STRUCTURAL REFORMS POLICY AND TECHNICAL EFFICIENCY: AN EMPIRICAL EVIDENCE FROM INDIAN ELECTRICITY DISTRIBUTION SECTOR

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Abstract

In this dissertation, we evaluate the impact of various external, environmental variables on the technical efficiency of the electricity distribution sector. For this purpose, we deploy two-stage bootstrap-DEA methodology, using the panel data across Indian states for the period 1995-2012. Bias corrected technical efficiency scores of decision making units (DMUs) are estimated using the bootstrap-DEA technique in the first-stage. While doing so, we also test the returns to scale of the underlying production technology of these DMUs. In the second stage we estimate the impact of external, environmental variables beyond the control of DMUs, such as, (a) ownership, (b) government subsidies to a class or group of customers, (c) policy reforms legislation, (d) different structural forms of generation, transmission, and distribution sectors existing in the electricity market, (e) state-level macroeconomic variables, namely, real gross domestic product (GDP) per capita and population density, and (f) electricity sector specific variables (viz., consumer structure and size of the distribution sector), on these technical efficiency scores.

First, our results indicate that constant returns to scale are exhibited in the underlying production technology of the state-level electricity distribution sector in India. Second, we found that publicly owned utilities have efficiency advantages in India, but deduced that the reason behind such an advantage is open for further research. Third, we discovered that, in high population density areas, private enterprises have efficiency advantages in electricity distribution over public sector utilities. Fourth, when the impact of reforms and of different unbundling structures were examined, we found that the transmission unbundling (i.e., generation and distribution sectors are together and transmission is separate), has a significant positive impact on the technical efficiency of

the distribution sector as compared to one under a fully vertically integrated electric monopoly. Fifth, we discovered that Indian electricity reforms legislation had negative impact on the technical efficiency of the distribution sector. Sixth, we found that "small-sized" states with partially or fully unbundled structures experience significant positive impact on the technical efficiency of their electricity distribution sector. The "medium-sized" states, on the other hand, show negative (but statistically insignificant) impact on the efficiency of their distribution sector after partial or full unbundling. It appears that, unlike "medium-sized" states, managers of "small-sized" state/distribution sectors have "size advantage," as they are able to adjust quickly to gain from "economies of scale" in order to overcome "diseconomies of scope" caused by unbundling of vertical monopolies. While analyzing the impact of state-level, time-varying covariates, we found that real GDP per capita and consumer structure have positive impact on technical efficiency of the electricity distribution sector in India, but it is not statistically significant. Last, we discovered that population density, which also represents consumer density, has a significant positive impact on the technical efficiency, while government subsidies have a negative impact on the performance of distribution utilities. Our results for these state-level variables are in conformity with the existing literature.

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1 Introduction

The Indian electricity sector witnessed enactment of landmark federal legislation related to structural reforms more than a decade ago. Establishment of State Electricity Regulatory Commissions (SERCs) and unbundling of vertical electric monopolies were two important salient features of this legislation. Post-reforms, the main role of SERCs was to issue tariff orders covering the cost of electricity supply, with some returns for the utilities. Sen and Jamasb (2012) observed that these reforms were aimed to make the sector more competitive and efficient. However, in a recent World Bank publication, Pargal and Banerjee (2014) observed that, even a decade after implementation of reforms, the Indian electricity distribution sector is loss making and inefficient. In another World Bank publication, Khurana and Banerjee (2014) also observed that some Indian states have done poorly, even after unbundling the vertical structure of monopoly, while few states have done better without unbundling after the legislation enactment. Given the diverse political-economy across India and concurrent jurisdiction for both federal and prefectural governments in India, different states adopted different timing and different forms of unbundling for their electricity sector. The states also adopted innovative policies for making the distribution sector efficient. Private participation in the distribution sector was one such measure adopted by many states in post-reform era.

The existing academic literature is deficient when it comes to empirical evaluation of Indian electricity reforms. Sen and Jamasb (2012) deduced in their empirical findings that Indian electricity reforms have negatively affected the efficiency of the distribution sector. However, in their findings, the term "efficiency" has different connotations. They used "technical and commercial losses" of the distribution sector to analyze the efficiency improvements of the distribution sector, and used a dynamic panel estimator for arriving at this conclusion. Sugathan et al. (2013) also concluded that unbundling of the Indian electric sector did not show any significant impact on the efficiency of the distribution sector. However, they used parametric stochastic frontier analysis (SFA) with ten years of data for a limited number of distribution utilities. Other existing literature from authors of Indian origin, Thakur et al. (2006), Meenakumari and Kamraj (2008), and Yadav et al. (2011), used non-parametric data envelopment analysis (DEA) for evaluating the Indian electric sector. However, these empirical studies could not capture the dynamic efficiency changes over longer time periods and, also, could not look into wider variation across Indian states. The existing literature also could not clearly distinguish the performances of distribution utilities based on ownership in the Indian context. The prevailing literature is almost non-existent which investigates the effect of various structures of unbundling on the technical efficiency of the distribution sector in a diverse country like India. The literature investigating dynamic interaction of “economies of scale” and “diseconomies of scope,” captured through interaction of “size” of DMUs with various “forms of unbundling structures,” of the electric sector is almost non-existent.

In prevailing literature, one strand of evaluation of electrical structural reforms uses a parametric approach by assuming multi-product cost function, and then, econometrically investigating whether economies of scope exist. Kwoka (2002), Nemoto and Goto (2004), Jara-Dıaz et al. (2004), Fraquelli et al. (2005), Piacenza and Vannoni (2009), and Goto et al. (2013) represent this direction of research. All these evaluations belong mostly to developed countries. However, the literature which uses a non-parametric method, like DEA, for structural reforms evaluation of the electricity sector is scarce. Existing literature has only two studies which used DEA to evaluate the impact of various structures of the electricity sector on efficiency. Arocena (2008) constructed hypothetical companies for creation of integrated frontiers from the post-unbundled companies to compare the pre-reform frontier of integrated companies. Meyer (2011) used bootstrap-DEA, but used a *super-efficiency* concept to compare the post-reform efficiency based on the pre-reform technology reference. However, both of these studies assumed variable returns to scale (VRS) for underlying technology while estimating the efficiency frontier.

From a methodological point of view, Simar and Wilson (2007, 2011) have observed that drawing inference from second-stage regression in the two-stage DEA method is not correct if the statistical model of the first-stage of DEA-efficiency scores estimation is not correctly specified. They proposed a bootstrap-DEA algorithm for mimicking the data generating mechanism for first-stage efficiency estimation which, (a) gives a strong statistical foundation of the first-stage DEA and makes inference drawing from second-stage regression valid, and (b) by removing bias from the efficiency scores and establishing the confidence interval, gives an opportunity to build test statistics to check various underlying assumptions of DEA (e.g., testing the returns to scale assumption of underlying technology).

Given the scarcity of literature and shortcomings from the methodological point of view, this dissertation makes an effort to partially fill this gap by contributing in the following ways:

(a) First, we use two-stage bootstrap-DEA methodology wherein we estimate bias-corrected efficiency scores of DMUs[1] in the first stage. Then we test the assumption

[1] In Chapter 3, our data is firm-level data. DMUs in this refer to firms involved in electricity distribution, while in Chapter 4, we consider State-level data of the distribution sector with the data of 21 states. Hence,

with regard to returns to scale of underlying technology. In the second stage, we use the efficiency scores, based on the statistically significant underlying technology, to investigate the impact of various environmental variables using parametric regression. Thus, methodology used in this dissertation is statistically sound.[2]

(b) Second, we use ownership structures, population density, customer structures, and government subsidies to investigate their impact on the efficiency of distribution of utilities, using limited time periods and limited state utilities. Adding Indian empirical evidence, in this regard, contributes to a better understanding of how the ownership and population density can affect the performance of distribution sector.

