.1	20.1	155	74.4	66.1	30.0

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. Weighted means are capacity weighted. Difference in means according to a two-sample *t*-test with unequal variances*** p<0.01, ** p<0.05, * p<0.1

Table 3B. Variables Means, State Plants, by Time of Unbundling (Plant Data)

			Phase 1				Phase 2				Phase 3			
			1988-1995				1988-1995				1988-1995			
Diff. in Means (Early v. Mid.)	Diff. in Means (Early v. Late)		Obs.	Wt. mean	Mean	Std. dev.	Obs.	Wt. mean	Mean	Std. dev.	Obs.	Wt. mean	Mean	Std. dev.
		No. of operating units	97		4.1	3.0	98		3.9	1.6	42		4.3	2.2
*		Nameplate capacity (MW)	97		478	426	98		580	390	41		578	287
***	**	Average unit capacity (MW)	97		114	65	98		141	60	41		140	58
**		Net generation (GWh)	89	759	528	446	96	850	656	397	41	692	561	417
	**	Age	97	11.4	13.3	8.2	98	11.0	12.1	7.1	41	10.4	10.9	5.9
***		Forced outage (%)	97	18.7	19.7	14.3	98	13.2	14.5	12.2	41	15.6	18.3	13.2
		Planned maintenance (%)	97	10.7	12.2	11.9	98	12.2	12.7	8.6	41	15.1	15.8	12.3
**		Availability (%)	97	70.6	68.1	17.2	98	74.6	72.8	14.8	41	69.2	65.9	16.7
		Plant load factor (%)	97	54.7	51.3	17.3	98	55.6	52.1	15.6	41	51.7	46.9	19.6
	***	Heating value of coal (kcal/kg)	41	3936	4111	579	47	4246	4246	611	24	3768	3773	369
***	***	Design heat rate (kcal/kWh)	36	2628	2637	191	41	2390	2438	148	12	2463	2486	70
**		Operating heat rate (kcal/kWh)	42	3231	3394	638	49	3060	3088	456	24	3060	3231	706
*		Deviation from operating heat rate	24	0.27	0.36	0.21	34	0.25	0.26	0.18	12	0.25	0.34	0.31
***		Specific coal cons. (kg/kWh)	82	0.83	0.86	0.28	83	0.72	0.71	0.11	41	0.78	0.82	0.14
***		Auxiliary cons. (% gross gen.)	89	9.58	10.00	1.66	96	9.01	9.35	1.57	41	9.43	10.10	2.44
			2006-2009				2006-2009				2006-2009			
	**	No. of operating units	87		4.5	2.7	93		4.0	1.9	43		3.6	1.7
	**	Nameplate capacity (MW)	86		758	550	93		688	509	43		574	340
		Average unit capacity (MW)	86		152	75	93		166	68	43		161	56
		Net generation (GWh)	86	1317	943	659	93	1228	948	511	43	1170	923	611
		Age	86	18.1	21.4	11.1	93	21.3	21.7	11.6	43	21.5	22.4	8.5
		Forced outage (%)	86	8.3	13.4	13.3	93	11.1	13.4	13.0	43	9.9	15.8	18.0
	*	Planned maintenance (%)	86	6.5	6.9	6.3	93	6.0	5.7	4.0	43	9.6	13.0	21.0
	*	Availability (%)	86	85.2	79.7	14.1	93	82.9	81.0	12.8	43	80.5	71.3	26.9
		Plant load factor (%)	86	75.4	66.6	21.9	93	70.4	68.0	16.3	43	74.4	62.8	30.3
	***	Heating value of coal (kcal/kg)	48	3533	3547	386	45	3541	3673	493	29	3726	3773	334
		Design heat rate (kcal/kWh)	52	2347	2406	179	66	2364	2423	201	29	2358	2383	110
		Operating heat rate (kcal/kWh)	53	2699	2901	642	65	2836	2932	323	29	2669	2777	456
		Deviation from operating heat rate	52	0.15	0.20	0.19	65	0.20	0.21	0.10	29	0.13	0.16	0.15
		Specific coal cons. (kg/kWh)	76	0.77	0.82	0.13	63	0.78	0.78	0.09	41	0.74	0.78	0.15
***	**	Auxiliary cons. (% gross gen.)	86	8.84	10.02	2.37	93	8.72	9.20	1.50	43	8.45	9.01	2.47

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. Weighted means are capacity weighted. Difference in means according to a two-sample *t*-test with unequal variances*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 4A. Variable Means, Central and State (EGUs)

Diff. in means		CENTER 1988-1995 N	wt. mean	Mean	St Dev	STATE 1988-1995 N	wt. mean	Mean	St Dev
***	Nameplate capacity (MW)	404		194	132	1141		131	72
***	Generation (GWh)	404	1598	1046	917	1141	838	602	493
	Age	404	9	14	11	1141	11	14	8
***	Forced outage (%)	404	13	15	17	1141	16	19	20
***	Planned maintenance (%)	404	8	9	14	1141	13	14	21
***	Availability (%)	404	79	76	20	1141	71	67	24
***	Plant load factor (%)	404	64	59	21	1141	54	49	22
			2006-2009				2006-2009		
***	Nameplate capacity (MW)	435		259	155	924		166	85
***	Generation (GWh)	435	2634	1928	1281	924	1371	1054	699
***	Age	435	15	20	12	924	20	24	12
***	Forced outage (%)	435	6	6	10	924	10	12	16
***	Planned maintenance (%)	435	5	6	6	924	7	8	15
***	Availability (%)	435	89	89	11	924	84	80	21
***	Plant load factor (%)	435	86	85	14	924	73	68	24

