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Estimation of firm-level productivity changes in the Indian power sector: Disentangling unobserved heterogeneity by a transformed fixed-effect stochastic frontier model*

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Abstract

We measure firm-level productivity changes in the Indian electricity sector during a period that witnessed several pro-market regulatory changes. Using information collected from multiple sources we construct a unique panel of generating firms and transmission and distribution utilities spanning the years 2000 to 2009. We employ a recently developed improvement in the Stochastic Frontier panel method that allows controlling for time-invariant unobserved heterogeneity. Using the method we jointly estimate inefficiency and exogenous determinants of inefficiency. We estimate a flexible translog production model and compute decomposition of productivity into components of changes in technology, efficiency, scale and price effect. During this period, especially post Electricity Act 2003, we observed a general decline in firm-level productivity at the mean rate of -1.6% per year. A positive and large technical change is observed in the sector at the rate of 8% per year, attributable possibly to newer capacity addition. Except for smaller gas based generators, inefficiency is observed to be increasing at the mean rate of 3.1% per year in the sector. Consistent with extant findings we also document no significant impact of un-bundling on firm-level efficiency.

Keywords: India's Electricity Sector Reform, Stochastic Frontier Analysis, Total Factor Productivity, Firm-Level Panel Data

JEL Codes: L43, L94, L98, C13, C23

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1 Introduction

In the past two decades the Indian power sector has witnessed structural reforms through several landmark regulatory changes. Along the lines of power sector reforms elsewhere internationally, primarily reforms in India also emphasized un-bundling of vertically integrated utilities into functionally separate entities dealing with generation (production) and transmission and distribution (T&D) (service). The reforms also attempted to attract private capital to the sector. The primary policy objectives of initiating reforms in the sector were anticipated efficiency gains and cost reduction. Therefore, an empirical assessment of firm-level productivity changes in the generators and T&D utilities shall reveal the extent to which reforms have influenced the sector in the intended direction. However, pan-India measurement of productivity changes across the power sector value-chain poses two key challenges. First, firm-level heterogeneity due to diversity in geography, local regulations, technology employed and other unobserved factors makes pan-sector (and pan-India) measurements prone to omission-bias. Second, due to relatively lax regulatory requirements of central collection and maintenance of firm-level operating data in India, productivity measurements have to rely on data collated from multiple sources or estimated from aggregate numbers. Hence, a majority of extant research investigating efficiency changes in firms in the Indian power sector have have been confined in scope to specific geography, firm or technology.

In this context we attempt to estimate pan-India firm-level productivity changes in the generating firms, T&D utilities and a few remaining vertically integrated utilities. Our empirical strategy to measure pan-sector efficiency change is to structurally control for firm-level heterogeneity.¹ Causal inference is crucial specifically in studies attempting to attribute observed efficiency differences to explanatory factors. For instance, investigating the influence of un-bundling on the performance of Indian power sector, Cropper et al. (2011) employ the difference-in-difference econometric technique. The method adjusts for omitted variable bias caused due to unobserved variables aggregated at the state and time period level. Therefore by design, the method provides the regression coeffi-

¹After controlling for firm-level fixed effects, two important endogeneity issues still remain unresolved. First, the problem of simultaneity, that relates to the fact that managers may adjust the firms' output in accordance to the observed efficiency of inputs. Second, the problem of selection bias, that results from the fact that negative productivity shocks may drive firms to exit and due to absence of information on non-existent firms the observations only represents a truncated distribution. These issues are not unique to our research setting, as Fabrizio et al. (2007) points out, studies of the electricity industry have typically not treated both these issues. However in our setting, firms are predominantly government owned and are not forced to exit due to low profitability. In addition, electricity production in India has remained in short supply historically, therefore the opportunity to cut back on output due to inefficiency of inputs hardly exists. Hence, unobserved heterogeneity remains the larger econometric issue that we proceed to address in our empirical work.

cients on explanatory variables close to causal interpretation. In our setting to enable causal inference in panel SFA models that jointly estimates inefficiency and the exogenous determinants of inefficiency, (models following Battese and Coelli, 1995), it is critical to control for unobserved heterogeneity. In a recent comparative investigation of methods, Kopsakangas-Savolainen and Svento (2011) measures inefficiencies in the Finnish electricity distribution utilities using five different SFA models. The study reports that models accounting for unobserved heterogeneity produce lower inefficiency measures and considerably different inefficiency rank orders. Thus, ignoring unobserved heterogeneity could result in confounded regression coefficients with severely limited causal interpretation.

Greene (2005a,b) suggests two new methods for controlling unobserved heterogeneity in panel SFA models: the “*true fixed-effects*” model and the “*true random-effects*” model. The problem of identification² is addressed in these newer models by structurally constraining the positive inefficiency term to be time-varying and the unobserved heterogeneity to be time-invariant. However, Wang and Ho (2010) points out that the ‘*true fixed-effects*’ SFA model suffers from the problem of incidental parameters (Neyman and Scott, 1948; Lancaster, 2000) that might contaminate estimates of other model parameters when simultaneous estimation of fixed effects and the inefficiency variance parameter is attempted. Wang and Ho (2010) suggests a solution to this problem by developing a model that enables elimination of unobserved fixed-effect variables (either by *within* or *difference* transformation) prior to estimation of inefficiency.

In our study of the Indian power sector during the reforms period, we therefore employ the Wang and Ho (2010) transformed SFA model to disentangle unobserved firm-level heterogeneity from technical inefficiency. We empirically investigate the nature of productivity changes in 98 firms operating in the Indian power sector during the period of 2000-2009. Our sample represents 51 generators, 38 transmission & distribution firms and 9 vertically integrated utilities with a total of 542 firm-year observations. The unbalanced panel of sample contains observations of firms that are under the ownership of central government, state government and private investors. Our sample is fairly representative and accounts for 45.7% of total electricity generated and 59.4% of total electricity consumed in India during the period of 1999-2009. Using a flexible translog production specification we decompose the measure of productivity change into components of changes in technology, efficiency, scale and price effects. Based on the firm-level sample we estimate that post Electricity Act 2003 there had been no improvements in firm level

²A well known problem with conventional fixed effects SFA models with the assumption of time-invariant inefficiency is that its not possible to distinguish inefficiency from unobserved heterogeneity captured by the fixed effect term (Schmidt and Sickles, 1984).

productivity. In addition, bulk of the productivity change is attributable to technology change (newer capacity addition), whereas efficiency is observed to be generally declining. Further, we also show that reforms had a varying degree of influence on different entities contingent on its role in the value-chain, technology employed and ownership.

2 Deregulation and Measuring Firm Level Productivity Change

The global wave of restructuring since the early 1990's, systematically brought about significant changes in industry structure, ownership pattern and mode of regulation in the electricity sector in several countries. A common feature in many of these reforms initiatives is the dismantling of vertically integrated utilities, thus separating generation of electricity (production) from T&D (service), such that coordination of demand-supply, post restructuring, happens over a specialized market based mechanism. It is suggested that the introduction of competition and market-based transactions in the sector is made on ex-ante anticipation of improvement in technical efficiency, reduction in operating costs and hence positive welfare gains (Joskow and Schmalensee, 1983). Wolfram (2005) argues that restructuring would lead to efficiency gains because of: (a) the new incentives faced by the incumbents to improve efficiencies, (b) takeover of inefficient older plants and the arrival of new entrants with newer technologies, and (c) competition driving efficient allocation of factors of production. Thus, in the restructured industry setting, ex-post measurement of efficiency improvements for firms across the electricity value-chain provides a basis for critical empirical scrutiny of the reforms policy³.

In this context, several extant studies investigate the influence of restructuring on firm-level productivity changes in the electricity sector. Among alternative methods, the non-parametric Data Envelopment Analysis (DEA) is a popular technique employed for the measurement of efficiency in the power sector, e.g. Vaninsky (2006)⁴. However, with access to panel data, the SFA method presents a natural way to incorporate information obtained from multiple observations of the production unit spread over time. And among other things, it also allows for a richer production specification and formal statisti-

³Fabrizio et al. (2007), employing plant level data on generators in U.S., use the difference-in-difference method to find that introduction of market-based industry structure has led to modest medium-run cost efficiency gains. Similarly Newbery and Pollitt (1997), find that restructuring the U.K power sector led to gains in cost efficiency and reduction in emissions. An exhaustive survey of empirical studies on electricity sector reforms in the developing countries by Jamasb et al. (2005) finds that institutional development in the country and governance of the sector are key to success or failure of the reforms initiative. Similarly, in a cross country study spanning 36 developing countries, Zhang et al. (2008) finds that introduction of competition has relatively more significant impact than privatization in stimulating efficiency improvements

⁴A survey of DEA applications in energy and environmental studies can be found in reviews by Jamasb and Pollitt (2000) and Zhou et al. (2008).

cal testing of hypotheses (Hjalmarsson et al., 1996). SFA is used by Knittel (2002), using a Cobb-Douglas specification, and by Hiebert (2002), using the more flexible translog specification for measuring efficiency of U.S. power generators. Knittel (2002) partly controls for firm-level fixed effects by incorporating plant vintage information in the SFA model. The study checks for influence of alternative regulatory schemes on inefficiency and finds that performance incentive based regulation is associated with improvement in plant-level efficiency. The SFA model used by Hiebert (2002), follows Battese and Coelli (1995) to jointly measure inefficiency and the influence of firm-level factors associated with the observed heterogeneity in measured inefficiency. The study identifies capacity utilization and ownership as factors influencing efficiency, overall mixed results on efficiency gains are seen across the restructured U.S. states.

The literature examining productive efficiency of the Indian electricity sector during the reforms phase is also growing. Scholars have used broadly three class of methods in their empirical work: the non-parametric DEA, parametric SFA, and other econometric specifications with a dependent plant-level efficiency variable (like plant load factor, or thermal efficiency). The DEA technique had been used to measure relative efficiencies by: Shrivastava et al. (2012) for thermal plants during 2008-2009, Yadav et al. (2010, 2011) for divisions of distribution utility in the north Indian state of Uttarakhand, Thakur et al. (2006) for state owned utilities during the period 2001-2002, Chitkara (1999) for thermal plants operated by NTPC,⁵ and Singh (1991) for state owned coal fired plants during 1986-1987. The parametric SFA method had been used by: Shanmugam and Kulshreshtha (2005) for 56 coal based plants for the period 1994-2001 (using a panel data specification), and by Khanna et al. (1999) for 66 thermal plants during 1987-1990. Econometric specifications with plant-level efficiency as dependent variable had been used by: Khanna and Zilberman (1999) on 63 coal based plants during 1987-1990 to check for regulatory and technology factors as determinants of efficiency, Cropper et al. (2011) follows the difference-in-difference method on a sample of 82 thermal power plants during 1994-2008, and Sen and Jamasb (2010) use dynamic panel-data estimator with a sample of 19 states for 1991-2007. The later two studies specifically investigate the causal influence of restructuring on efficiency changes at the aggregate state (Sen and Jamasb, 2010), and plant (Cropper et al., 2011) level. The research on the impact of restructuring reveals mixed outcomes. Sen and Jamasb (2010) points out that there are substantial state-level differences in improvements attributable to heterogeneity in historic as well as political context. (Cropper et al., 2011) finds that while un-bundling has not resulted in improvements in thermal efficiency, there has been improvements in capacity utilization

⁵National Thermal Power Corporation (NTPC), with majority ownership of the central government of India, is the single largest producer of electricity in India

(+4.6%) and reduction in forced outages (−2.9%).