(c) Third, we broaden the time horizon, covering both pre-reform and post-reform

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DMUs in Chapter 4 refer to states. Each state may have one, or many, firms involved in electricity distribution. We have created hypothetical single state-level DMUs by adding all inputs and outputs of these distribution companies. These State-level DMUs have the same size and area of operation before and after reforms.

[2] Both Chapters 3 and 4 use methodology of Two-stage Bootstrap-DEA. This method of Bootstrap-DEA is preferred over Conventional-DEA in this dissertation due to following reasons: (a) Simar and Wilson (2007) observe that none of the papers in the existing literature, based on two-stage conventional-DEA method, explain the underlying data-generating process (DGP) for such models. They further observe that the conventional approach of inference from the second-stage is invalid in these papers due to complicated, unknown serial correlation among the estimated efficiencies of the first-stage. They prescribe Bootstrap-DEA which explains DGP for such models, permits the valid inference of the second-stage regression, and also improves the statistical efficiency of the second-stage. (b) As we use Bootstrap-DEA, it is possible to construct test-statistics using the approach of Bogetoft and Otto (2011) to test the assumption for returns to scale of underlying technology after estimating the efficiency scores in the first-stage.

periods, in addition to coverage of nearly 90% of electricity distribution during period 1995-2012 across Indian states. We investigate specifically the impact of (i) reforms legislation, and (ii) various forms of unbundling structures of the electric sector adopted by different states on the efficiency of their distribution sector. While doing so, we control for regional variation across Indian states in terms of real GDP per capita, population density, and consumer structure.

(d) Fourth, we investigate why results differ across different structures of unbundling. We examine this through interaction of the "size" of the distribution sector, combined with different "forms of unbundling structures," evaluating their impact on the technical efficiency of the distribution sector.

This dissertation has made the following major findings. First, when we analyzed firm-level data of the distribution companies, we found that public sector ownership has efficiency advantage. Second, we also found a positive significant impact of population density on the technical efficiency of the firms involved in electricity distribution. However, thirdly, we found that in high population density areas, public ownership has a negative impact on the technical efficiency of these firms, thus leading to policy implications that privately owned distribution companies are more efficient in high population density areas. Fourth, we also discovered that subsidies provided by the government to the distribution utilities affect technical efficiency negatively.

When we studied state-level data of the electricity distribution sector, we first found that transmission sector unbundling (i.e., generation and distribution sector being together) appears to have a more synergetic effect. Thus, this unbundling structure has a significant positive impact on the technical efficiency of its distribution sector, as compared to that by the fully vertically integrated structure of electric monopoly. Second, generation unbundling or full unbundling does not appear to have a significant impact on the efficiency of the distribution sector. Third, the establishment of SERC and the issue of tariff orders have a negative, but statistically insignificant, impact on the technical efficiency of the distribution sector. Fourth, the enactment of reforms legislation in India has negatively affected the technical efficiency of the distribution sector. It seems that enactment of "legislation" gives some sort of "policy signal" which introduces uncertainty and disincentives to the managers of the distribution sector. Fifth, we ascertained that "small-sized" distribution sectors were found to have a significant positive impact on the technical efficiency of their distribution sector after they were partially or fully unbundled from generation and/or transmission sectors. "Medium-sized" states, on the other hand, were found to have a negative, but insignificant, impact on the efficiency. It appears that "small-sized" states are quickly able to overcome "diseconomies of scope" caused by unbundling by using "economies of scale." In contrast, "medium-sized" states' response to "diseconomies of scope" through improvements in "economies of scale" appears to be sluggish. Sixth, we determined that state-level, real GDP per capita and consumer structure have positive, but insignificant, impact on the technical efficiency of the electricity distribution sector of the state.

The rest of this dissertation is organized as follows. Chapter 2 gives the background of Indian electricity reforms and the world trend in electricity reforms through existing literature. Chapter 3 uses post-reform, firm-level, electricity distribution data from three Indian states for the period of 2005-2012, to examine the impact of ownership, government subsidy, consumer structure, and population density on the technical efficiency of these distribution utilities. Chapter 4 broadens the perspective from the utility-level to the state-level distribution sector, using data for 21 Indian states over the period of 18 years, which include pre-reform and post-reform periods. We specifically investigate the impact of reforms legislation, tariff orders, different forms of unbundling structures, and size on the efficiency scores. Chapter 5 summarizes the findings of the empirical analyses of Chapters 3 and 4, and discusses the policy implications and future direction for research.

2 Background of Electricity Reforms in India vis-à-vis World Trend.

This Chapter briefly describes the status of electricity reforms across various countries of the world, and then briefly gives the background and status of reforms in the Indian electricity sector.

2.1 World experience in the electricity market reforms

We briefly cover the reforms in the electricity sectors of various countries based on the broad geographical regions. This Section is largely based on the information from Erdogdu (2010).

2.1.1 Reforms in South America

Chile was the first country to implement the power sector reforms, in 1982, by privatizing the state-owned electric monopoly without transmission sector unbundling. However, the biggest challenge in Chilean reforms was related to reducing market power and introducing competition. Nagayama (2007), Politt (2004), and Nagayama and Kashiwagi (2007) evaluate the Chilean and South American power sector reforms. Haselip and Potter (2010) observed that Argentina was also one of the first countries to implement reforms and was also one of the most successful ones. They adopted full unbundling and privatization of the generation and transmission sectors. According to Pollitt (2008), public ownership remained limited to nuclear power plants, a few hydro-electric plants, and some provincial distribution companies.

Brazil initiated power sector reforms in 1995, and again after crisis, in 2004. In the first phase of reforms, the generation sector was opened to private investments and free market reforms were aimed at establishing a nationwide power grid operator and wholesale electricity market. However, the second phase of reforms was aimed at long-term stability, instead of free market. Mota (2003) evaluates the impact of Brazilian electricity sector reforms. According to Perez-Reyes and Tovar (2009), Peru also implemented neo-liberal market reforms in the electricity sector in the early 1990s. State-owned utilities were restructured and privatized. However, in 2002, some of the companies were again renationalized. Cherni and Preston (2007) and Anaya (2010) evaluated impacts of Peruvian electricity sector reforms.

2.1.2 Reforms in Europe

European Union Electricity Directives of 1996, 2003, and 2009, are the major landmark policy decisions related to reforms in energy markets across all European Union member countries. All of these directives aimed to create a market-based system and single European electricity market. Fiorio et al. (2007), Trillas (2010), Thomas (2006), and Defeuilley (2009) evaluate European electricity market reforms.

The British electricity reforms started with the restructuring of the vertically integrated public sector power utility in the 1990s, and involved privatization, regulation, and competition to finally reach the present status of fully liberalized sector. Thomas (2004), Newberry and Pollitt (1997), and Domah and Pollitt (2001) evaluate electricity sector reforms of the UK. In contrast, the French model of electricity reforms is opposite of that in the UK, retaining a vertically integrated public sector monopoly in all stages, but creating a sector regulator allowing third party access to networks, and introducing a wholesale market. However, they also introduced accounting separation between various sectors of the vertical electric monopoly. Germany, in compliance of EU directive, implemented overall liberalization of the electricity sector, but without restructuring the vertically integrated monopolies. Similar to France, they introduced a regulator, opened the markets, and established an electricity exchange. On the other hand, Italy, after adoption of EU directive 1996, unbundled the public sector electric monopoly, created a state-owned transmission system operator, and allowed privatization of the generation sector. Ferrari and Giulietti (2005) evaluate Italian electricity sector reforms.