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

Table 4B. Variable Means, Central and State Plants

Diff. in Means		CENTER Obs.	CENTER Wt. mean	CENTER Mean	CENTER Std. dev.	STATE Obs.	STATE Wt. mean	STATE Mean	STATE Std. dev.
		1988-1995				1988-1995			
	No. of operating units	77		4.5	2.2	237		4.0	2.4
***	Nameplate capacity (MW)	76		884	599	236		538	392
***	Average unit capacity (MW)	76		207	109	236		130	63
***	Net generation (GWh)	76	1520	1076	852	226	788	589	423
	Age	76	9.0	11.8	10.5	236	11.0	12.4	7.4
	Forced outage (%)	76	13.0	16.5	12.3	236	15.7	17.3	13.4
***	Planned maintenance (%)	76	7.9	8.3	6.8	236	12.2	13.0	10.8
***	Availability (%)	76	79.1	75.2	13.4	236	72.1	69.6	16.3
***	Plant load factor (%)	76	64.6	58.5	17.8	236	54.5	50.9	17.1
	Heating value of coal (kcal/kg)	30	4084	4028	550	112	4048	4095	580
	Design heat rate (kcal/kWh)	12	2524	2530	164	89	2477	2525	184
***	Operating heat rate (kcal/kWh)	31	2828	2976	386	115	3115	3229	594
	Deviation from operating heat rate	9	0.30	0.31	0.10	70	0.26	0.31	0.22
	Specific coal cons. (kg/kWh)	56	0.71	0.79	0.40	206	0.77	0.79	0.21
***	Auxiliary cons. (% gross gen.)	76	8.18	8.80	1.79	226	9.30	9.74	1.81
		2006-2009				2006-2009			
***	No. of operating units	87		5.0	2.2	223		4.1	2.3
***	Nameplate capacity (MW)	87		1297	854	222		693	500
***	Avergae unit capacity (MW)	87		266	134	222		159	69
***	Net generation (GWh)	86	2481	1930	1154	222	1256	941	589
**	Age	87	15.4	18.2	11.5	222	20.0	21.7	10.8
***	Forced outage (%)	87	5.9	7.4	12.1	222	9.7	13.8	14.2
**	Planned maintenance (%)	87	5.3	5.7	3.0	222	6.8	7.6	10.6
***	Availability (%)	87	88.7	87.0	11.7	222	83.5	78.6	17.2
***	Plant load factor (%)	87	86.1	82.6	14.9	222	73.2	66.5	21.7
***	Heating value of coal (kcal/kg)	11	4287	4323	267	122	3574	3647	424
***	Design heat rate (kcal/kWh)	23	2541	2505	137	147	2356	2409	178
**	Operating heat rate (kcal/kWh)	23	3108	3138	398	147	2750	2890	486
*	Deviation from operating heat rate	23	0.22	0.25	0.12	146	0.17	0.20	0.14
***	Specific coal cons. (kg/kWh)	74	0.70	0.71	0.07	180	0.77	0.80	0.12
***	Auxiliary cons. (% gross gen.)	86	6.78	7.57	1.68	222	8.72	9.48	2.11

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

Table 5: Thermal Efficiency - Impact of Unbundling on State Plants

	[1]	[2]	[3]	[4]
	Log	Log	Log	Log
	Heat rate	Specific Coal Cn.	Heat rate	Specific Coal Cn.
[Unbundled]	0.0320	0.0356*		
	(0.133)	(0.0787)		
[Phase-I*Unbundled]			-0.0183	-0.0107
			(0.438)	(0.558)
[Phase-II*Unbundled]			0.0820***	0.0818***
			(0.00220)	(0.00128)
Time Trend	State	State	State	State
Plant FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: (1) Std. errors clustered at state level**. *p*-values in parentheses. *** *p*<0.01, ** *p*<0.05, * *p*<0.1.**
(2) 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.
(3) Number of observations=478 (46 Plants).

Table 6: Operating Reliability - Impact of Unbundling on State EGUs

	[1]	[2]	[3]	[4]
	Average Impacts		Heterogeneous Impacts	
	Availability	Forced Shutdowns	Availability	Forced Shutdowns
[Unbundled]	0.743	-1.824		
	(0.699)	(0.196)		
[Phase-I*Unbundled]			6.793**	-5.110***
			(0.0284)	(0.00920)
[Phase-II*Unbundled]			-5.559*	1.599
			(0.0818)	(0.526)
Time Trend	State	State	State	State
Unit FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: (1) Std. errors clustered at state level**. *p*-values in parentheses. *** *p*<0.01, ** *p*<0.05, * *p*<0.1.**
(2) All equations control for a quadratic for EGU age, year and plant fixed effects and state time trends.
(3) Number of observations=4298 (270 Units).

Table 7: Falsification - Impact of Unbundling on Central EGUs

	[1]	[2]	[3]	[4]
	Availability	Forced Shutdowns	Availability	Forced Shutdowns
[Unbundled]	-1.516	-1.504		
	(0.522)	(0.548)		
[Phase-I*Unbundled]			-1.845	-2.175
			(0.590)	(0.513)
[Phase-II*Unbundled]			-0.681	0.196
			(0.754)	(0.939)
Time Trend	State	State	State	State
Unit FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes: (1) Std. errors clustered at state level**. *p*-values in parentheses. *** *p*<0.01, ** *p*<0.05, * *p*<0.1.**
(2) All equations control for a quadratic for EGU age, year and EGU fixed effects and state time trends.
(3) Number of observations=1756 (119 Units).

Table 8: Triple Difference Estimates (DDD) - Impact of Unbundling on State EGUs

	[1]	[2]
	Availability	Forced Shutdowns
[Phase-I*Unbundled]	5.959*	-4.938**
	(0.0742)	(0.0149)
[Phase-II*Unbundled]	-3.684	3.104
	(0.118)	(0.223)
Fixed Effects	Unit, State*Year, Sector*Year	Unit, State*Year, Sector*Year

Notes: (1) Std. errors clustered at state level**. *p*-values in parentheses. *** *p*<0.01, ** *p*<0.05, * *p*<0.1.**
(2) All equations control for a quadratic for EGU age, state-year, ownership-year and EGU fixed effects.
(3) Number of observations=1756 (119 Units).

Table 9: Capacity Utilization Factor – Impact of Unbundling on EGUs

	[1]	[2]
	Capacity Utilization	
	DD	DDD
[Phase-I*Unbundled]	3.955	1.101
	(0.272)	(0.698)
[Phase-II*Unbundled]	-4.039	0.571
	(0.236)	(0.792)
Observations	4,298	6,054
Number of EGUs	270	385

Notes: (1) Std. errors clustered at state level**. *p*-values in parentheses. *** *p*<0.01, ** *p*<0.05, * *p*<0.1.**
(2) Both equations, respectively, control for all the same controls as the earlier estimations for DD and DDD.