We note that the extant research has focused either at the aggregate state-level or to level of generating plants. However, economically important decisions of investment in capacity, technology and choice of factor allocations are made at the level of the firm that operates several productive assets under its ownership and control. Especially post un-bundling of generation from distribution and transmission, the role of the firm as the decision making entity is more salient. Hence, in our empirical work we focus on the firm as the unit of analysis to measure dynamic changes in efficiency at the firm-level. We also trace the extent to which the changes are driven by factors such as ownership differences, vintage of assets, un-bundling status of the state in which the firm is operating and competition.

3 Indian Power Sector Reforms

The Indian Electricity Act 1910, promulgated primarily to ensure safety, was the earliest legislative attempt to regulate the working of the Indian electricity industry. Post independence, the Indian Constitution accorded *concurrent status* to the electricity sector, thus placing it simultaneously under the responsibility of the central and state governments. Subsequently the Electricity (Supply) Act 1948 came into effect that paved the way for the formation of vertically integrated government owned agencies: the *State Electricity Boards* (SEBs), entrusted with the responsibility of generation, transmission and distribution of electricity in the respective states. However, the power sector continued to be characterized by capacity underutilization, inefficient operations and financially imprudent pricing policies. This consequently lead to chronic shortages, poor quality of supply, frequent breakdowns and bankruptcy of the SEBs (World bank reference here). The genesis of reforms in the power sector can be broadly traced to these deteriorating conditions. Arun and Nixson (1998) presents a detailed discussion on the nature and genesis of reforms, beginning the amendments to the Electricity Act 1910 and Supply Act 1948 in the year 1991, which primarily opened up the sector to private investments. Subsequently in 1998 the electricity Regulatory Commissions Act was enacted resulting in the setting up of the Central Electricity Regulatory Commission (CERC) and other state level regulatory bodies. While primarily CERC was concerned with the regulation of firms owned and operated by the central government, it also regulated coordination activities for entities spanning multiple states. However these early attempts hardly made any substantial impact on the growth and recovery of the power sector. In a critical examination of this early phase of reforms D'Sa et al. (1999), and Dubash and Rajan (2001) highlight that the piecemeal approach to reforms failed to rein in the progressively

languishing state of the power industry.

In contrast to these earlier fragmented reform attempts, a paradigm shift in the power sector reform process was brought about by the legislation of the Electricity Act 2003 (GOI, 2003) on 10th July 2003. The Electricity Act 2003 replaced and consolidated the existing legislations aiming for substantial structural changes in the Indian electricity industry. The salient features of the Act included de-licensing of thermal and captive generation, de-licensing of distribution in rural areas, open access to transmission, phased open access to distribution, multiple licenses in distribution and recognition of electricity trading as a distinct activity enabling the creation of electricity markets. A detailed exposition of the implications of Electricity Act 2003 for generation, transmission, distribution and electricity trading can be found in Bhattacharyya (2005); Ranganathan (2004); Singh (2006) and Thakur et al. (2005), while several limitations of the Act are discussed in Sankar (2004).

While the reforms started in the early 1990s, structurally significant changes were set in motion only after the enactment of the Electricity Act 2003, especially in terms of potential to influence the technological efficiency of firms operating in the electricity sector. The Act specifically articulates intention to instill competition in the industry and outlines the framework to transit from vertically integrated monopoly structure to a multi-buyer and multi-seller model. With the establishment of wholesale electricity market⁶, the institutional framework for a competitive industry structure got further augmented. Similar to observations by Ranganathan (2004) and Singh (2010) we also expect that the series of structural changes in the electricity sector, especially during the decade starting year 2000, demonstrates potential to incentivize firms to improve technological as well as operational efficiency. In addition, given wide variation in ownership structure, local regulation and historical context, we anticipate substantial pan India heterogeneity in firm-level productivity outcome, in response to these institutional incentives. It is in this overarching institutional context that we empirically investigate a substantial duration of the reform period (2000-2009), attempting to measure the extent of overall productivity improvement in the sector and identify exogenous observable factors responsible for firm-level heterogeneity in outcomes.

⁶The first Indian power exchange, Indian Energy Exchange Limited (IEXL), became operational in June 2008 and Subsequently Power Exchange India Limited (PXIL) came into existence in October 2008. These markets are in a nascent stage of development with low transactions volumes. At present the two exchanges together trade close to only 2% of the total power generated in the country. The functioning of these wholesale power markets is explored in a few recent studies (Shukla and Thampy, 2011; Siddiqui et al., 2012).

4 Data and Method

4.1 Data

We create a sample dataset of Indian power generators and T&D utilities for the period of 2000-2009. The sample represents about 46% of total generation and about 60% of total electricity consumption in India during the period. The sample spans across 19 states and represents ownership under central Government, state Government and private investors. We collect from multiple sources data on total electricity generated/distributed and the factors of production, aggregated at the firm level. Variable definition, unit of measurement and respective sources of data is summarized in table 1 & 2. Power generating firms are classified as “coal-based”, “gas-based” or “mixed” depending on the type of fuel consumed most. Firms with generating assets using coal, gas and other sources with no one dominant fuel type is classified under the “mixed” category. Similarly, firms engaged only in T&D function are classified as “distribution utilities” and firms operating generators as well as engages in T&D are classified as “vertically integrated”. The distribution of firms across the various categories is described in table 3. Summary statistics for all the variables is shown in table 5 and the distribution of key input-output variables across categories of firms is shown in table 4. The unit of fuel input is normalized to energy equivalent GWhr units. From table 4, the ratio of electricity generated to fuel input shows an aggregate input-output efficiency of about 28% and 26% for coal and gas based generators respectively. Transmission loss estimated from the distribution utilities is about 28%. These estimates of aggregate efficiencies conforms well with other estimates based on plant level measurements like CEA (2008).

4.2 Transformed fixed-effect stochastic frontier model

We start by representing a primal stochastic production frontier using a deterministic kernel $f(x_{nit}, t; \beta_n)$ producing a scalar output y_{it} as

$$y_{it} = f(x_{nit}, t; \beta_n) \cdot \exp(\epsilon_{it}), \quad (1)$$

for the i^{th} producer $i = 1, \dots, I$ during time period $t = 1, \dots, T$ using inputs $x_n, n = 1, \dots, N$, where ϵ_{it} represents producer specific time-varying stochastic inefficiency term. We choose the flexible translog form, developed in Christensen et al. (1971); Christensen and Jorgenson (1973), to express the time-varying stochastic production function in equation (1). The translog production function is a local second-order approximation to any arbitrary production function, and thus displays several desirable properties for empirical estimation. The translog specification places no prior functional constraints on returns to scale, elasticity of substitution between inputs and homotheticity. Christensen and Jorgenson

(1973), discuss the aforementioned and other related properties of the translog production function in detail. Additionally Diewert (1976) shows the translog form to be “exact” for the Divisia index (Divisia, 1925). We shall use the Divisia index subsequently to estimate efficiency change and productivity change over the period of study. For our sample of unbalanced panel data on I producers over T time periods we assume that the production function can be expressed in the following translog form

$$\begin{aligned}
\ln E_{it} = & \alpha_i + \beta_K \ln K_{it} + \beta_L \ln L_{it} + \beta_F \ln F_{it} + \beta_t t \\
& + \frac{1}{2} \beta_{KK} \ln K_{it}^2 + \frac{1}{2} \beta_{LL} \ln L_{it}^2 + \frac{1}{2} \beta_{FF} \ln F_{it}^2 \\
& + \beta_{KL} \ln K_{it} L_{it} + \beta_{KF} \ln K_{it} F_{it} + \beta_{LF} \ln L_{it} F_{it} \\
& + \frac{1}{2} \beta_{tt} t^2 + \beta_{Kt} t \ln K_{it} + \beta_{Lt} t \ln L_{it} + \beta_{Ft} t \ln F_{it} + \epsilon_{it},
\end{aligned} \tag{2}$$

We define the inefficiency term $\epsilon_{it} = v_{it} - u_{it}$, where $v_{it} \sim N(0, \sigma_v^2)$ is the noise component and u_{it} is the nonnegative stochastic technical inefficiency component. Similar to Kumbhakar and Lovell (2003), in this translog specification as well, time (t) proxies technical change in the stochastic production frontier as well as represents technical efficiency change in the error component. Subsequently we shall impose distributional and model specification restrictions to econometrically disentangle the two effects. We attempt to separate the firm specific unobserved heterogeneity, like Greene (2005b), by introducing the α_i ‘fixed-effect’ term ⁷. The consequent technical challenges in econometric estimation of such a specification arise broadly due to, (a) the increased computational burden on account of introduction of additional unknown parameters for estimation (one additional parameter for each firm in the sample in case of fixed-effect model), (b) the problem of incidental parameters (Neyman and Scott, 1948; Lancaster, 2000) contaminates estimates of other model parameters when simultaneous estimation of α_i and the inefficiency parameter is attempted (e.g. the “true fixed-effect” proposed in Greene (2005b) and Greene (2005a)). The former of the two issues is addressed to some extent by recent developments in computer algorithms (one such algorithm is detailed in Greene (2005a)). However, in a sample with fixed T and where $I \rightarrow \infty$, the later problem of incidental parameters results in inconsistent estimates of the variance-covariance matrix (Wang and Ho, 2010). Since, the inefficiency parameters of interest are contained in the variance-covariance matrix, we cannot afford to ignore inconsistency of estimates produced by a

⁷Other formulations that treat both the firm-specific heterogeneity α_i as well as the the technical inefficiency error component u_i to be time-invariant encounter a fundamental problem of identification. In such specifications (e.g. Pitt and Lee (1981) and Schmidt and Sickles (1984)) the time invariant term remain inseparable in the form $\alpha_i - u_i$. However, with a time-varying inefficiency specification u_{it} , the presence of within group variation in the sample enables separate analysis of unobserved heterogeneity and inefficiency. This separability between the two effects is limited by the extend to which technical inefficiency is time persistent. Greene (2005b) analyses these issues in greater detail.