Norway, along with the other Nordic countries of Sweden, Finland, and Denmark, created Nord Pool in the 1990s, a common electricity exchange operator. Amundsen and Bergman (2006) evaluated the success of the Nordic electricity market. Norway adopted the British model of reforms; but, without privatization and ownership, remains largely in the public sector. Sweden opened the retail market and allowed consumers to choose their own supplier, but the transmission system remained in public ownership. In Finland, consumers could also choose their own supplier by the late 1990s, as the transmission sector was unbundled but not the distribution sector. Denmark, too, followed the model of other Nordic countries and completed reforms by 2001. However, the electricity sector was fully unbundled, and the overall ownership structure remained largely in the public sector.

In the late 1990s, Spain unbundled the transmission sector and introduced a public-private system operator. Third party access for transmission and distribution networks was allowed under regulation. Since 2006, a single, integrated wholesale electricity market, Iberian Pool, has been in operation within Portugal. However, according to Crampes and Fabra (2005), Spain's reforms failed to attract new investments. Poland witnessed vertical and horizontal unbundling of the state owned vertical electric monopoly in the 1990s. Then, the distribution utilities and generating companies were corporatized and privatized through equity sale of these joint stock companies. However, the transmission system operator, as a single buyer of electricity, remained in public ownership. According to Williams and Ghanadan (2006), the Polish electricity sector is presently witnessing re-bundling and vertical re-integration. Slovenia, also witnessed full opening of its electricity market by 2007, and its reforms included unbundling, regulated third party access, establishment of a regulator, and introduction of the organized power market. Hrovatin et al. (2009) analyzed these reforms in Slovania. Romania also fully unbundled its vertical electric monopoly by 2000, and further horizontally unbundled the distribution sector to introduce privatization. According to Diaconu et al. (2009), by 2007, the Romanian electricity market was fully liberalized and consumers free to choose their own supplier.

Greece initiated electricity market reforms late in the EU. It converted the state-owned vertically integrated electric monopoly to a share company, but neither unbundled nor changed the ownership. Mandatory pool and full market opening was implemented in 2007. However, according to Iliadou (2009), Greece's electricity market is still the least reformed of those in the EU. Conversely, Turkey, initiated electricity reforms in the early 1980s, by dismantling the public monopoly in generation, allowing the private sector into the generation sector. In 1993, one company for generation and transmission combined, and another for distribution in the public sector were established. The distribution sector was further horizontally unbundled and corporatized for privatization. Erdogdu (2010) evaluates the Turkey power sector reforms in detail.

2.1.3 Reforms in Eurasia

Since the fall of the Soviet Union, each country adopted its own strategy for power sector reforms. Russia maintained the state-owned monopoly in generation. The transmission grid and distribution network also remained under public sector. However, as a reform, the generation sector was divided into multiple wholesale electricity companies in order to participate in wholesale market competitively. In 1996, Ukraine unbundled the vertical electric monopoly of the public sector; and established a common pool market, with a single buyer. Armenia unbundled and privatized the distribution sector and allowed foreign investments. Georgia also unbundled and allowed privatization of the generation and distribution sectors. On the other hand Azerbaijan kept the generation and transmission sectors vertically together under public ownership, and only unbundled the distribution sector. The distribution sector was further horizontally unbundled. Concessions were then auctioned for these distribution companies to the private sector.

Kazakhstan unbundled and privatized the generation sector first, establishing a power wholesale market in 1998. Transmission and distribution sectors remained under state ownership. In Tajikistan, the vertically integrated monopoly corporatized in 2001, but, no further reforms were adopted. However, Kyrgyzstan not only corporatized, but also unbundled all three sectors. Then, they further horizontally unbundled the distribution sector. Although all companies are owned by the public sector, full functional autonomy is given to its management. Mehta et al. (2007) and Nagayama (2007) evaluated the reforms in Eurasian countries.

2.1.4 Reforms in North America

Joskow (2008) observed that many US states have introduced limited liberalization in the power sector without restructuring, as there have never been comprehensive, federal electricity market reforms in the US. Most US states are dominated by vertically integrated and regulated private electric utilities. In the late 1990s, the US electricity reforms were mainly aimed to bring competition among the generators in the wholesale market so that retail consumers and distribution utilities could directly and cost-effectively buy power. The reforms established a power exchange and an independent system operator, restructuring and banning long term power purchase agreements. According to Amundsen and Bergman (2006), after the mid-2000 California blackouts, the power exchange went bankrupt in March of 2001. Based on California's experience, Sweeney (2002) observed that reversible regulatory reforms are perhaps more preferable than irreversible market reforms.

2.1.5 Reforms in Asia and Oceania

Since the 1980s, in China the Ministry of Electric Power was in charge of the electricity sector. This ministry was abolished; and, a vertically integrated, public sector electric monopoly was established in 1998. After corporatization of this monopoly, the generation sector was vertically and horizontally unbundled into five corporations. Soon a sector regulator was established and a wholesale electricity market also introduced. However, the transmission and distribution sector remained in the public domain. Du et al. (2009) and Yeoh and Rajaraman (2004) evaluated Chinese power sector reforms. In contrast, the Japanese electricity sector allowed independent power plants (IPPs) into the generation sector; and competitive bidding was introduced in the wholesale market for generation. Nakano and Managi (2008) observed that cost cutting competition was promoted in the generation sector due to this structure, and also, due to the introduction of yardstick competition. Ida et al. (2007) found that both periods of reforms (1996-1999 and 2000-2002) resulted in substantial cost cutting in Japanese electricity markets.

Though the Philippines aimed at full privatization of existing electric utilities in the public sector and the establishment of wholesale spot market through structural reforms and market mechanism. However, the actual implementation progress of reforms was found to be slow. However, Toba (2007) found increased social welfare due to power reforms in Philippines. In the late 1990s, South Korea started with vertical and horizontal unbundling of the state-owned, vertically integrated electric monopoly. Horizontally unbundled, corporatized generation companies were planned in order to privatize, along with introduction of wholesale and retail competition, but the reforms were suspended in 2004, due to uncertain costs, benefits, and risks associated with it. Hong Kong's electricity supply is marked by the presence of long term regulatory contracts, known as Scheme of Control agreements, with two vertically integrated companies. This system has been in operation for over five decades.

Some states in Australia went through electricity reforms, in the 1990s, by vertical and horizontal unbundling of the state-owned electric monopoly, privatizing horizontally unbundled generation companies, establishing a wholesale electric pool, and introducing competition. However, the extent of reform varies across geographic regions. Eastern Australian states have a fully liberalized, competitive, retail sector, while in Western Australia, a vertically integrated structure of the electricity sector exists. After enactment of 1992 reforms law, New Zealand went through electricity sector reforms by liberalization of market and regulation of the transmission and distribution segments. The 1998 law made the ownership unbundling of distribution sector i.e. a situation in which transmission and distribution networks are operated under different ownership than generation/production and supply, mandatory. Although regulation was left to competition authority, the sector specific regulatory commission was established in 2001. Nillesen and Pollitt (2008) observe that ownership unbundling led to lower costs and higher quality of service, but also facilitated greater competition in New Zealand. Filippini and Wetzel (2014) also evaluated New Zealand power sector reforms.