Table 10: Robustness Checks - Impact of Unbundling on State EGUs

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	Drop Phase 2		**Phase Trends**		**Drop Shutdown - DD**		**Drop Shutdown - DDD**	
	Availability	Forced Outage	Availability	Forced Outage	Availability	Forced Outage	Availability	Forced Outage
[Phase-I*Unbundled]	5.983**	-3.885**	6.711**	-5.258***	7.736**	-4.326**	6.851**	-4.386**
	(0.0364)	(0.0212)	(0.0327)	(0.00808)	(0.0232)	(0.0109)	(0.0301)	(0.0328)
[Phase-II*Unbundled]			-6.656**	1.754	-2.868	2.481	-1.485	3.356
			(0.0472)	(0.466)	(0.263)	(0.313)	(0.568)	(0.273)
Controls	Unit FE, Year FE, State Trend	Unit FE, Year FE, State Trend	Unit FE, Year FE, Phase Trend	Unit FE, Year FE, Phase Trend				
Observations	2,605	2,605	4,298	4,298	4,154	4,154	5,897	5,897
Number of EGUs	166	166	270	270	270	270	385	385

	[9]	[10]
	Drop Enter/Exit - DD	
	Availability	Forced Outage
$1[\text{Phase-I*Unbundled}]_{it}$	7.398	-5.088**
	(0.121)	(0.0356)
$1[\text{Phase-II*Unbundled}]_{it}$	-4.239	1.679
	(0.460)	(0.797)
Observations	4,024	4,024
Number of EGUs	203	203

Notes: (1) Std. errors clustered at state level**. *p*-values in parentheses. *** *p*<0.01, ** *p*<0.05, * *p*<0.1.**
(2) All equations control for a quadratic for EGU age, state-year, ownership-year and EGU fixed effects.
(3) Columns [1]-[2] drop Phase 2 states. Columns [3]-[4], substitute phase-wise trends instead of state-specific trends. Columns [5]-[8] drop any unit with almost zero (avl<1). Columns [9]-[10] use a balanced panel for the estimation