maximum likelihood estimator (MLE). Wang and Ho (2010) propose a transformation for the panel stochastic frontier model that allows tractable MLE estimation of the 'true fixed-effects' model. We follow this approach to estimate the parameters of the stochastic production function we specify in equation(2). Here MLE tractability is achieved by the use of 'scaling-property' (Alvarez et al., 2006; Wang and Schmidt, 2002) to represent the inefficiency component u_{it} as a product of a positive non-stochastic time-varying function and a stochastic time-invariant inefficiency term as

$$u_{it} = h_{it} \cdot u_i^*, \quad (3)$$

$$h_{it} = g(z_{kit} \delta_k) \quad (4)$$

where $u_i^* \sim N^+(0, \sigma_u^2)$ is assumed to be non-negative half-normal and z_{kit} represents $k = 1, \dots, K$ exogenous and non-stochastic determinants of inefficiency. In this "composed error" representation ($\epsilon_{it} = v_{it} - u_{it}$), the noise component v_{it} is assumed to be iid and distributed independently of u_{it} . Further both u_i^* and v_{it} are assumed to be independent of $\{x_{nit}, z_{kit}\}$ for all T observations of the i^{th} firm. The scaling property lends several theoretically appealing properties enabling versatile model specifications for empirical work, some of them are discussed in detail in (Alvarez et al., 2006; Wang and Schmidt, 2002; Wang and Ho, 2010). Specifically, we adopt the 'within' transformation of stochastic frontier models made tractable by the scaling property. The 'within' transformation removes the individual fixed-effect (incidental parameter) α_i from the model, thus inefficiency parameters can be estimated without contamination due to the incidental parameter problem.⁸ The 'within' transformation model that we use for MLE estimation is described in greater detail in the technical appendix (A) to this paper. Furthermore we specify the time-varying component of the inefficiency term, h_{it} , as

$$h_{it} = \exp(z_{kit} \delta_k), \quad (5)$$

where, we investigate the influence of three different class of exogenous factors: (a) Vintage, proxied by the year of incorporation of the firm. (b) Ownership dummies, identifying a firm to central government, or state government ownership class and private ownership is the reference class. (c) External environmental factors, primarily the time since electricity sector is unbundled in the state in which the firm has majority of operations and extent of competitiveness enabled by institutional conditions. (d) Time trend, all other dis-embodied factors proxied by a quadratic time specification. Then in equation(5), the

⁸Wang and Ho (2010) develop the 'first-difference' and 'within' transformation as two alternative approaches to eliminate the incidental variable. They also demonstrate that the log likelihood functions for both are equivalent. However, since the 'first-difference' transformation uses only $(T - 1)$ observations from each panel in the sample we instead prefer to adopt the 'within' transformation method for our empirical investigation.

inefficiency determinant is specified as

$$\begin{aligned}
z_{kit}\delta_k &= \text{time}.\delta_t + \text{time}^2.\delta_{tt} + \text{Vintage}.\delta_V + \text{Central Gov. Dummy}.\delta_{CG} \\
&+ \text{Private Gov. Dummy}.\delta_{SG} \\
&+ \text{Unbundled Dummy}.\delta_{Udl} \\
&+ \text{Competition}.\delta_{Cmp},
\end{aligned} \tag{6}$$

4.3 Estimating productivity changes

Differentiating the production specification with respect to time, following Kumbhakar and Lovell (2003), yields various components of TFP change. The rate of shift in production frontier or technical change is given by

$$\Delta T = \frac{\partial \ln f(x, t; \beta)}{\partial t}, \tag{7}$$

and the change in technical efficiency is obtained by

$$\Delta TE = -\frac{\partial u}{\partial t}. \tag{8}$$

The Divisia index of productivity change (Divisia, 1925) is defined for a scalar output as

$$\begin{aligned}
T\dot{F}P &= \frac{d \ln y}{dt} - \frac{d \ln X}{dt} \\
&= \dot{y} - \dot{X} = \dot{y} - \sum_n (S_n \dot{x}_n)
\end{aligned} \tag{9}$$

Where $S_n = w_n x_n / \sum_n w_n x_n$ is the observed expenditure share of the input x_n . Substituting for \dot{y} in equation(9) obtained by totally differentiating equation(1) yields with minor algebraic manipulation the following decomposition of productivity change,

$$T\dot{F}P = \Delta T + \Delta TE + (\Gamma - 1) \sum_n \left(\frac{\gamma_n}{\Gamma}\right) \dot{x}_n + \sum_n \left(\frac{\gamma_n}{\Gamma} - S_n\right) \dot{x}_n, \tag{10}$$

where the elasticity of output with respect of input x_n is defined as $\gamma_n = x_n \frac{\partial f}{\partial x_n}$. The returns to scale characterizing the production function is then expressed as $\Gamma = \sum_n (\gamma_n)$. The third term in equation (10),

$$\Psi = (\Gamma - 1) \sum_n \left(\frac{\gamma_n}{\Gamma}\right) \dot{x}_n, \tag{11}$$

represents the contribution of scale effects due to expansion or contraction of inputs towards total productivity change. Evidently under constant returns to scale ($\Gamma = 1$) there is no contribution of scale effects. However, under increasing/decreasing returns

to scale ($\Gamma > 1/\Gamma < 1$) input expansion positively/negatively contributes to productivity change. The allocative efficiency (or price effect) given by

$$\Omega = \sum_n \left(\frac{\gamma_n}{\Gamma} - S_n \right) x_n, \quad (12)$$

represents productivity changes that are resulting from factor prices being at deviance from their respective marginal contribution to production. Thus, in case of factor prices reflecting perfect marginal costs ($\frac{\gamma_n}{\Gamma} - S_n = 0$) the contribution due to price effect would be nil ($\Omega = 0$). TFP change and its decomposition, derived in equation (10), can be computed using the parameter estimates of the production function in equation (2) as follows,

$$\Delta \hat{T}_{it} = \hat{\beta}_t + \hat{\beta}_{tt}t, \quad (13)$$

$$\Delta \hat{T}E_{it} = -\hat{u}_{it} \frac{d h_{it}}{dt} \approx -\hat{u}_{it} \frac{(h_{it} - h_{it-1})}{(t - t_{-1})}, \quad (14)$$

$$\hat{\gamma}_{nit} = \hat{\beta}_n + \sum_k \hat{\beta}_{nk} \ln \mathbf{x}_{it} + \hat{\beta}_{nt}t, \quad n = 1, \dots, N, \quad (15)$$

$$\hat{\Gamma}_{it} = \sum_n \hat{\gamma}_{nit} \quad (16)$$

5 Results

Our empirical investigation is guided by two key objectives. First, to know the distribution and nature of productivity change in the power sector. Second, to identify the sources of inefficiency. We attempt to fulfill these objectives by first, jointly estimating inefficiency and the exogenous determinants of inefficiency. Then we decomposing the estimated TFP changes into constituents of: technical change, efficiency change, scale effects and price effects, to understand the nature of change.

For different classes of firms in the power sector, we estimate the primal production model, equation (2), using the transformed fixed-effects SFA method. We employ the Maximum Likelihood Estimator (MLE) technique to fit the model with empirical data. The estimated parameters of the model are shown in table (6) and TFP and its decompositions are shown in table (7). For all the estimated models, except ‘Mixed Generators’, the inefficiency component, $\ln(\sigma_u)$, is significant and larger than the stochastic noise component $\ln(\sigma_v)$. Therefore, for these models the data shows existence of stochastic inefficiency different from noise. We observe that $\sum_n \beta_n \neq 1$ and $\beta_{nk} \neq \beta_{nt} \neq 0, \forall n, k$. Therefore, the production technology does not conform to the linearly homogeneous and simpler Cobb-Douglas specification. This justifies our choice of the flexible translog specification and also implies that the scale component, γ_n , varies across firms and through

time. We expect that the during this period TFP changed differently for the generators, T&D and integrated utilities.

5.1 Generators: Coal & Gas

For the coal based generators only ownership is significantly causing efficiency differences. We estimate the central Government owned generators to be about 57% ($= 1 - e^{-0.835}$) less inefficient than state Government or private owned ones. As expected the assets vintage influences reduction in inefficiency for newer plants, about 0.25% ($= 1 - e^{-0.239/(10*(2008-1913))}$) reduction for assets newer by one year, however the effect is not statistically significant. No influence of competition, un-bundling or time trend in inefficiency is observed. During this period the average per year TFP change observed is 11%. We observe that in the period post Electricity Act 2003, after 2004, there had been increase in technical change (shift in frontier), 13% per year, while efficiency had been declining at -7.5% per year. The mean returns to scale, $\bar{\Gamma} = 1.15$, indicates that coal based power generation shows increasing returns to scale.

For gas based generators, increased state-level competition is reducing inefficiency. Such that for every one index point increase in competition there is about 25% reduction in inefficiency. Inefficiency also show a significant time-trend. The quadratic terms indicate that inefficiency is increasing till the year 2007 and there is improvement subsequently (see figure (1)). No influence of asset vintage, un-bundling or ownership differences on inefficiency is observed. There is an average reduction in TFP of -1.4% per year, and the decline is mostly post year 2004. Post 2004, we observe that technical change has reduced from 12.8% per year to 1.3%, whereas efficiency change has improved from -7.6% to -0.1% per year. The mean returns to scale, $\bar{\Gamma} = 0.56$, indicates that gas based power generation shows decreasing returns to scale.

5.2 T&D & Integrated Utilities

For the T&D utilities, assets vintage has a significant influence as seen by reduction in inefficiency for newer plants. About 1.6% ($= 1 - e^{-1.496/(10*(2008-1913))}$) inefficiency reduction for assets newer by one year is observed. Inefficiency also show a significant time-trend. The quadratic terms indicate that inefficiency is increasing at a reducing rate till the year 2008 and there is no decline subsequently (see figure (1)). No influence of competition, un-bundling or ownership differences on inefficiency is observed. TFP changed at a mean rate of 46% per year. Post 2004, technical change reduced from 13.8% to 8.4% per year and efficiency change marginally worsened from -7.3% to -8.1% per year. The mean returns to scale, $\bar{\Gamma} = 20$, indicates that T&D firms show increasing

returns to scale.

Only ownership is observed to be significantly associated with inefficiency differences for the integrated utilities. The state Government owned utilities are observed to be significantly inefficient compared to the private utilities. No influence of competition, un-bundling or time-trend in inefficiency is observed. TFP is changing at a mean rate of about -11% per year. Post 2004, technical change declined from 17.2% to -5.6% per year, while efficiency improved from -13.2% to 3.3% per year. The mean returns to scale, $\bar{\Gamma} = 8$, indicates that integrated utilities show increasing returns to scale.