2.1.6 Reforms in Africa

In South Africa during mid-1990s, a national regulator was established as a successor to the Electricity Control Board. Although the state owned, vertically integrated utility still operates as one of the single, largest monopolists, it was converted into a public company in 2002, and was subjected to regulation by enactment of 2006 regulatory legislation. Newbery (2006) observed that, although the regulatory mechanism is in place, the prices are based on the historical costs; and, the progress of reforms in South Africa is not sufficient. The Western African nations of Nigeria, Cameroon, and Ghana were also marked by the existence of vertically integrated, state-owned electric monopolies before the reforms. Nigeria had commercialized its electric monopoly in 1988, but it was vertically unbundled in 2005. The generation and distribution sectors were also horizontally unbundled and corporatized. In addition, the wholesale competition model was also aimed to be established. Ikeme and Ebohon (2005) observe that, although corporatized companies are public in nature, they are gradually going to be privatized. In Cameroon, the ownership of monopoly was directly changed from public to private by selling a majority of shares and signing a 20-year concession. Neither sector restructuring nor market reforms ever did take place in Cameroon's electricity market. Ghana retained the pre-reform structure of two public sector companies, of which one is vertically integrated with generation and transmission while the other is in distribution, even after reforms of 1990s. The reforms just ensured the creation of an independent regulator; but, the rest of the structure, according to Williams and Ghanadan (2006), remained the same. The world experiences show the electricity sector reforms vary across developed and developing nations in terms of structural change, ownership change, and, also, in terms of market reforms.

2.2 Indian Electricity Sector Background and Reforms

Since independence of India in 1947, the Indian electricity sector was governed by the Electricity (supply) Act 1948, which established vertically integrated monopolies in each State for generation (G), transmission (T), and distribution (D) of electricity. These monopolies were known as State Electricity Boards (SEBs), and in some states as State Electricity Departments (SEDs). The constitution of India, adopted in 1950, included "electricity" as a subject in the concurrent list. Although this arrangement gave both the federal/central government and the state government simultaneous jurisdiction for legislation in this sector, the federal government has more controlling powers over this sector. However, it also gives sufficient autonomy to the regional state governments in the routine governance and administration of the electricity sector in the state. Tongia (2003) observed that all of the three pillars, G, T, and D, of the electricity sector were dominated by the State. The performance of the electricity sector, until the early 1990s, and the causes for initiating reforms, are well elaborated in Dubash and Rajan (2001), Tongia (2003), and Sharma et al. (2005). Chan et al. (2014) observe that since establishment of SEBs, the process of tariff determination by the SEBs was marred by the political-economy, and hence, tariffs failed to cover costs. In turn, the revenue shortfalls were backed up by the state governments. A few of the main reasons for Indian power sector reform, as cited in the existing literature, were (a) inadequate generation capacity, (b) high technical losses, and (c) poor financial conditions of SEBs, leading to the financial burden on the state governments, etc. All these reasons amounted to "inefficient operations" of SEBs, in general, and of the distribution sector, in particular.

The power sector in India witnessed the reforms beginning in 1991. According to Tongia (2003), the early efforts were focused on the generation sector to attract private investment. However, according to Reddy (2002), the distribution sector, in particular, was shifted to a "new paradigm" with the enactment of The Electricity Regulatory Commissions Act in 1998, which led to the establishment of independent regulators known as Central Electricity Regulatory Commissions (CERCs) at federal-level and State

Electricity Regulatory Commissions (SERCs) at the prefectural/state-level. This act also provided for the determination of tariff by both CERCs and SERCs for supply of electricity. But, before the 1998 enactment, the eastern Indian state of Orissa had already started reforms in 1996, with World Bank's initiative, and it allowed participation of private sector in distribution. Between 1998 and 2003, many state governments established SERCs. A few of these states also unbundled the vertical monopolies of SEBs and corporatized three pillars (G, T, and D), adopting various combinations of organizational structures of G, T, and D. Almost all states also retained the State ownership of these structures, with the exception of Delhi and Orissa (which had already allowed private participation in distribution in 1997).

The second most important step in the reforms process was enactment of The Electricity Act, 2003. This act replaced all the previous existing legislation. This act is now pivotal in all policy decisions applicable to the electricity sector in India. The 2003 act made the establishment of SERCs and the unbundling and corporatization of SEBs/SEDs mandatory. It also aimed to (a) rationalize the tariffs by cost-coverage and removal of subsidies, (b) provide open access of networks to third parties, and (c) allow private participation in the distribution sector. The purpose of the 2003 act was not only to structurally and institutionally reform the electricity sector, but also to make it competitive and efficient.

The discussions on the Indian electricity sector are further discussed in Section 4.2 of Chapter 4.

3 Efficiency Evaluation of Electricity Distribution Utilities in India: A Two-stage DEA with Bootstrap Estimation

3.1 Introduction

Efficiency of electricity distribution industries has received considerable attention in the last two decades, particularly because of restructuring in the electric power sector, such as privatization. The literature of efficiency evaluations based on data envelopment analysis (DEA) has many applications in electricity distribution industries across developed countries (see, e.g., Santos et al., 2011 and Jamasb and Pollitt, 2000, for a detailed survey). However, studies of such evaluations applied to the power distribution industry are limited in developing countries. Particularly, studies on India, with its diverse socio-political conditions, are still scarce. In 2013, India was the third-largest energy consumer in the world, after China and the US.[3] Thus, efficiency of the energy sector in India is becoming relevant amid growing concerns about global warming.

Some works applying DEA to the electricity distribution industry in India can be found in the literature. Most of these works have employed Charnes-Cooper-Rhodes (CCR) and Banker-Chames-Cooper (BCC) models proposed by Charnes et al. (1978) and Banker et al. (1984), respectively, demonstrating that the performance of several utilities is sub-optimal and implying potential cost reductions and possible staffing reductions. Thakur et al. (2006) evaluated the performance of state-owned electricity utilities (SOEUs) for 2001 data using DEA (one input/two inputs and three outputs). They used total cost for the one-input case and number of employees and adjusted cost for the two-input case. The three outputs were number of customers, energy sold, and distribution

[3] Global Energy Statistical Yearbook 2014. https://yearbook.enerdata.net

line length. Meenakumari and Kamaraj (2008) evaluated operational efficiency of SOEUs for 2005 data using DEA with three inputs (installed capacity, distribution line length, and technical losses) and two outputs (number of consumers and amount of energy sold). Saxena and Thakur (2011) applied DEA with three inputs (distribution line length, total expenditure, and aggregate technical and commercial losses) and two outputs (number of consumers and energy sold) using data for the year 2008. Yadav et al. (2011) focused on electricity distribution divisions in one state in India, Uttarakhand, for the year 2007. They considered a DEA model with two inputs (number of employees and operating costs) and six outputs (number of customers, energy sold, duration of interruption per feeder, distribution line length, transformer capacity, and total sanctioned load per square kilometer).

However, some limitations exist for these works. (1) Most of these papers use data for a single year; and thus, do not fully capture the possible changes in efficiency in a longer period. (2) Most of these works do not clearly compare the possible difference in performance between public and private utilities; and the ownership structure may affect overall efficiency of utilities. (3) These studies do not investigate, in detail, the determinants of variation in efficiency among utilities. Thus, it is not clear what external factors have significant impacts on the efficiency of the power distribution sector in India. (4) From a methodological viewpoint, these works do not provide statistical inference based on nonparametric estimates of efficiency. Nonparametric models, such as traditional DEA, are subject to uncertainty because of sampling variation (Daraio and Simar, 2007).