Figure 1: Units Operating in Unbundled State-owned Generation Plants by year

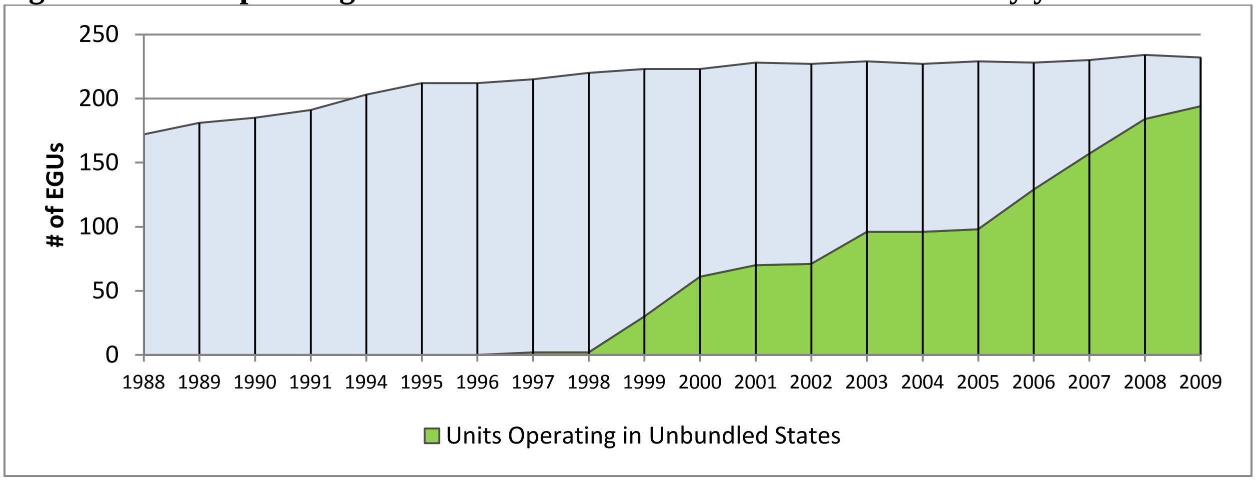


Figure 2: Trends in Outcome Variables

Figure 2A: Trend in Availability for State and Center Owned EGUs

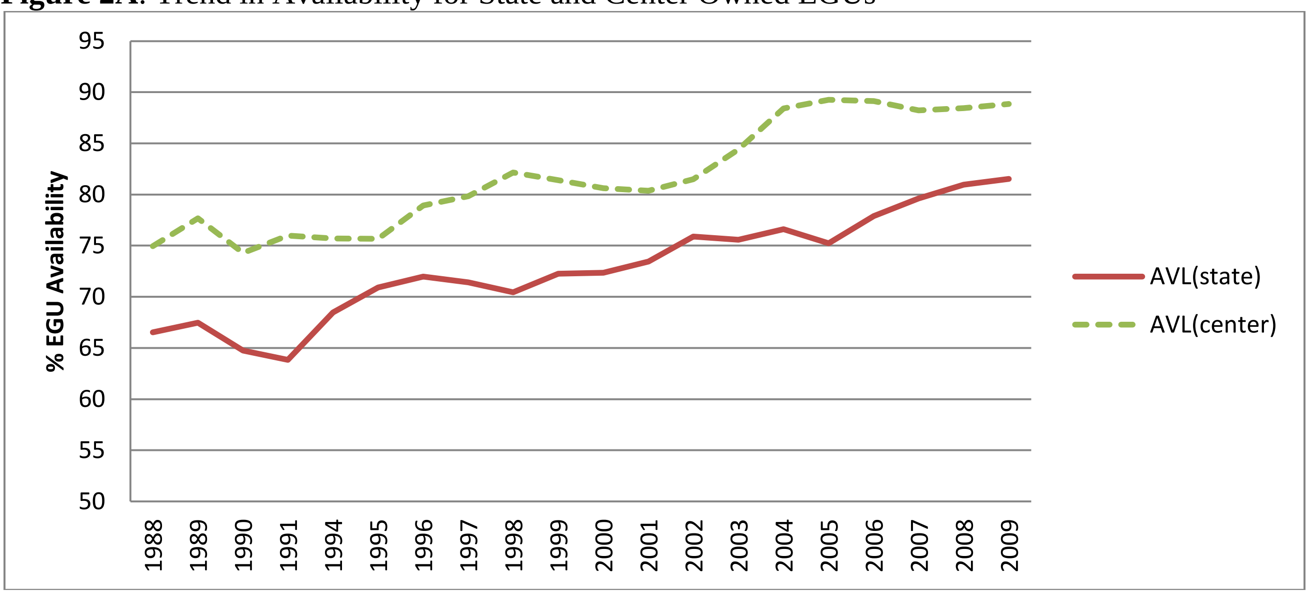


Figure 2B: Trend in Forced Outage for State and Center Owned EGUs