6 Conclusion

Our results suggests that firm-level productivity in the Indian power sector has generally declined during the period of 2000-2009. We document that state-level un-bundling of the sector is not significantly associated with firm-level efficiency change. Further, efficiency improvements attributable to increased competition is observed only in the case of smaller gas based generators. During the period post Electricity Act 2003, we observe positive technology change while simultaneously a decline in efficiency is observed for the coal based generators. Improvement in efficiency over time is observed only for gas based generators and integrated utilities, whereas T&D firms show a decline in both technical change and efficiency.

Our results are consistent with earlier findings. For instance Cropper et al. (2011) finds no statistically significant improvement in thermal efficiencies post un-bundling while Sen and Jamasb (2010); Cropper et al. (2011) find a significant improvement in plant-load factors (capacity utilization). We also observed a similar effect reflected in the increase in mean scale change effect from 1.8% to 12% per year post year 2004. However, contribution to TFP improvement from increased capacity utilization is offset partially by the declining efficiencies.

These results are indicative of the piecemeal approach to power sector reforms in India. The emphasis of reforms in India had been towards un-bundling of utilities and opening up the sector to private independent power producers. However, market for power remains under-developed, tariff reforms are not initiated and fuel remains short in supply. These anomalies are likely to create skewed incentives for firms. The generators are governed by rate of return regulation and generally do not face retail competition. Therefore de-licensing investment in generation creates incentives for private investors to invest in large capital intensive projects. We observe this effect in the form of increased

technical change only in the coal based generators, that is a result of increased investments in newer and larger plants. From a policy perspective, our results point towards the need for tariff reforms to encourage increased participation of independent power producers. For the T&D firms controlled and low retail prices hardly makes-up for cost recovery and creates disincentive for private investments. For the larger generators there is lack of market incentives to reduce costs or improve efficiency, therefore strengthening the electricity markets and introduction of retail competition are possible policy alternatives to pursue.

A Within Transformed SFA Model

A.1 SFA Model Specification

The within transformed SFA model (Wang and Ho, 2010) used in this paper is described here. Consider an SFA model with the following general specifications:

$$y_{it} = \alpha_i + \mathbf{x}_{nit}\boldsymbol{\beta} + \epsilon_{it}, \quad i = 1, \dots, I, \quad t = 1, \dots, T, \quad n = 1, \dots, N \quad (17)$$

$$\epsilon_{it} = v_{it} + u_{it}, \quad (18)$$

$$v_{it} \sim N(0, \sigma_v^2), \quad (19)$$

$$u_{it} = h_{it} \cdot \bar{u}_i, \quad (20)$$

$$h_{it} = f(\mathbf{z}_{kit}\boldsymbol{\delta}), \quad k = 1, \dots, K \quad (21)$$

$$\bar{u}_i \sim N^+(\mu, \sigma_u^2). \quad (22)$$

Here, \mathbf{x}_{nit} is a vector of N production factor variables (or explanatory variables in general) and α_{it} represents unobserved fixed effect corresponding to the i^{th} firm. $v_{it} \sim N(0, \sigma_v^2)$ is the noise component and \bar{u}_{it} is the nonnegative stochastic technical inefficiency component. While \bar{u}_{it} is defined as a truncated normal distribution (Eq.22), in our model we set $\mu = 0$ and assume a half-normal distribution for the inefficiency component. The vector \mathbf{z}_{kit} represents K exogenous variables determining inefficiency.

A.2 Transformed Specification

The *within transformation* is obtained by subtracting the sample mean of each panel from every individual observation in the panel. The transformation, by de-meaning, removes time-invariant fixed effects from the model. The model specification (Eq.17-22) post transformation may be represented as:

$$\tilde{y}_{i*} = \alpha_i + \tilde{\mathbf{x}}_{ni*}\boldsymbol{\beta} + \tilde{\epsilon}_{i*}, \quad (23)$$

$$\tilde{\epsilon}_{i*} = \tilde{v}_{i*} + \tilde{u}_{i*}, \quad (24)$$

$$\tilde{v}_{i*} \sim \mathbf{N}(0, \Pi), \quad (25)$$

$$\tilde{u}_{i*} = \tilde{h}_{i*} \cdot \bar{u}_i, \quad (26)$$

$$\bar{u}_i \sim N^+(\mu, \sigma_u^2). \quad (27)$$

Here, we denote mean of individuals over the panel by $y_{i*} = (1/T)\sum_{t=1}^T y_{it}$, and the mean differenced value by $y_{it*} = y_{it} - y_{i*}$. The full panel as a vector stack is represented as

$\tilde{y}_{i*} = (y_{i1}, y_{i2}, \dots, y_{iT})'$. The variance-covariance matrix of \tilde{v}_{i*} (Eqn. 25) is

$$\Pi = \begin{bmatrix} \sigma_v^2(1-1/T) & \sigma_v^2(-1/T) & \dots & \sigma_v^2(-1/T) \\ \sigma_v^2(-1/T) & \sigma_v^2(1-1/T) & \dots & \sigma_v^2(-1/T) \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_v^2(-1/T) & \sigma_v^2(-1/T) & \dots & \sigma_v^2(1-1/T) \end{bmatrix} \quad (28)$$

A.3 Log-Likelihood Function

For the model described above, Wang and Ho (2010) derives the marginal log-likelihood function of the i^{th} panel as follows,

$$\begin{aligned} \ln L_i = & -\frac{1}{2}(T-1)\ln(2\pi) - \frac{1}{2}(T-1)\ln(\sigma_v^2) - \frac{1}{2}\tilde{\epsilon}_{i*}'\Pi^{-}\tilde{\epsilon}_{i*} + \frac{1}{2}\left(\frac{\mu_1^2}{\sigma_1^2} - \frac{\mu^2}{\sigma^2}\right) \\ & + \ln\left(\sigma_1\Phi\left(\frac{\mu_1}{\sigma_1}\right)\right) - \ln\left(\sigma_u\Phi\left(\frac{\mu}{\sigma_u}\right)\right), \end{aligned} \quad (29)$$

where Π^{-} is the generalized inverse of Π , ϕ the normal density function, Φ the cumulative density function and,

$$\mu_1 = \frac{\mu/\sigma_u^2 - \tilde{\epsilon}_{i*}'\Pi^{-}\tilde{h}_{i*}}{\tilde{h}_{i*}'\Pi^{-}\tilde{h}_{i*} + 1/\sigma_u^2}, \quad (30)$$

$$\sigma_1^2 = \frac{1}{\tilde{h}_{i*}'\Pi^{-}\tilde{h}_{i*} + 1/\sigma_u^2}, \quad (31)$$

$$\tilde{\epsilon}_{i*} = \tilde{y}_{i*} - \tilde{\mathbf{x}}_{i*}\beta \quad (32)$$

The log likelihood function of the model L is obtained by summing the marginal likelihood over $i = 1, \dots, I$

$$L = \sum_{i=1}^I L_i \quad (33)$$

A.4 Inefficiency and Fixed-Effect Estimation

The inefficiency index of observation/firm, i , during period, t , can be estimated as the expectation of u_{it} conditional on the model residue, $\tilde{\epsilon}_{i*}$:

$$E(u_{it}|\tilde{\epsilon}_{i*}) = h_{it} \left[\mu_1 + \frac{\phi\left(\frac{\mu_1}{\sigma_1}\right)\sigma_1}{\Phi\left(\frac{\mu_1}{\sigma_1}\right)} \right] \quad (34)$$

The fixed-effects, α_i 's, can be recovered from the estimates of parameters obtained,

$$\hat{\alpha}_i = y_{i*} - \mathbf{x}_{i*}\hat{\beta} + \hat{\mu}_2\hat{h}_{i*} + \hat{\sigma}_2\hat{h}_{i*} \frac{\phi\left(\frac{\hat{\mu}_2}{\hat{\sigma}_2}\right)}{\Phi\left(\frac{\hat{\mu}_2}{\hat{\sigma}_2}\right)}, \quad (35)$$

where

$$\hat{\mu}_2 = \frac{\hat{\mu}\hat{\sigma}_u^{-2} - \hat{\sigma}_v^{-2T}\sum_t\hat{\epsilon}_{it}\hat{h}_{it}}{\hat{\sigma}_v^{-2T}\sum_t\hat{h}_{it}^2 + \hat{\sigma}_u^{-2}} \quad (36)$$

$$\hat{\sigma}_2^2 = \frac{\hat{\sigma}_v^{2T}}{\sum_t \hat{h}_{it}^2 + \hat{\sigma}_v^{2T} \hat{\sigma}_u^{-2}} \quad (37)$$

A routine, in the R-statistical language, is written to estimate the maximum likelihood function (Eq. 29). Additional routines computes inefficiency indices following Eq. 34 and the firm fixed-effects following Eq. 35. The R-code is tested with STATA procedure and test data obtained from Hun-Jen Wang, as described in detail in Wang and Ho (2010). In addition Monte Carlo simulations are done to test the R-routine. The complete R-code is available freely from the authors on request.

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Table 1: Variable Definition and Units-I

Variable	Units	Description	Source
1.	Electricity Output	GWhr	Total electricity generated or distributed. Computed by dividing the reported revenue from operations by yearly average region-wise electricity for each type of generating technology. In case of T&D and vertically integrated utilities the region-wise yearly average retail electricity prices are used.
2.	Capital Deployed	million Indian Rupees (INR)	Gross fixed assets (real) deployed. Current values deflated by GDP (1999=100). Computed for a period by adding Net-fixed assets of the period with cumulated depreciation till that period.
3.	Labor Employed	Numbers	Computed by dividing the total reported employee expenditure by the yearly average estimated wages in the power sector in India.
4.	Fuel Consumed: Coal	GWhr energy equivalent of coal used.	Computed by dividing the total reported expenditure on fuel/raw-material by the yearly average estimated purchase price of coal in each region. An average calorific value of 4000KCal/Kg or 4648.9KWhr/metric tonne is assumed for coal.
5.	Fuel Consumed: Gas	GWhr energy equivalent of natural gas used.	Computed by dividing the total reported expenditure on fuel/raw-material by the yearly average estimated purchase price of gas in each region. An average calorific value of 40 Mjoule/m ³ or 11.11KWhr/m ³ is assumed.
6.	Electricity Input	GWhr	Computed by dividing the total reported expenditure on fuel/electricity purchased by the yearly average sale price to utilities in each region.

Continued on Table.2 . . .