In contrast, this Chapter adds to the literature of efficiency evaluation in the context of the electricity distribution sector of India in the following ways. (1) We use panel data for the power distribution sector for the years 2005–2012 to track possible changes in efficiency over a longer period. (2) The ownership structure is explicitly considered in the analysis to compare the performance of public and private utilities in India. (3) In order to examine the determinants of efficiency variation, we employ a two-stage DEA, where DEA efficiency estimates are regressed on some external-environmental variables in a second-stage analysis. (4) Bootstrap methods are used to analyze the statistical properties of the nonparametric estimates. Specifically, we statistically test a returns-to-scale hypothesis using bootstrapping. Furthermore, we apply bootstrap (bias-corrected) efficiency estimates to a two-stage DEA.

This Chapter has the following major findings. First, we find positive impacts of the customer structure (the ratio of high-voltage electricity sales to total electricity sales) and population density on the efficiency of utilities. These results are in line with existing studies. Second, we find efficiency advantages of public utilities in the Indian power distribution sector. However, the interaction of ownership and population density is found to be negative. This implies that public utilities are less efficient than private companies in high population density areas. Our results shed some light on the issue of the ownership structure of distribution sectors, because existing studies have found mixed evidence regarding the effects of public/private ownership on efficiency. Lastly, we find that subsidy by the government is negatively related to efficiency. This suggests that subsidy may lead to inefficient management of power distribution utilities.

The rest of the Chapter is organized as follows. Section 3.2 briefly presents the methodology of the two-stage DEA with bootstrap estimation. Section 3.3 details the dataset and variable selection in this study. Section 3.4 reports our estimation results. Section 3.5 concludes.

3.2 Methodology

This Section presents the methodology of the two-stage DEA with bootstrap estimation. In a conventional two-stage approach, technical efficiency was estimated using non-bootstrap DEA in the first stage, and the estimates were subsequently regressed on some external-environmental variables in the second stage. In this Chapter, we calculated bootstrap (bias-corrected) efficiency estimates in the first stage, and tested our returns-to-scale hypothesis using bootstrapping. We then applied bias-corrected efficiency estimates to the second-stage regression.

3.2.1 Conventional DEA

Let $\boldsymbol{x} \in \mathbb{R}_{+}^{N}$ denote a vector of N inputs and let $\boldsymbol{y} \in \mathbb{R}_{+}^{M}$ denote a vector of M outputs. For decision-making units (DMUs) $i = 1,2,\ldots,I$, we observe $\boldsymbol{X} = (\boldsymbol{x_1}, \boldsymbol{x_2}, \ldots, \boldsymbol{x_I})$ and $\boldsymbol{Y} = (\boldsymbol{y_1}, \boldsymbol{y_2}, \ldots, \boldsymbol{y_I})$.

The DEA[4] estimate of the production set under constant returns to scale (CRS) was initiated by Farrell (1957) and recast within a linear programing framework by Charnes et al. (1978) in a CCR model. The CRS production set estimator, $\widehat{\boldsymbol{T}}_{CRS}$ of the true unknown technology $\boldsymbol{T}_{CRS}$ can be expressed as follows:

$$\widehat{\boldsymbol{T}}_{\boldsymbol{CRS}} = \{(\boldsymbol{x}, \boldsymbol{y}) \in \mathbb{R}_{+}^{N+M} \mid \boldsymbol{y} < \boldsymbol{Y\lambda}, \boldsymbol{x} > \boldsymbol{X\lambda}, \boldsymbol{\lambda} \in \mathbb{R}_{+}^{I}\} \qquad \ldots\ldots.. (1)$$

[4] In DEA methodology with *I*-DMUs, *N*-inputs and *M*-outputs; Pedraja-Chaparro et al. (1999) observed that DEA loses its discrimination power between efficient and inefficient DMUs when the value of *I/(N+M)* is too small. Cooper et al. (2007) suggested that value of *I* should be greater than 3*(N+M)* while Dyson et al. (2001)[4] recommended that it should be greater than 2*N*M*

On the other hand, Banker et al. (1984) considered variable returns to scale (VRS) for the estimate of the production set in the BCC model. This can be easily expressed with an additional constraint on vector$\boldsymbol{\lambda}$, that is, requiring the $\boldsymbol{\lambda}$ values to sum to 1 :

$$\widehat{\boldsymbol{T}}_{\boldsymbol{VRS}} = \{(\boldsymbol{x}, \boldsymbol{y}) \in \mathbb{R}_+^{N+M} \mid \boldsymbol{y} < \boldsymbol{Y\lambda}, \boldsymbol{x} > \boldsymbol{X\lambda}, \boldsymbol{1}'\boldsymbol{\lambda} = \boldsymbol{1}, \boldsymbol{\lambda} \in \mathbb{R}_+^I\} \quad \text{........ (2)}$$

where $\boldsymbol{1}'$ denotes transpose of vector of ones.

We can then derive the estimator, $\widehat{\theta}_i$, of the true unknown efficiency θ_i for each DMU using the estimate of the production set. The estimators of the Farrell input efficiency measure for CRS and VRS, $\widehat{\theta}_{i,CRS}$ and $\widehat{\theta}_{i,VRS}$, can be respectively derived as follows:

$$\widehat{\theta}_{i,CRS} = \inf\{\theta | \left(\theta \boldsymbol{x}_i, \boldsymbol{y}_i\right) \in \widehat{\boldsymbol{T}}_{\boldsymbol{CRS}}\} \quad \text{........ (3)}$$

$$\widehat{\theta}_{i,VRS} = \inf\{\theta | \left(\theta \boldsymbol{x}_i, \boldsymbol{y}_i\right) \in \widehat{\boldsymbol{T}}_{\boldsymbol{VRS}}\} \quad \text{........ (4)}$$

We seek to test the returns-to-scale assumption. For this purpose, the measure of the scale efficiency, $\widehat{S}_i = \widehat{\theta}_{i,CRS}/\widehat{\theta}_{i,VRS} \le 1$, can be used. The CRS can be regarded as a specific case of VRS, and the CRS assumption is justified in theory if the scale efficiency is equal to 1 for all DMUs. Otherwise, the technology is VRS. However, because the conventional DEA is deterministic in nature, statistical tests for the scale efficiency are not possible. Therefore, we used bootstrapping that allows for such statistical tests.

3.2.2 Bootstrap DEA[5]

Bootstrap is a computer-based simulation method for statistical inference, in which sampling uncertainty is replicated by producing repeated samples of the original sample

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[5] As mentioned in Chapter 1, Simar and Wilson (2007)[5] observe that none of the papers in the existing literature based on two-stage conventional-DEA method explain underlying data-generating process (DGP)

Daraio and Simar (2007). The sample $\{(\boldsymbol{x}_1, \boldsymbol{y}_1), \dots, (\boldsymbol{x}_I, \boldsymbol{y}_I)\}$ is regarded as a realization of identically and independently distributed random variables under some data-generating process (DGP), $\mathcal{P}$. Bootstrap is intended to approximate the sampling distributions of interest by simulating the DGP.