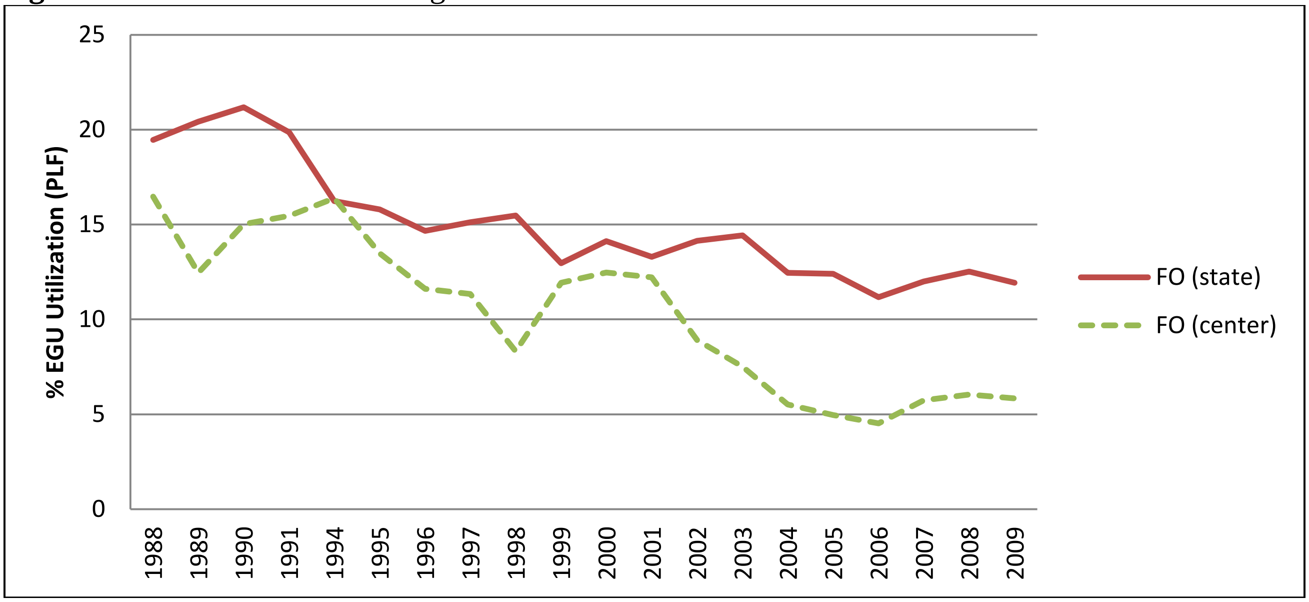


Figure 2C: Trend in Capacity Utilization for State and Center Owned EGUs

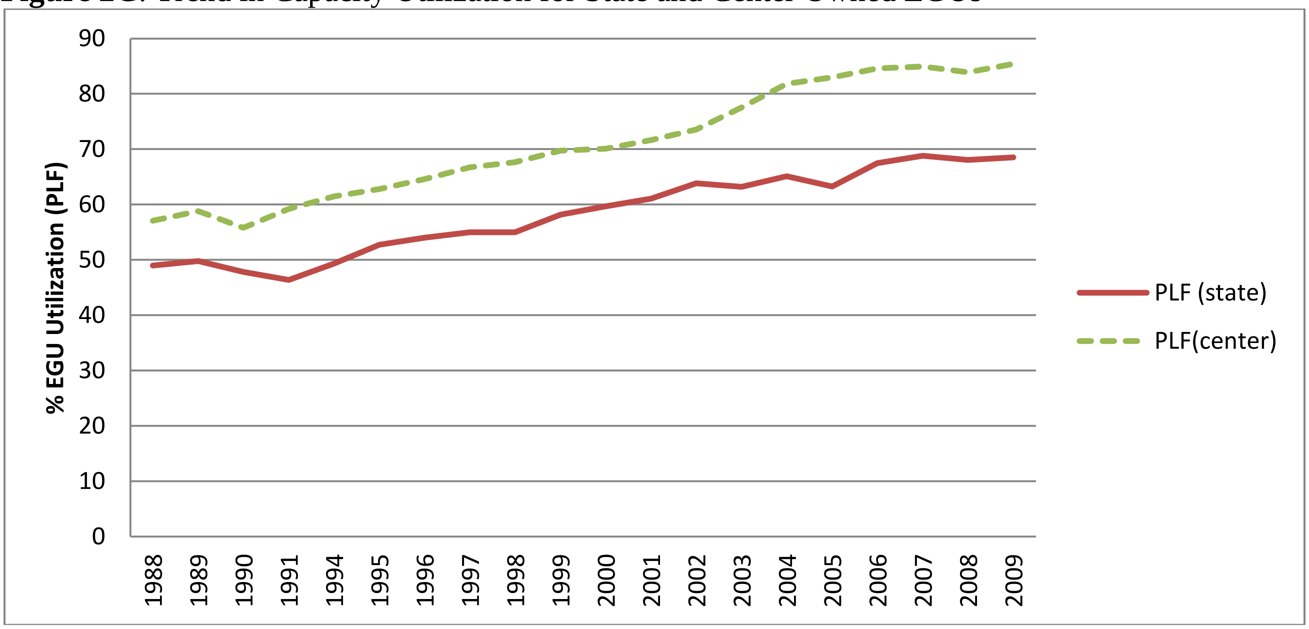
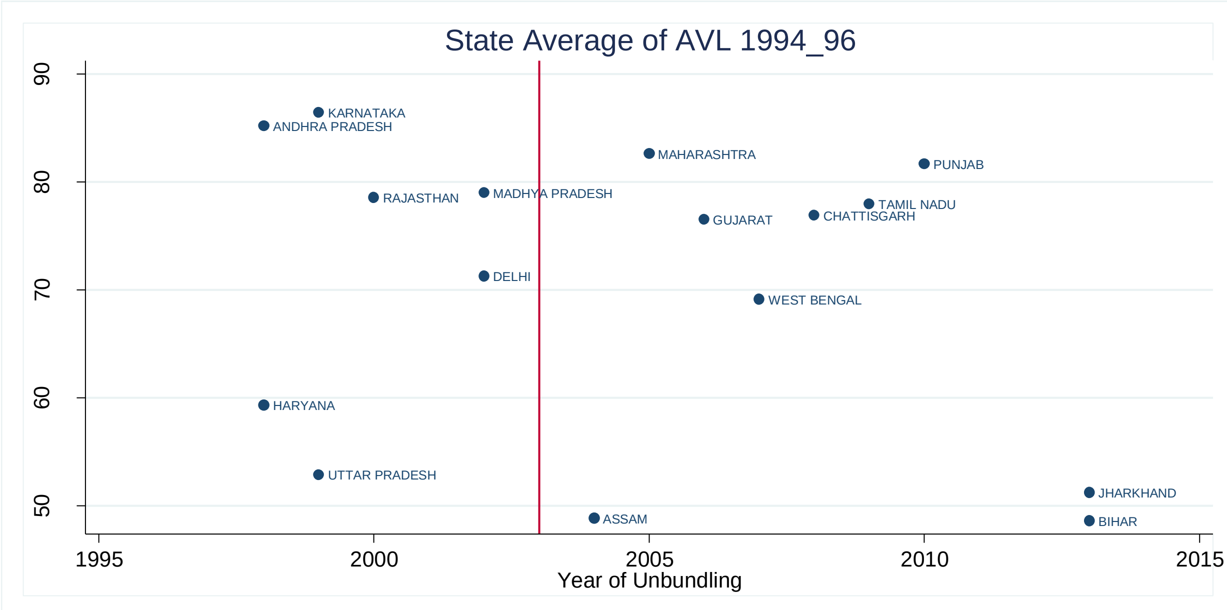
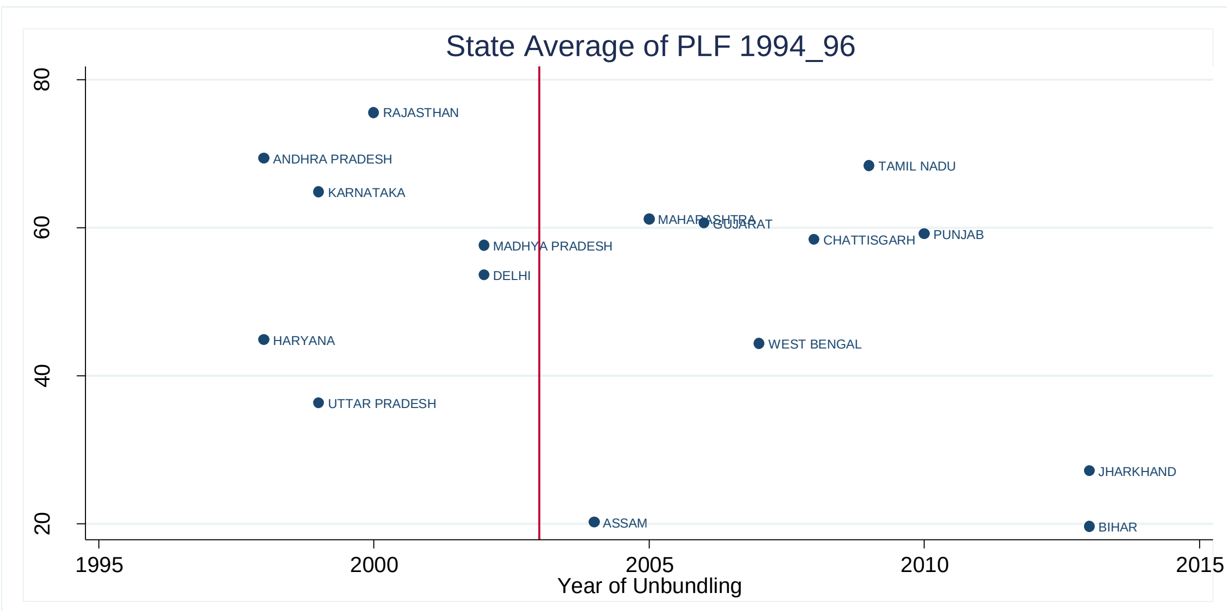


Figure 3: Correlates of the Year of Unbundling across States

Panel A: (i) Average plant performance prior to reform (AVL)