Table 2: Variable Definition and Units-II

Variable	Units	Description	Source
7. <i>Coal Price</i>	INR per metric tonne	Region-Year average purchase price of coal in power sector estimated by a smaller sample of firm data reporting both quantity of fuel and the total expenditure on fuel from each region.	The smaller sample of firm data obtained from CMIE PROWESS.
8. <i>Gas Price</i>	INR per cubic meter	Region-Year average purchase price of natural in power sector estimated by a smaller sample of firm data reporting both quantity of fuel and the total expenditure on fuel from each region.	The smaller sample of firm data obtained from CMIE PROWESS.
9. <i>Sale Price of Electricity by Coal Based Generators</i>	INR per KWhr	Region-Year average sale price of electricity by Coal based generators. Estimated by a smaller sample of firm data reporting both quantity of electricity sales and the total revenue from electricity sales from each region.	The smaller sample of firm data obtained from CMIE PROWESS.
10. <i>Sale Price of Electricity by Gas Based Generators</i>	INR per KWhr	Region-Year average sale price of electricity by Gas based generators. Estimated by a smaller sample of firm data reporting both quantity of electricity sales and the total revenue from electricity sales from each region.	The smaller sample of firm data obtained from CMIE PROWESS.
11. <i>Retail Price of Electricity</i>	INR per KWhr	State-Year average sale price of electricity by utilities.	Electricity retail prices obtained from TEDDY year-book
12. <i>Price of Capital</i>	Percentage	Computed as... (a) Price of Capital = Expense of Capital/Gross Fixed Assets. (b) Expense of Capital= Interest Share of Capital + Depreciation. (c) Interest Share of Capital=(Annual Interest on Long-Term Debt)*(Fixed Assets)/(Long Term Debt)	Company financial data in annual reports obtained from CMIE PROWESS.
13. <i>Vintage</i>	Year	The year of incorporation of the company is taken as a proxy for the approximate vintage of the firm's productive assets.	Company annual reports.
14. <i>Time Since Un-bundling</i>	Year	Years past since the vertically integrated state electricity boards (SEBs) were unbundled and separated as generators and distribution utilities in the respective states.	TEDDY year-book
16. <i>Index of Competition in Power Sector in the State</i>	Index Number	Measure of the competitiveness of the state power sector. Score of 0-to-40, higher score indicating more sustainable revenue model	Ministry of Power, Government of India

(a) CMIE PROWESS: The PROWESS database of Indian companies details maintained by the Center for Monitoring of Indian Economy, Mumbai India.

(b) TEDDY: TERI Energy Data Directory and Yearbook, annual publication of The Energy and Resource Institute, New Delhi India.

(c) World Bank Development Indicators: maintained at <http://data.worldbank.org/data-catalog/world-development-indicators>

(d) Ministry of Power Report: http://www.powermin.nic.in/indian_electricity_scenario/pdf/Final_Report_Rating.pdf

Table 3: Description of Sample

Year	Generation		Transmission & Distribution			Total Generation (GWhr)	Generation Sample Coverage	Total Consumption (GWhr)	Distribution Sample Coverage
	Fossil Fuels	Mixed	Distribution Utilities	Vertically Integrated	Total Generation (GWhr)				
	Coal	Gas							
2000	8	4	3	5	3	501,204	33.9%	316,600	27.3%
2001	8	5	3	9	7	517,439	31.3%	322,459	70.0%
2002	16	9	5	11	7	532,693	45.6%	339,598	57.9%
2003	16	11	5	17	6	565,102	50.8%	360,937	62.0%
2004	15	13	4	23	6	594,456	42.7%	386,134	58.5%
2005	14	15	6	25	6	623,820	47.5%	411,887	67.4%
2006	14	18	2	25	4	670,654	48.6%	455,748	61.4%
2007	13	16	5	30	4	722,626	48.5%	501,977	70.5%
2008	12	17	6	25	4	741,167	48.4%	527,564	63.0%
2009	15	17	3	23	4	790,766	51.9%	553,151	50.1%
Firms=98	21	19	11	38	9	6,259,927	45.7%	4,176,055	59.4%
Firm- Years=542	131	125	42	193	51				

Table 4: Summary Statistics

Variable	Mean	S.d.	Min	Max	N
Electricity Output ^a	9,848.67	20,111.82	16.29	207,351.79	542
Capital Deployed ^b	38,992.40	72,951.23	160.60	668,474.20	542
Labour ^c	4,800.83	9,006.34	2.25	77,528.54	542
Fuel:Coal ^d	63,731.08	141,227.98	117.04	738,319.02	131
Fuel:Gas ^e	8,055.95	18,477.04	56.94	102,879.34	125
Electricity Input ^f	11,858.73	14,095.34	0.55	89,783.45	193
Coal Price ^g	1,533.57	246.48	1,227.40	1,839.40	542
Gas Price ^h	5.21	0.88	4.00	6.60	542
Capital Price ⁱ	8.68%	5.43%	0.10%	42.00%	542
Coal Gen. Price ^j	2.10	0.57	0.64	3.26	131
Gas Gen. Price ^k	3.05	1.51	1.14	9.41	125
Retail Electricity Price ^l	2.11	0.76	0.48	4.05	193
Year of Incorporation ^m	1,987.15	22.35	1,913.00	2,008.00	542
Time Since Unbundled ⁿ	2.63	4.72	-9	13	542
Competition Index ^p	23.49	7.45	0.00	40.00	542

Variable Definition and Units

^a Electricity generated or distributed in GWhr. Computed by dividing reported revenue from operations by yearly average regional electricity prices for each generating technology. In case of T&D and vertically integrated companies the state-wise yearly average retail electricity prices are used.

^b Real gross fixed assets deployed in million Indian Rupees, deflated by GDP (1999=100)

^c No. of employees. Computed by dividing the total reported employee expenditure by the yearly average estimated wages in the power sector.

^d GWhr equivalent of coal used. Computed by dividing the reported fuel expenditure by the yearly average purchase price of coal obtained from a smaller sample of firms reporting this information. An average calorific value of 4000KCal/Kg or 4648.9KWhr/metric tonne is assumed for coal.

^e GWhr equivalent of gas used. Computed by dividing the reported fuel expenditure by the yearly average purchase price of gas obtained from a smaller sample of firms reporting this information. An average calorific value of 40 Mjoule/m³ or 11.11KWhr/m³ is assumed.

^f Electricity purchased in GWhr. Computed by dividing reported expenditure on fuel by yearly average region-wise electricity sale price of generators to distribution utilities.

^g INR per metric tonne. Region-Year average purchase price of coal used in the power sector.

^h INR per cubic meter. Region-Year average purchase price of natural in power sector.

ⁱ Percentage, computed as: Price of Capital = Expense of Capital/Gross Fixed Assets.

^j INR per KWhr. Region-Year average sale price of electricity by Coal based generators.

^k INR per KWhr. Region-Year average sale price of electricity by Gas based generators.

^l State-Year average sale price of electricity by utilities.

^m Year of incorporation of the firm. used as proxy for asset vintage.

ⁿ Time in years, since the home State power sector is unbundled.

^p Index of competitiveness of power sector in the State.(0=low to 40=high)

Table 5: Variable Statistics, Mean (s.d), by Technology

Year	Generation				
	Fossil Fuels		Mixed	Transmission & Distribution	
	Coal	Gas		Distribution Utilities	Vertically Integrated
Electricity Output ^a	17,970.34 (35,971.94)	2,054.39 (3,614.19)	5,898.20 (6,580.76)	8,560.41 (8,459.28)	16,219.20 (16,848.78)
Capital Deployed ^b	46,060.92 (74,565.80)	6,648.24 (7,760.42)	11,926.62 (17,180.15)	14,266.73 (13,024.37)	51,048.37 (53,554.72)
Labour ^c	5,963.04 (9,457.96)	329.26 (963.34)	2,233.28 (2,783.19)	4,759.15 (5,595.16)	15,047.49 (18,709.51)
Fuel:Coal ^d	63,731.08 (141,227.98)				
Fuel:Gas ^e		8,055.95 (18,477.04)			
Electricity Input ^f				11,858.73 (14,095.34)	122,108.12 (132,853.61)
(Firms:98)	21	19	11	38	9
(Firm-Years:542)	131	125	42	193	51

Variable Definition and Units

^a Electricity generated or distributed in GWhr. Computed by dividing reported revenue from operations by yearly average regional electricity prices for each generating technology. In case of T&D and vertically integrated companies the state-wise yearly average retail electricity prices are used.

^b Real gross fixed assets deployed in million Indian Rupees, deflated by GDP (1999=100)

^c No. of employees. Computed by dividing the total reported employee expenditure by the yearly average estimated wages in the power sector.

^d GWhr equivalent of coal used. Computed by dividing the reported fuel expenditure by the yearly average purchase price of coal obtained from a smaller sample of firms reporting this information. An average calorific value of 4000KCal/Kg or 4648.9KWhr/metric tonne is assumed for coal.

^e GWhr equivalent of gas used. Computed by dividing the reported fuel expenditure by the yearly average purchase price of gas obtained from a smaller sample of firms reporting this information. An average calorific value of 40 Mjoule/m³ or 11.11KWhr/m³ is assumed.

^f Electricity purchased in GWhr. Computed by dividing reported expenditure on fuel by yearly average region-wise electricity sale price of generators to distribution utilities.