Simar and Wilson (1998, 2000) introduced a bootstrap application for nonparametric DEA estimators.[6] The estimator $\widehat{\mathcal{P}}$ of the unknown $\mathcal{P}$ is produced by a Monte Carlo approximation. We can derive $\widehat{\theta}_i^* = \inf\{\theta | (\theta \boldsymbol{x}_i, \boldsymbol{y}_i) \in \widehat{\boldsymbol{T}}^*\}$ for both CRS and VRS under the DGP $\widehat{\mathcal{P}}$. Note that $\widehat{\boldsymbol{T}}^*$ and $\widehat{\theta}_i^*$ are estimators of $\widehat{\boldsymbol{T}}$ and $\widehat{\theta}_i$ in the conventional DEA approach in Subsection 2.2.1. We can further obtain the bootstrap estimate of the bias by calculating$E_{\widehat{\mathcal{P}}}\left(\widehat{\theta}_i^*\right) - \widehat{\theta}_i$.[7]

The estimator of the Farrell input efficiency measure, $\widehat{\theta}_i$, derived by a conventional DEA model is upward biased. This is because the observations are from the

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for such models. They further observe that the conventional approach of inference from the second-stage in these papers is invalid due to complicated, unknown serial correlation among the estimated efficiencies of the first-stage. They prescribe Bootstrap-DEA which explains DGP for such models, permits (a) to draw the valid inference of the second-stage regression and also improves the statistical efficiency of the second-stage and (b) to construct test-statistic using Bogetoft and Otto (2011) approach to test the assumption for returns-to-scale of underlying technology after estimating the efficiency scores in the first-stage.

[6] Simar and Wilson (2007, 2011) observe that the bootstrap estimates in the first-stage DEA makes the inference made about the results in the second-stage statistically valid. Because of the replication of underlying DGP, the effect of "environmental variables" on the input and output variables used in the first-stage is "separated out," and, it also gives a strong statistical foundation to the first-stage efficiency estimates.

[7] $E_{\hat{\mathcal{P}}}(\hat{\theta}_i^*) - \hat{\theta}_i$ is the estimator of $E_{\mathcal{P}}(\hat{\theta}_i) - \theta_i$.

production set estimator$\widehat{\boldsymbol{T}}$, which is a subset of the true unknown technology $\boldsymbol{T}$; that is, $\widehat{\boldsymbol{T}} \subset \boldsymbol{T}$. Using the bootstrap method, we can obtain a bias-corrected estimator $\widetilde{\theta}_i$ of the true unknown efficiency θ_i by subtracting bias from $\widehat{\theta}_i$.[8] Figure 3-1 illustrates the bias-corrected bootstrap frontier (input direction) for an example of one input and one output. Bootstrap confidence intervals can be also calculated (Figure 3-1 shows the upper-95% confidence frontier).

[Figure 3-1 here]

Moreover, we test the returns-to-scale assumption following the method proposed by Bogetoft and Otto (2011). We use the test statistic, $\widehat{S} = \sum_{i=1}^{I} \widehat{\theta}_{i,CRS} \,/\, \sum_{i=1}^{I} \widehat{\theta}_{i,VRS} \leq 1$ as in Bogetoft and Otto (2011). If $\widehat{S}$ is significantly less than 1, or, more specifically, less than a critical threshold for $\widehat{S}$, we reject the hypothesis of the CRS assumption. Although the distribution of $\widehat{S}$ is not known, we can bootstrap this distribution using the approach by Bogetoft and Otto.

3.2.3 Second-Stage Regression

In a typical two-stage DEA model, efficiency estimates in the first stage are regressed[9] on external-environmental variables in the second-stage analysis. The purpose is to

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[8] More specifically, $\tilde{\theta}_i = \hat{\theta}_i - \{ E_{\hat{\mathcal{P}}}(\hat{\theta}_i^*) - \hat{\theta}_i\} = 2\hat{\theta}_i - E_{\hat{\mathcal{P}}}(\hat{\theta}_i^*)$. See, for example, Daraio and Simar (2007) and Bogetoft and Otto (2011) for more details.

[9] In two-stage DEA literature, there exist two views on which econometric method is to be used for second-stage regression. These two view-points are represented by Simar and Wilson (2011) and McDonald (2009), respectively. This debate is still continuing and is not settled as to which the best method is for second-stage regression. McDonald observed in his paper that in the literature, only two statistical models have been proposed in which second-stage regressions are well-defined and meaningful. In the model considered

determine what factors have significant impacts on efficiency. Here, we consider a panel data setting.

Let $\boldsymbol{z_{it}}$ denote a vector of K external-environmental variables for DMU i at period t. Typically, efficiency estimates $\widehat{\theta}_{it}$ are regressed on $\boldsymbol{z_{it}}$. In this Chapter, we also regress bias-corrected estimate $\widetilde{\theta}_{it}$ on $\boldsymbol{z_{it}}$. A panel data regression for the second stage is expressed as follows:

$$\widetilde{\theta}_{it} = \alpha + \boldsymbol{z}_{\boldsymbol{it}}'\boldsymbol{\beta} + \upsilon_i + \epsilon_{it} \; \ldots .(5)$$

where α is a constant scalar, $\boldsymbol{\beta}$ is a vector of K regressors, υ_i is unobservable individual heterogeneity, and ϵ_{it} is the remainder disturbance. We use a standard random-effects (RE) model[10] addressing both time-invariant and time-variant variables[11]. A feasible

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by Simar and Wilson (2007), truncated regression provides consistent estimation in the second stage, where as in the model proposed by Banker and Natarajan (2008)[9], ordinary least squares (OLS) provides consistent estimation.

[10] As we considered firm/DMU level data in this Chapter, our primary aim was to see the effect of ownership of firms on their technical efficiency. If we had used Fixed Effect (FE) estimation then it would not have been possible to see the effect of ownership, as ownership is time-invariant variable. By using panel-RE estimation, we assume omitted variables are uncorrelated to explanatory variables. In Indian context, for example, cultural differences, geographic locations, etc. of the individual firms are assumed to be uncorrelated to explanatory variables of ownership, population density, subsidy, etc. in this Chapter.

[11] A random-effects approach assumes that individual effects are uncorrelated with regressors. In contrast, a fixed-effects approach allows for correlation between the individual effects and regressors, but it cannot estimate the coefficients of the time-invariant variables.

generalized-least-squares (FGLS) procedure is performed to obtain the estimates of the coefficients.[12] In addition, we conduct a pooled-OLS estimation.[13]

3.3 Data and Variable Selection

This Section describes the dataset used in this study. We discuss the selection of input and output variables in the first stage and external-environmental variables in the second stage.

3.3.1 Data

Data availability for electricity distribution utilities in India depends on whether each state government appropriately maintains its database. Particularly, the availability of consistent panel data of electricity distribution utilities is relatively limited in India. In this study, we collected panel data from 2005 to 2012 for 13 electricity distribution utilities in three states: Maharashtra, Gujarat, and Delhi. Maharashtra and Gujarat, respectively have the largest and second-largest installed capacity of power generation, while Delhi is the National Capital Territory of India.[14] Six utilities are state owned, while seven are privately owned. The data were collected from the public records of the Regulatory Commission of each state and from the annual publications and statutory reports of each electricity distribution utility. The data were checked for consistency with the help of the Ministry of Power, Government of India, and Tata Energy Research

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[12] The parameters of the random-effects model can be estimated consistently but not efficiently using OLS. The FGLS estimator is efficient (Greene, 2012).

[13] Banker and Natarajan (2008) and McDonald (2009) discussed in detail the application of OLS to a two-stage DEA model. Simar and Wilson (2007, 2011) examined a truncated regression for such a model.

[14] Executive Summary of Power Sector, the Ministry of Power, Government of India (February 2014).

Institute's (TERI) annual reports. Population data and the consumer price index for each state were collected from the census and statistical departments of each state.