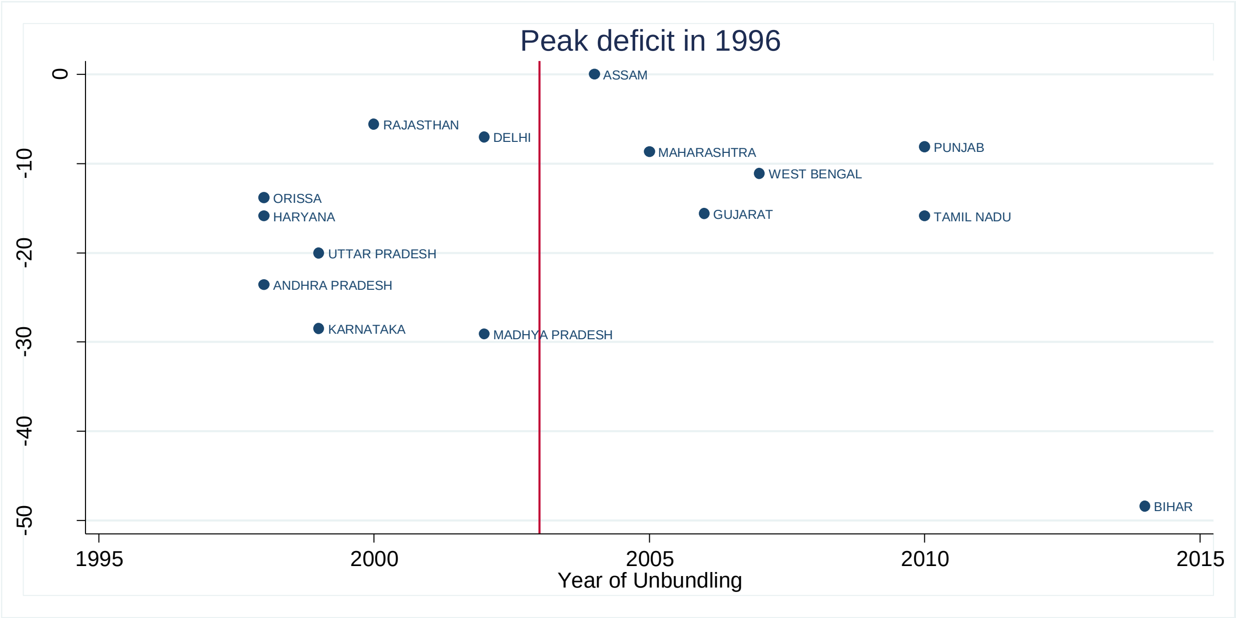


Panel A: (ii) Average plant performance prior to reform (Capacity Utilization)

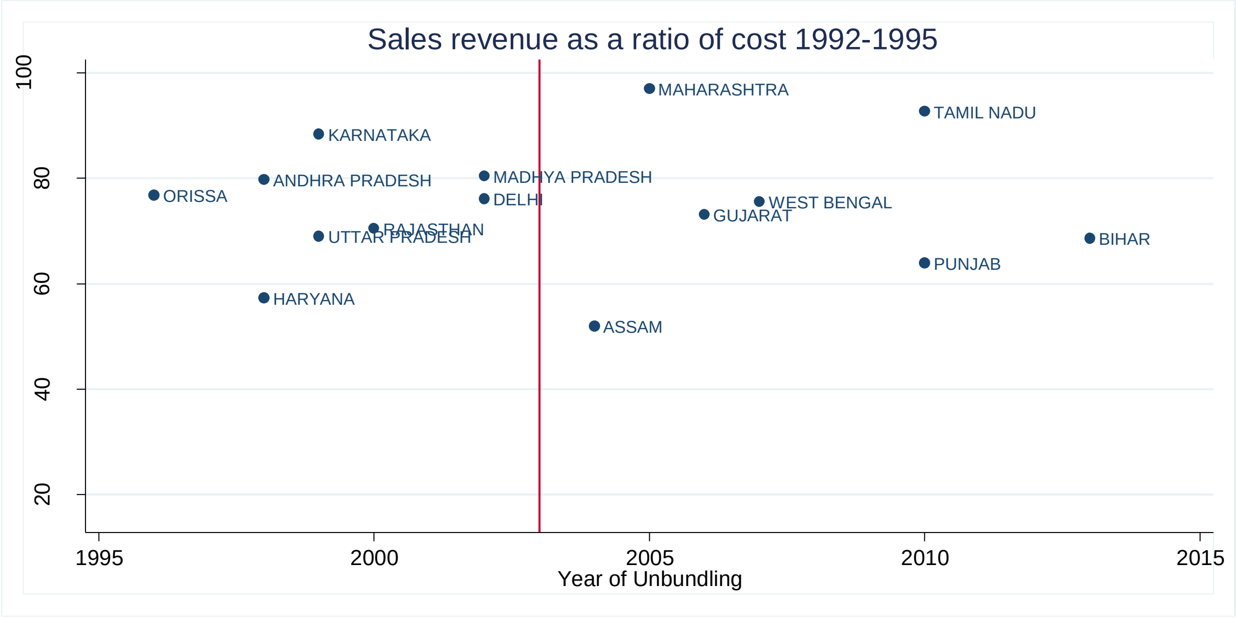


Note: 1. Jharkhand and Bihar have not unbundled as of 2012. I set 2013 as their arbitrary unbundling date to plot their averages.
2. The red line represents the Electricity Act of 2003 which divides the first and second phase of reforms.
3. Averages are capacity weighted averages at the state level calculated from plant data.