Table 6: Maximum Likelihood Estimates of the Translog Production Model Parameters

Variable	Par.	Coal	Gas	Mixed	TnD	Integr.
$\ln(K)$	β_K	-0.412 (0.550)	0.205 (1.052)	1.686† (1.314)	-2.138 (3.349)	-0.284* (0.169)
$\ln(L)$	β_L	1.550*** (0.364)	0.864* (0.399)	0.210 (1.083)	-0.070 (0.867)	-0.720*** (0.048)
$\ln(F)$	β_F	0.340 (0.287)	0.654† (0.464)	1.924*** (0.520)	0.767* (0.363)	0.286 (0.349)
$\frac{1}{2}\ln(K)\ln(K)$	β_{KK}	0.180* (0.088)	0.256* (0.145)	0.074 (0.264)	0.212 (0.340)	0.122† (0.084)
$\frac{1}{2}\ln(L)\ln(L)$	β_{LL}	-0.113** (0.044)	0.119* (0.054)	0.330** (0.118)	-0.111 (0.134)	0.361** (0.140)
$\frac{1}{2}\ln(F)\ln(F)$	β_{FF}	0.050* (0.023)	0.224*** (0.035)	0.436*** (0.075)	0.070*** (0.013)	0.022 (0.085)
$\frac{1}{2}\ln(K)\ln(L)$	β_{KL}	-0.062 (0.105)	-0.201† (0.153)	0.232 (0.308)	0.222† (0.165)	-0.331* (0.151)
$\frac{1}{2}\ln(K)\ln(F)$	β_{KF}	-0.079 (0.065)	-0.380*** (0.099)	-0.658*** (0.192)	-0.206** (0.081)	0.112 (0.177)
$\frac{1}{2}\ln(L)\ln(F)$	β_{LF}	-0.049 (0.041)	-0.076 (0.095)	-0.668*** (0.193)	0.062† (0.039)	-0.179† (0.120)
<i>Time</i>	β_t	-0.043 (0.072)	0.247† (0.184)	0.114† (0.088)	0.065 (0.221)	0.253* (0.111)
$\frac{1}{2}Time^2$	β_{tt}	0.026** (0.009)	-0.020* (0.010)	-0.003 (0.011)	-0.015* (0.008)	-0.046*** (0.012)
$\ln(K)Time$	β_{Kt}	-0.035*** (0.010)	0.035 (0.030)	0.062* (0.033)	0.038* (0.022)	-0.039** (0.015)
$\ln(L)Time$	β_{Lt}	0.028*** (0.007)	-0.022 (0.018)	0.021 (0.041)	-0.014 (0.020)	0.083*** (0.013)
$\ln(F)Time$	β_{Ft}	0.009* (0.005)	-0.031* (0.016)	-0.077** (0.026)	-0.012* (0.006)	-0.023 (0.027)
Exogenous explanatory variables						
<i>Time</i>	δ_t	-0.192 (0.211)	0.321† (0.219)	-0.944 (1.107)	0.924*** (0.290)	0.080 (0.085)
$Time^2$	δ_{tt}	0.018 (0.019)	-0.023† (0.016)	-1.318 (3.154)	-0.054** (0.018)	-0.007 (0.008)
<i>Asset Vintage</i>	δ_V	-0.239 (0.191)	0.217 (0.670)	0.506 (1.102)	-1.496* (0.883)	0.126 (0.139)
<i>Owner : Central Govt.</i>	δ_{CG}	-0.835*** (0.076)	-	-	-0.461 (1.601)	-
<i>Owner : State Govt.</i>	δ_{SG}	-0.045 (0.413)	0.193 (0.753)	-0.106*** (0.000)	0.043 (0.369)	1.033*** (0.050)
<i>Unbundled</i>	δ_{Ud}	0.081 (0.100)	0.034 (0.090)	-0.079 (0.590)	-1.803 (1.441)	-
<i>Competition</i>	δ_{Cmp}	0.025 (0.140)	-0.281† (0.210)	-0.483 (1.282)	-0.086 (0.121)	-0.045 (0.315)
Inefficiency						
	$\ln(\sigma_u)$	2.585*** (0.013)	-0.297*** (0.066)	0.174 (0.165)	-1.052† (0.722)	0.087*** (0.010)
	$\ln(\sigma_v)$	-4.422*** (0.148)	-3.967*** (0.145)	-4.980*** (0.258)	-4.028*** (0.128)	-6.420*** (0.251)
<i>Log Likelihood</i>		72.676	54.149	32.997	69.358	62.061

Standard errors (in parenthesis) computed using delta method.

Significance denoted by †: $p < 0.1$, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$

Table 7: Power Sector TFP Changes and Decomposition of TFP

Year	Generator:Coal						Generator:Gas						Generator:Mixed					
	TFP	ΔT	$\Delta T E$	Ψ	Ω	Γ	TFP	ΔT	$\Delta T E$	Ψ	Ω	Γ	TFP	ΔT	$\Delta T E$	Ψ	Ω	Γ
2000-01	0.212	-0.034	0.158	0.095	-0.008	0.554	0.156	0.148	-0.076	0.092	-0.008	-0.258	0.336	0.057	0.093	0.193	-0.007	-18.704
2001-02	0.207	-0.018	0.125	0.006	0.094	1.714	0.016	0.146	-0.093	0.015	-0.052	0.916	0.205	0.030	0.002	0.182	-0.008	-19.211
2002-03	0.068	0.015	0.084	-0.023	-0.007	1.550	-0.017	0.122	-0.076	-0.066	0.003	0.794	-0.950	0.129	0.000	-1.098	0.018	-13.252
2003-04	0.063	0.039	0.043	-0.008	-0.012	1.781	0.054	0.096	-0.058	0.040	-0.025	0.632	-0.029	0.100	0.000	-0.126	-0.002	-14.647
2004-05	-0.115	0.065	-0.003	-0.151	-0.026	1.831	-0.392	0.073	-0.044	-0.383	-0.038	0.812	-1.430	0.188	0.000	-1.624	0.006	-7.765
2005-06	-0.001	0.100	-0.024	-0.058	-0.019	1.360	0.090	0.036	-0.022	0.103	-0.027	0.546	2.766	0.006	0.000	2.787	-0.026	-25.100
2006-07	0.190	0.136	-0.071	0.124	0.001	0.268	0.013	0.004	-0.001	0.030	-0.021	0.334	0.285	0.032	0.000	0.256	-0.003	-18.676
2007-08	0.244	0.161	-0.120	0.212	-0.008	0.662	-0.001	-0.014	0.015	0.022	-0.024	0.718	-0.434	0.037	0.000	-0.470	-0.001	-18.774
2008-09	0.091	0.188	-0.158	0.474	-0.412	0.469	-0.112	-0.034	0.045	-0.112	-0.011	0.548	-2.689	0.005	0.000	-2.699	0.005	-26.641
$mean_{2000-04}^a$	0.138	0.001	0.103	0.018	0.017	1.400	0.052	0.128	-0.076	0.021	-0.021	0.521	-0.109	0.079	0.024	-0.212	0.000	-16.454
$mean_{2004-09}^a$	0.082	0.130	-0.075	0.120	-0.093	0.918	-0.080	0.013	-0.001	-0.068	-0.024	0.592	-0.300	0.054	0.000	-0.350	-0.004	-19.391
	Distribution						Integrated						Power Sector All					
	TFP	ΔT	$\Delta T E$	Ψ	Ω	Γ	TFP	ΔT	$\Delta T E$	Ψ	Ω	Γ	TFP	ΔT	$\Delta T E$	Ψ	Ω	Γ
2000-01	1.761	0.155	-0.032	1.632	0.005	19.892	0.167	0.227	-0.130	0.068	0.002	6.713	0.606	0.084	0.034	0.490	-0.003	3.343
2001-02	0.487	0.146	-0.053	0.392	0.001	20.771	0.202	0.214	-0.169	0.146	0.011	8.586	0.239	0.105	-0.031	0.147	0.018	5.744
2002-03	0.951	0.133	-0.086	0.900	0.005	19.681	0.547	0.147	-0.127	0.506	0.021	8.590	0.213	0.089	-0.019	0.140	0.003	4.970
2003-04	0.202	0.119	-0.121	0.205	-0.001	19.304	-0.358	0.102	-0.103	-0.345	-0.012	8.441	0.045	0.088	-0.049	0.017	-0.011	6.270
2004-05	0.525	0.101	-0.124	0.544	0.004	18.444	-0.527	0.041	-0.027	-0.523	-0.017	7.663	-0.032	0.083	-0.060	-0.039	-0.016	7.923
2005-06	-0.359	0.101	-0.130	-0.329	-0.002	20.401	-0.421	-0.019	0.009	-0.404	-0.007	7.871	-0.056	0.072	-0.063	-0.052	-0.013	8.311
2006-07	-0.054	0.094	-0.100	-0.045	-0.003	20.962	-0.432	-0.060	0.047	-0.414	-0.005	7.868	0.012	0.066	-0.053	0.006	-0.007	7.924
2007-08	-0.069	0.066	-0.059	-0.074	-0.001	20.343	-0.067	-0.102	0.058	-0.021	-0.002	8.003	-0.019	0.049	-0.038	-0.021	-0.009	7.202
2008-09	0.316	0.058	0.007	0.249	0.001	20.339	-0.314	-0.141	0.078	-0.247	-0.004	8.041	-0.049	0.042	-0.011	0.007	-0.086	7.373
$mean_{2000-04}^a$	0.850	0.138	-0.073	0.782	0.003	19.912	0.139	0.172	-0.132	0.094	0.006	8.083	0.276	0.092	-0.016	0.198	0.002	5.082
$mean_{2004-09}^a$	0.072	0.084	-0.081	0.069	0.000	20.098	-0.352	-0.056	0.033	-0.322	-0.007	7.889	-0.016	0.067	-0.046	-0.014	-0.024	7.501

a: Mean year-on-year changes.

ΔT : Technology change, $\Delta T E$: Technical efficiency change, Ψ : Scale effect, Ω : Price effect, Γ : Returns to scale