The Electricity Act 2003 in India significantly expanded the jurisdiction of the Regulatory Commission of each state, granting functions of tariff setting, licensing, and enforcing performance standards for licensees (Kumar and Chatterjee, 2012). In Maharashtra, the Electricity Regulatory Commission (MERC) was restructured in 2005, and the vertically integrated Maharashtra State Electricity Board (MSEB) was unbundled into generation, transmission, and distribution companies. Maharashtra State Electricity Distribution Company Ltd. (MSEDCL), a public enterprise controlled by the Government of Maharashtra, started its operations in 2005. Electricity for the state capital, Mumbai, and its suburban areas is distributed by three companies. One is a public enterprise, Bombay (now Brihanmumbai) Electricity Supply and Transport Undertaking, and the two others are private companies, Tata Power and Reliance Energy (now Reliance Infrastructure).

Similar to Maharashtra, the Gujarat Electricity Regulatory Commission (GERC) was restructured in 2005. The vertically integrated Gujarat Electricity Board (GEB) was then unbundled, but unlike Maharashtra, the distribution sector of Gujarat was divided into four publically owned enterprises based on geographic areas. Uttar Gujarat Vij Company Ltd. (UGVCL) in the north, Dakshin Gujarat Vij Company Ltd. (DGVCL) in the south, Madhya Gujarat Vij Company Ltd. (MGVCL) in the central area, and Paschim Gujarat Vij Company Ltd. (PGVCL) in the west, started their operations in 2006. Power supply to the state capital, Ahmedabad, was handed over to a private enterprise, Torrent Power. Torrent Power also distributes electricity to the second-largest city in the southern area of Gujarat, Surat. We collected data from 2008 for these two cities.

Electricity for the National Capital Territory of India, Delhi, is supplied by three companies. They are all privately owned entities, BSES Rajdhani Power Ltd, BSES Yamuna Power Ltd., and North Delhi Power Ltd. (now Tata Power Delhi Distribution).

Table 3-1 summarizes the year-wise details of DMUs and their ownership structure. We could collect panel data from 2005 to 2012 for both public and private enterprises.

[Table 3-1 here]

3.3.2 Input and Output Variables in the First Stage

Santos et al. (2011) surveyed the existing literature on DEA models for electricity distribution utilities in detail. Common inputs for the evaluation of electricity distribution utilities include labor (e.g., number of employees and wages) and physical assets (e.g., distribution network and transformer capacity). Commonly used outputs are number of customers and electricity delivered.

In this Chapter, two models with different sets of variables are examined. We follow the same trend that exists in literature and choose three inputs for Model 1, namely, number of employees, distribution line length (in circuit kilometers), and transformer capacity (in MVA). Two outputs commonly found in the literature are used, that is, number of customers, and total electricity delivered (in GWh). Our set of variables is similar to, for example, those in Pombo and Taborda (2006), and Çelen (2013), who examined panel data for the power distribution sector in Colombia and Turkey, respectively. Each DMU in the power distribution sector has to meet the electricity demand of its consumers in each geographical area by efficiently using its inputs. Input-oriented DEA would be suitable for this case.

In Model 2, we substitute total assets in monetary terms (inflation-adjusted) for line length and transformer capacity. Total assets include not only physical/tangible assets, but also intangible assets, including monetized capital work in progress. In this sense, total assets represent a longer-term aspect of distribution facilities. Another input is number of employees. Number of customers and total electricity delivered are outputs, as in Model 1.

3.3.3 Environmental Variables in the Second Stage

Here, we discuss external-environmental variables, which may potentially affect the efficiency of electricity distribution utilities but are mostly not under their direct control. Our set of variables is similar to that in Çelen (2013), who used environmental variables such as customer structure, customer density, and ownership. We also try to identify environmental factors that are specific to the regulatory conditions in India.

The first environmental variable is the regulated tariff ratio, defined by the ratio of the average tariff for residential customers to that for industrial consumers. This variable may capture a possible cross-subsidy from industrial consumers to residential consumers for political reasons in the context of India. The tariffs are regulated by the Electricity Regulatory Commission in each state. If the cross-subsidy policy changes, the ratio also changes, which may in turn have some effect on the efficiency of utilities.

The second environmental variable is the customer structure of utilities. This is measured by the ratio of high-voltage electricity sales to total electricity sales. A similar variable representing the consumer structure was also used, for example, by Kwoka and Pollitt (2010) and Çelen (2013). Kwoka and Pollitt (2010) discussed that residential sales are more costly because of the increased service requirement and higher infrastructure costs, possibly resulting in lower efficiency. Thus, we expect that an increase in the ratio positively influences the efficiency of utilities.

The third environmental variable is the population density of the geographical area of utilities, measured by person per square kilometer. The population density is usually considered to have a positive relationship with efficiency. For example, Çelen (2013) also used a variable for customer density with an expectation for its positive influence on efficiency.

The fourth environmental variable is a dummy variable representing the public/private ownership of utilities. This variable is included to evaluate the effect of ownership on the efficiency of the electricity distribution sector in India. Studies on efficiency/productivity have found mixed evidence regarding the impact of ownership structure on efficiency (e.g., Pollitt, 1995), which is detailed in the next Section. Given mixed outcomes, and the lack of literature relating ownership to efficiency in the Indian electricity distribution sector, we do not make *a priori* expectations about the impact of ownership on efficiency.

The last variable we consider is the subsidy amount (inflation-adjusted) provided by the government to the distribution utilities. Before the start of the financial year, the level of subsidy is determined by the government ex ante. The amount of subsidy depends on government policies, particularly support for agricultural users and domestic customers in rural areas. The impact of the subsidy on efficiency can be either negative or positive. If utilities regard subsidy as an additional source of revenue, their management may prefer leisure, which has a negative impact on efficiency. On the other hand, if subsidy is used for innovation and technology improvements, it may have a positive impact on efficiency. A subsidy[15] determined on the basis of factors such as agriculture is specific to developing countries like India. Although such a variable is relevant for the investigation of Indian power industries, this variable has seldom been used in the existing DEA literature.

In Table 3-2, we summarize the inputs, outputs, and environmental variables used in our study.

[Table 3-2 here]

3.4 Estimation Results and Discussion

This Section presents the estimation results of the first- and second-stage models described in Section 3.2. The bootstrap (bias-corrected) efficiency estimates in the first stage are derived along with the test for the returns-to-scale hypothesis using bootstrapping. We then discuss the external factors having significant effects on the

[15] It is assumed that "subsidy" is beyond the control of the management of DMUs. In Indian context, subsidy is determined by the government. The government/policy makers decide which particular group of consumers (e.g., agricultural and/or rural residential) are going to receive subsidy and how much. This decision is an outcome of a political-economy process, so the management of DMU *prima-facie* do not have any control over this process. Hence, for the purpose second-stage regression we "theoretically" assume that "subsidy is exogenously determined." During the pre-reforms period, it was "practically" possible in Indian scenario that management of inefficient DMUs/ SEBs may directly or indirectly influence the political-economy process of subsidy determination. This may give rise to concern for endogeneity of this variable. However, during the post-reforms period, the regulatory commissions oversee and supervise the subsidy. We have considered "subsidy" as one of the variables in this Chapter only, and also, the data in this Chapter belongs to post-reform period only. Based on these reasons, the endogeneity concern for "subsidy" is reduced to a minimum possibility.

efficiency of the power distribution sector in India by applying bias-corrected efficiency estimates to the second-stage regression. R statistical software is used for estimation.[16]

3.4.1 Returns to Scale

We first test the returns-to-scale assumption following the method proposed by Bogetoft and Otto (2011, Chap. 6). As stated in Section 3.2, the test statistic, $\widehat{S} = \sum_{i=1}^{I} \widehat{\theta}_{i,CRS} \,/\, \sum_{i=1}^{I} \widehat{\theta}_{i,VRS} \leq 1$, is calculated. We bootstrap the distribution of $\widehat{S}$ using the approach of Bogetoft and Otto. The 5% critical thresholds of $\widehat{S}$ is then calculated. For example, the 5% threshold implies that 5% of the observations are found above this value. If the test statistic $\widehat{S}$ is less than the critical threshold, we reject the null hypothesis of the CRS assumption. As with Bogetoft and Otto (2011), we also derive the probability of a type-I error, which is the probability of rejecting the null hypothesis if it is true. If the value of the type-I error is sufficiently low, it is less likely to mistakenly reject the hypothesis.