Panel B: Energy deficit at peak demand in 1996

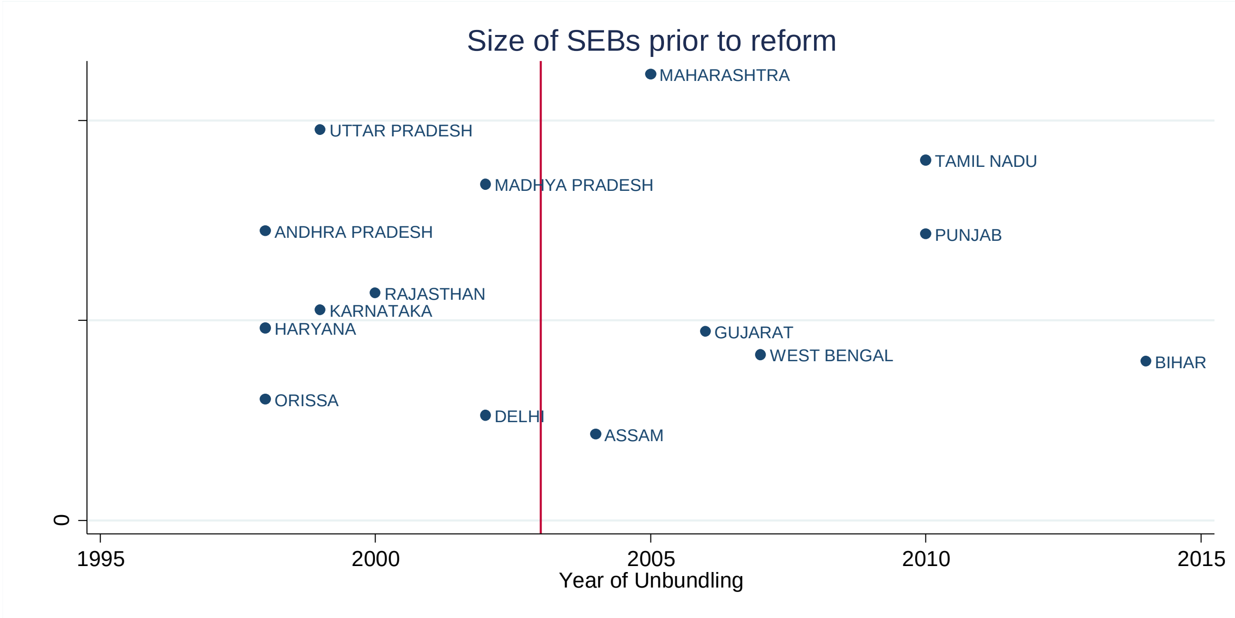


Panel C: Financial well-being of SEB prior to reform

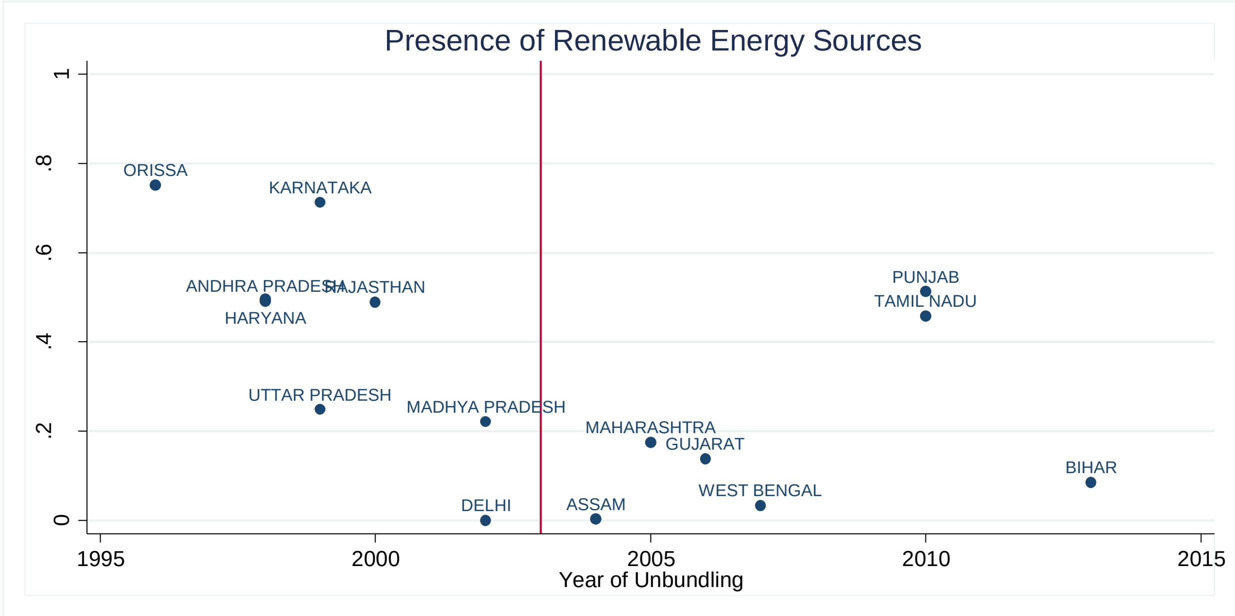


Note: 1. Jharkhand and Bihar have not unbundled as of 2012. I set 2013 as their arbitrary unbundling date to plot their averages.
2. The red line represents the Electricity Act of 2003 which divides the first and second phase of reforms.