Figure 1: Power Sector Technical Efficiency Time-Trend

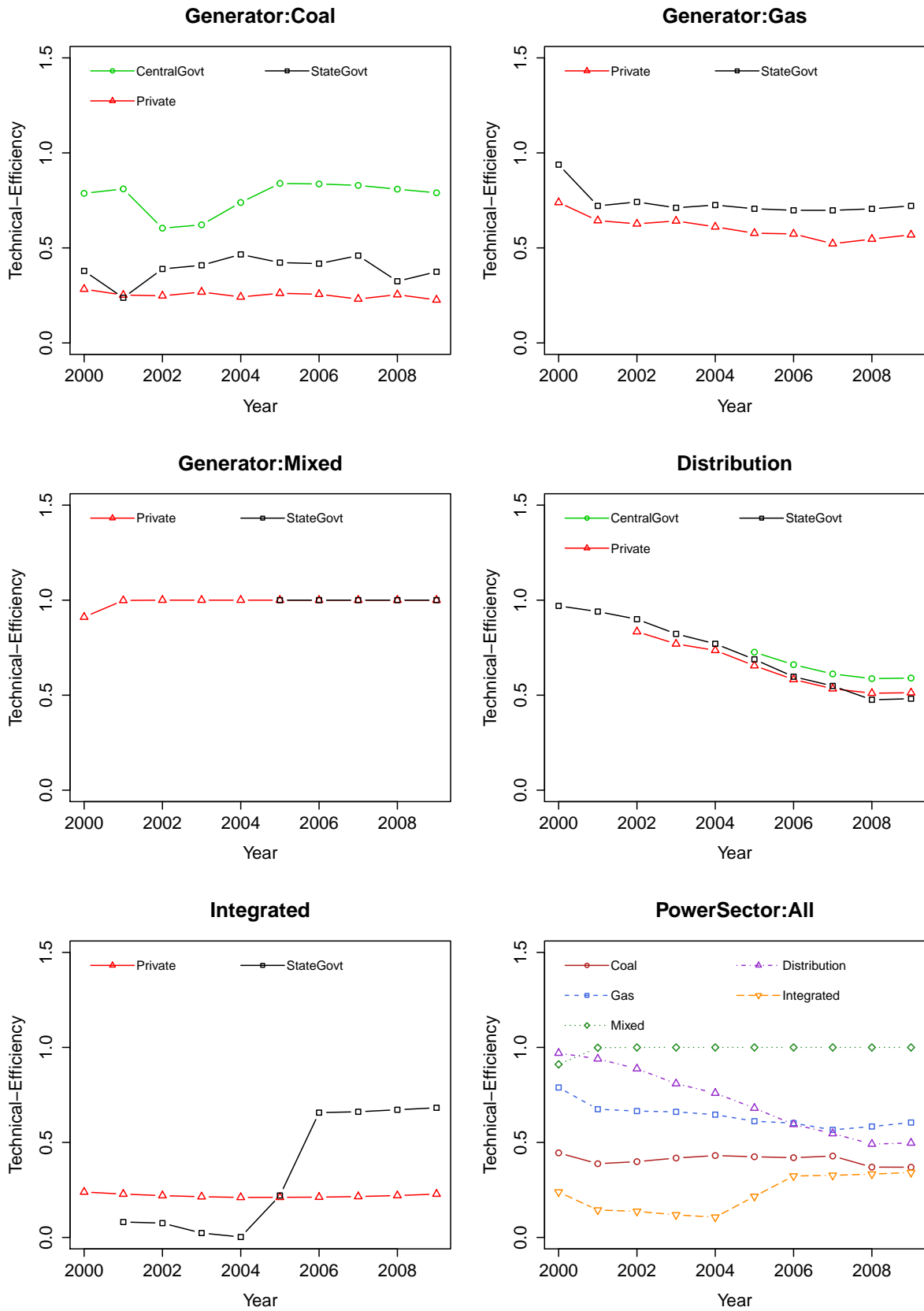


Figure 2: Power Sector Technical Efficiency Distribution

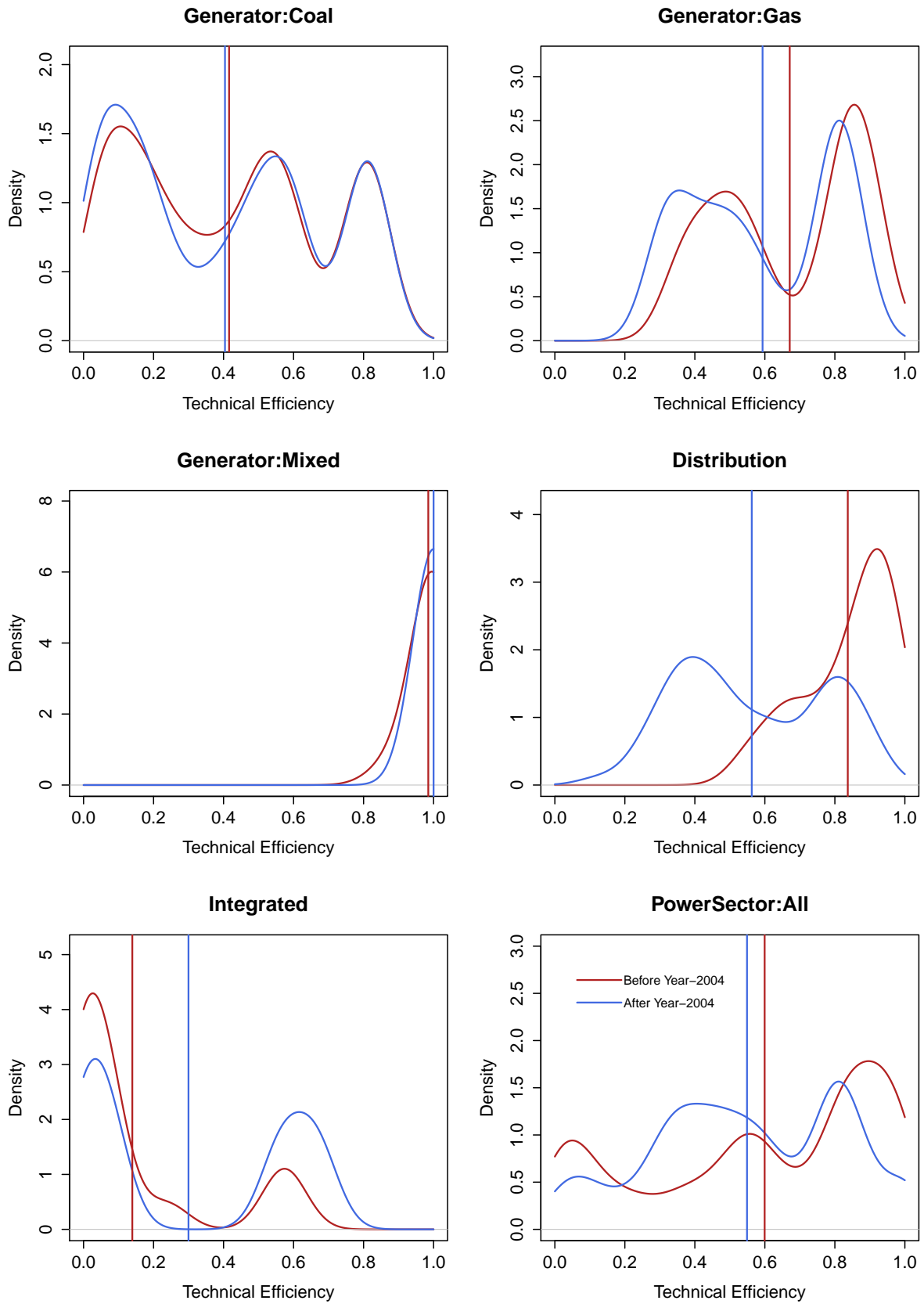


Figure 3: TFP Change in Power Sector

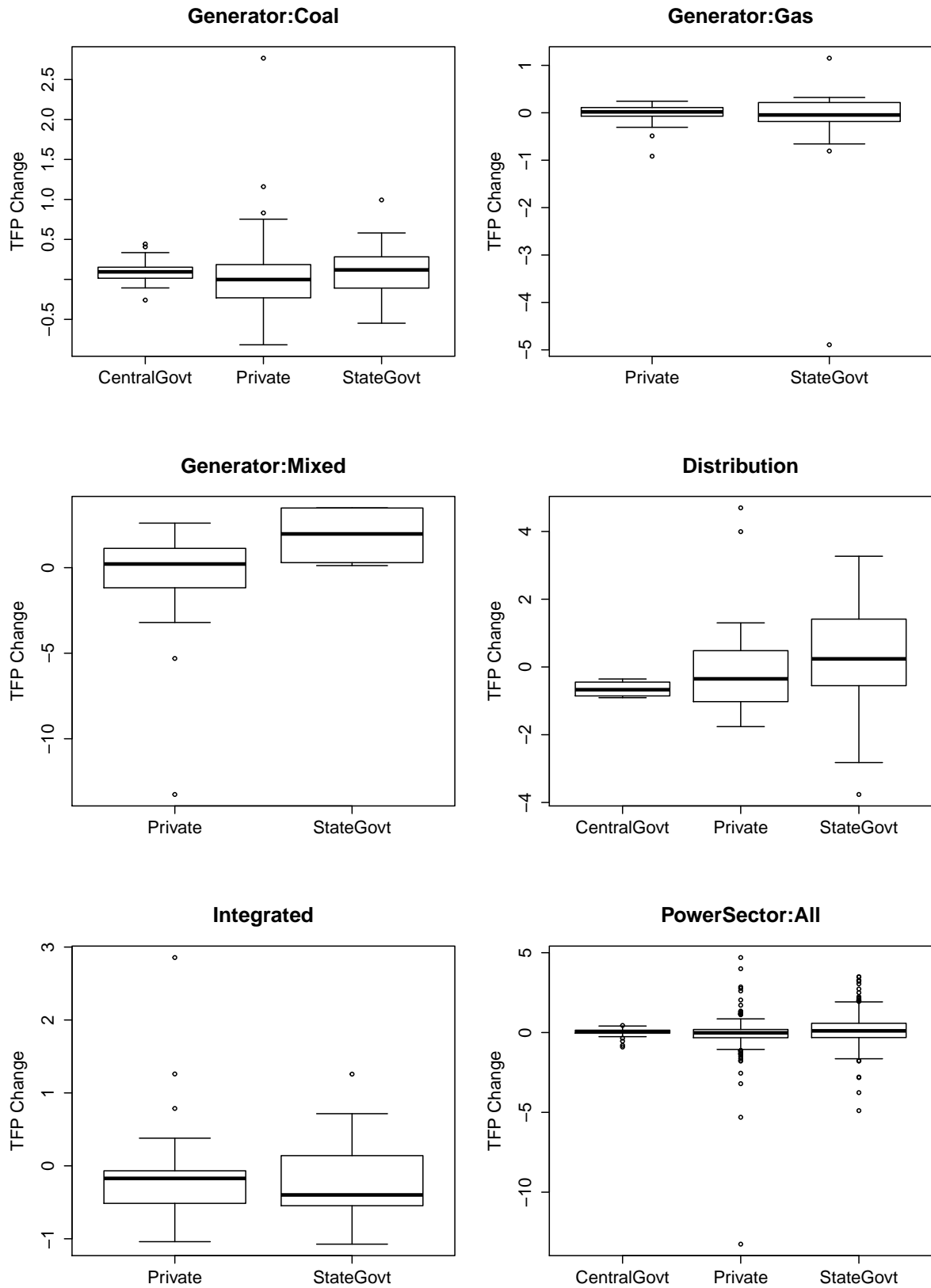


Figure 4: Technical Change in Power Sector