Panel D: Employee size of SEB prior to reform

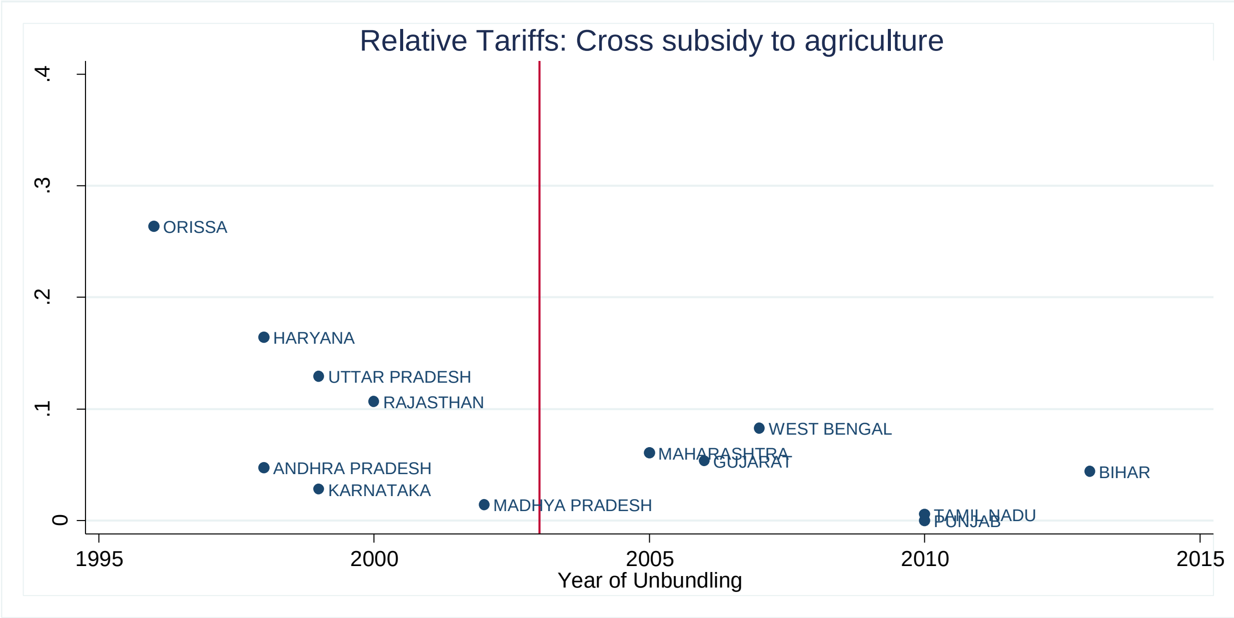


Panel E: Renewable energy capacity in 1997



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

Panel F: Cross-subsidy to agriculture in 1997



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

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

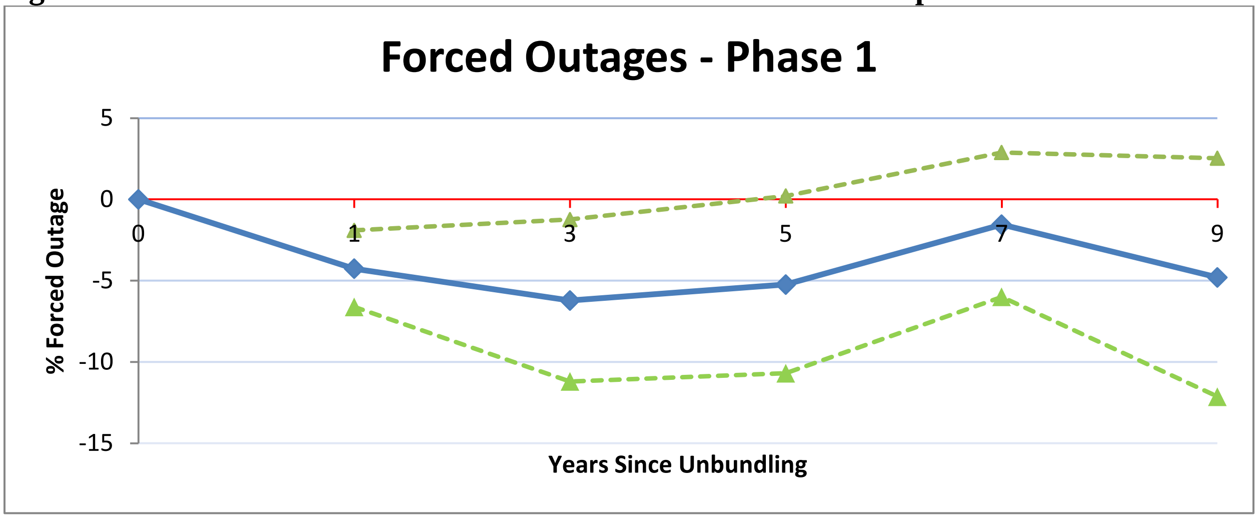


Figure 4B: Post Treatment Flexible Duration Estimates from DDD Specification

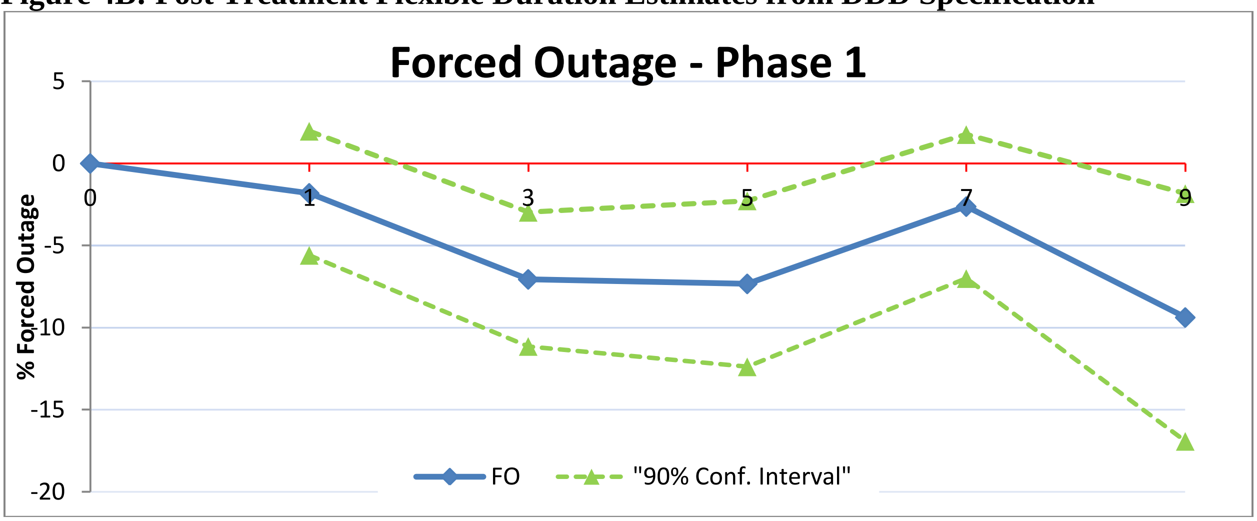


Figure 4C: Pre and Post Treatment Flexible Duration Estimates from DDD Specification

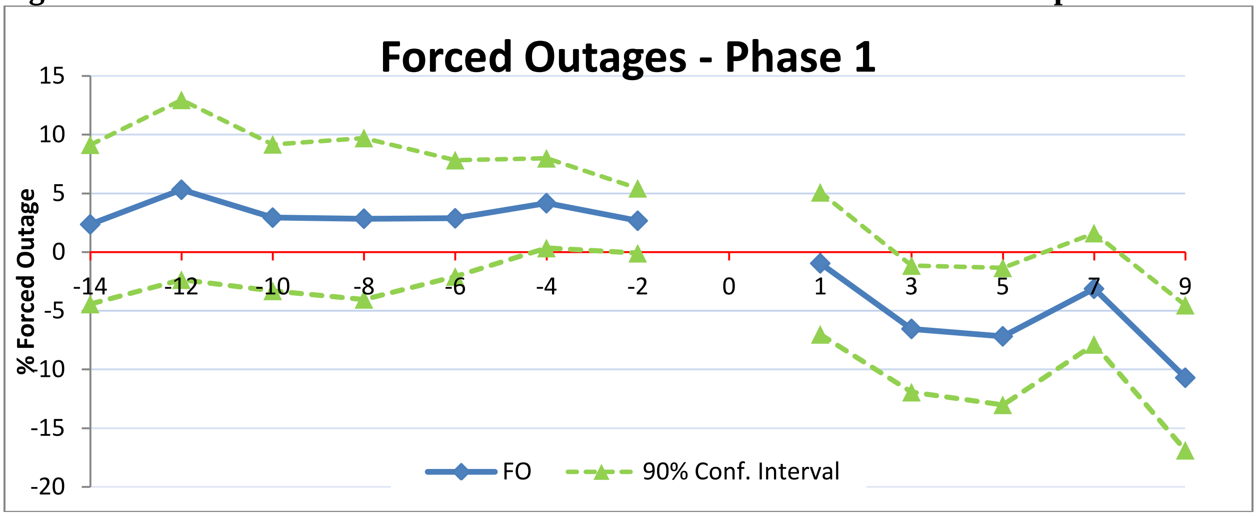


Figure 4D: Pre and Post Treatment Flexible Duration Estimates from DDD Specification