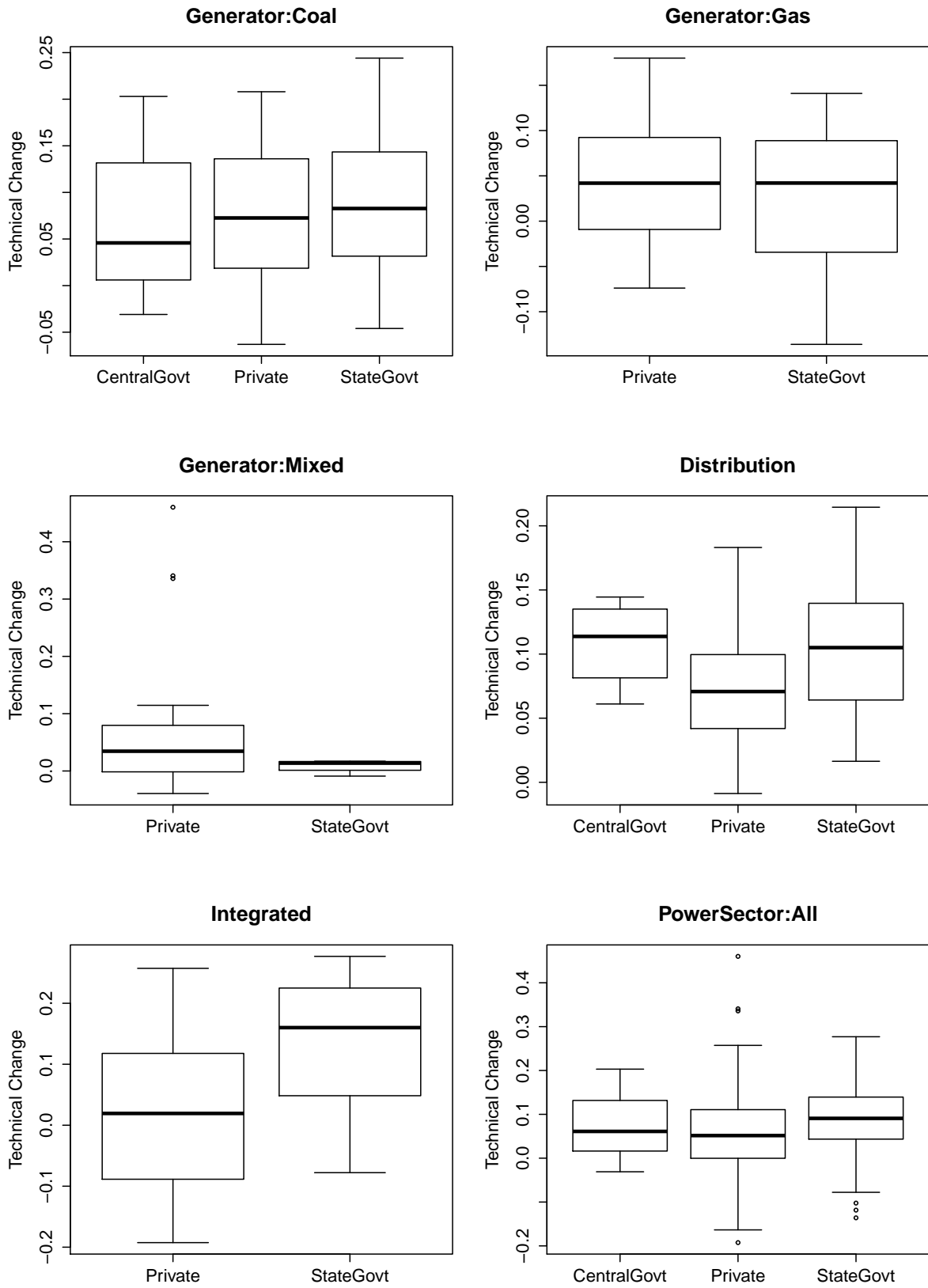


Figure 5: Efficiency Change in Power Sector

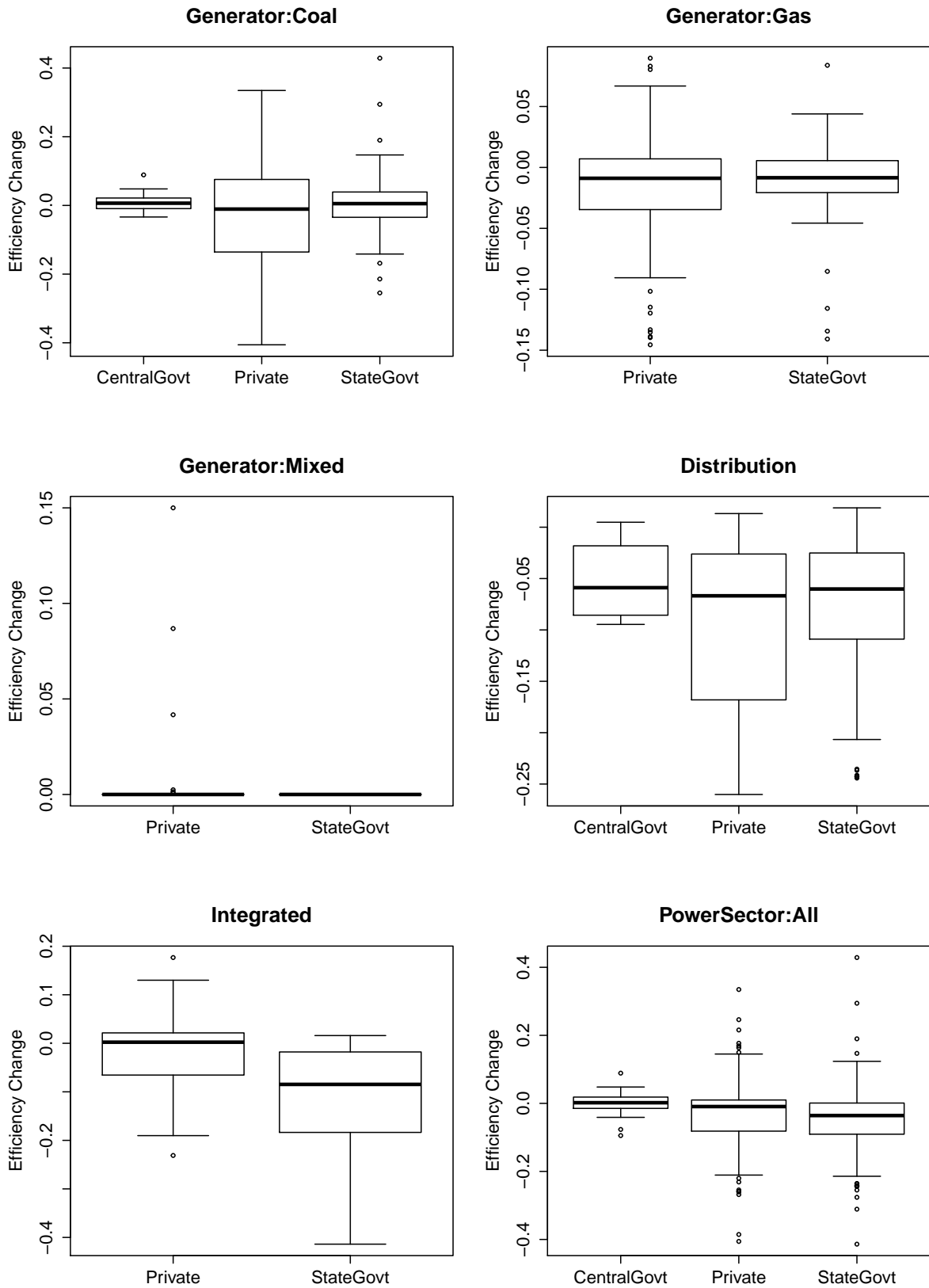


Figure 6: Scale Effect on TFP Change in Power Sector

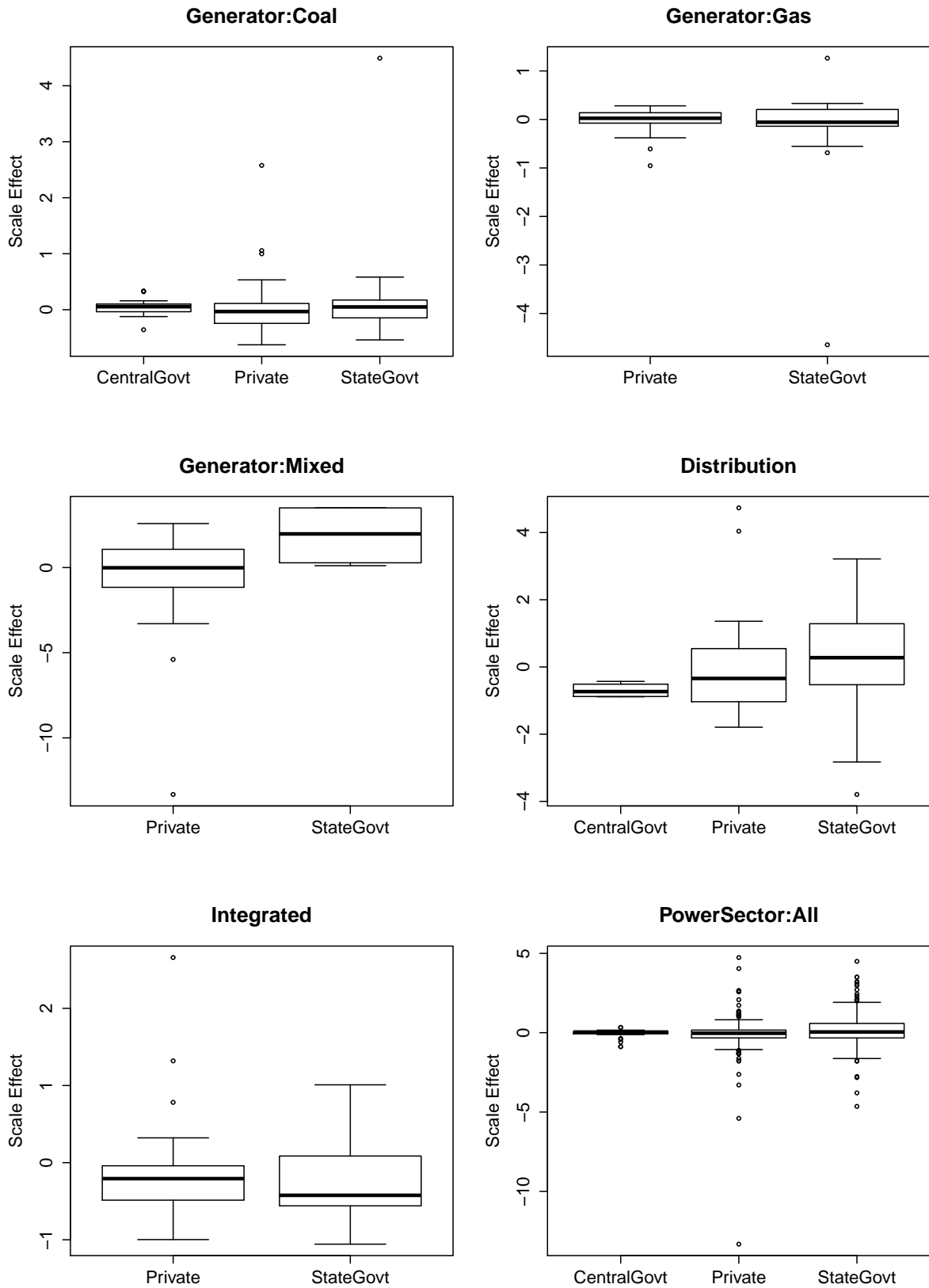


Figure 7: Price Effect on TFP Change in Power Sector