[Table 3-3 here]

[Table 3-4 here]

Table 3-3 and Table 3-4 report the results of the test with bootstrapping for Models 1 and 2, respectively. As shown in Table 3-3, the test statistics for all years in Model 1 are less than the critical value (5% or 10%), except for the year 2008. Furthermore, the values of the type-I errors suggest that the probability of mistakenly rejecting the null hypothesis is lower than 5% or 10% in all years, except 2008. We reject the hypothesis

[16] Particularly, the R packages Benchmarking (Bogetoft and Otto, 2011) and FEAR (Wilson, 2008) are used for bootstrap DEA estimates (2,000 repetitions for bootstrapping).

of the CRS assumption and consider the VRS production set for Model 1.[17] In contrast, the test statistics are greater than the critical value (5% or 10%) for all years in Model 2, as shown in Table 3-4. The values of the type-I error range, from 10% to 30%, suggests a relatively high possibility of mistakenly rejecting the null hypothesis. Thus, we fail to reject the hypothesis of the CRS assumption, and CRS production technology is assumed for Model 2.

3.4.2 First-Stage Bootstrap DEA Estimation

Figure 3-2 and Figure 3-3 illustrate the average bias-corrected bootstrap DEA estimates for Models 1 and 2, respectively. The 95% upper and lower confidence intervals are also shown in these figures. Furthermore, solid lines show estimates for public utilities, whereas, dotted lines are for private enterprises.

[Figure 3-2 here]

[Figure 3-3 here]

Here, we discuss two noticeable findings. First, in both Models 1 and 2, the efficiency estimates of public utilities are seemingly greater than those of private ones over the years 2005–2012. Although the difference in DEA estimates is not large in magnitude, a difference in efficiency between public and private enterprises may exist. We examine this in more detail in the next Subsection to determine whether there is a statistically significant difference by regressing efficiency estimates on ownership structure in the second stage. Second, Model 2 exhibits a declining trend in efficiency of

[17] We reject the null hypothesis of the CRS assumption for Model 1 from a statistical viewpoint. However, the test statistics are still practically close to 1 in Model 1. Thus, the CRS and VRS assumptions would not make a considerable difference to the analysis in this case.

both public and private sectors in later years, while Model 1 does not clearly show this trend. As stated before, we use total assets in monetary terms (inflation-adjusted) for the input variable in Model 2. Total assets include not only physical/tangible assets but also intangible assets, including monetized capital work in progress. The declining trend in efficiency in Model 2 would be attributed to the increasing trend of investment in new and lumpy facilities in India to meet the growing energy demand.

3.4.3 Second-Stage Regression Results

This Subsection discusses the results of the second-stage regression. Efficiency estimates in the first-stage DEA are regressed on external-environmental variables. We take the logarithm of the two variables, population density and subsidy. Table 3-5 and Table 3-6 report the result of Models 1 and 2, respectively. Our focus is on the results of a random-effects panel regression with bootstrap DEA efficiency estimates. That is Column (1) in both tables, in which the unobservable individual heterogeneity and bias correction are considered.

[Table 3-5 here]

[Table 3-6 here]

The regulated tariff ratio, defined by the ratio of the average tariff for residential customers to that for industrial consumers, does not have a statistically significant coefficient in Column (1) of both models. This variable, which may capture a possible cross-subsidy from industrial consumers to residential ones, does not significantly influence efficiency outcomes.

The customer structure of utilities, measured by the ratio of high-voltage electricity sales to total electricity sales, shows a statistically significant and positive coefficient in Column (1) of Model 1, as expected. As discussed before, residential sales are usually more costly because of the increased service requirements and higher infrastructure cost. If the utilities have more high-voltage electricity customers, efficiency would increase. This result is in line with those in Kwoka and Pollitt (2010) and Çelen (2013). In Column (1) of Model 2, we find a positive (but not statistically significant) coefficient.

Regarding the population density, measured by person per square kilometer, we find a statistically significant and positive coefficient in Column (1) of both Models 1 and 2. As in Çelen (2013), the population or customer density is usually considered to be positively related to efficiency. Our result is consistent with those reported in most studies in the literature.

The dummy variable of the public/private ownership (public = 1) is found to be positive and significant at the 1% level, as shown in Column (1) of both Models 1 and 2. Existing studies have found mixed evidence with regard to the effect of the ownership structure in the literature of efficiency/productivity. For example, Bagdadioglu (2005) and Çelen (2013) claimed that private ownership has advantages in the power distribution function in Turkey. In contrast, Kwoka (2005a, 2005b) found that publicly owned utilities are more efficient in the electricity distribution sector in the US. Moreover, a third group of studies (e.g., Pollitt (1995) and Pombo and Taborda (2006)), did not find statistically significant evidence of the effect of public/private ownership on efficiency in power distribution industries. As alluded to in Figure 3-2 and Figure 3-3, we find that public ownership has a positive effect on efficiency of the electricity distribution sector in India. Our result is similar to those of Kwoka (2005a, 2005b).

In India, there has been a trend over the past decade for private distribution companies to participate in urban and semi-urban areas. To further look into this trend, the ownership dummy is interacted with the population density variable. We find that this interaction term is negative and significant at the 1% level. This implies that public utilities are less efficient than private enterprises in high population density areas.

The subsidy coefficient (inflation-adjusted) is negative and significant at the 1% level in Column (1) of both Models 1 and 2. As stated previously, subsidy depends on specific factors, such as support for agricultural users and domestic customers in rural areas in India. Our result indicates that subsidy is negatively related to efficiency and may lead to inefficient management of utilities.

Last, we briefly compare the results among models. It is shown that Models 1 and 2 give consistent results, particularly the signs of coefficients, across different estimation methods (panel RE and pooled OLS). The results of our two-stage DEA are robust in this sense. We note again that a random-effects panel regression with bootstrap DEA efficiency estimates is preferred, because we can take account of unobservable individual heterogeneity and bias correction.

3.5 Conclusion

In this study, we investigated the efficiency of electricity distribution industries in India, focusing on panel data from 2005 to 2012 for 13 utilities in three states: Maharashtra, Gujarat, and Delhi. We used a two-stage DEA with bootstrap estimation. In the first stage, bias-corrected bootstrap efficiency estimates of DEA were calculated, and in the second stage, they were regressed on external-environmental variables. Our focus has been on the environmental factors having significant effects on the efficiency of the power distribution sector in India.

Several remarkable results of the second-stage model are summarized as follows. We found statistically significant and positive effects of the customer structure and population density on efficiency. These results are in line with existing studies. We also found statistically significant and positive effects of public ownership on efficiency in India. However, the interaction term of the ownership dummy and population density was negative, implying that public utilities are less efficient than private enterprises in high population density areas. Results on the effects of the ownership structure have been mixed in the literature on efficiency/productivity, and it is still an open research question. Given the lack of literature relating ownership to efficiency in Indian electricity distribution utilities, our results shed some light on this issue. Lastly, we found statistically significant and negative effects of a subsidy on efficiency. This suggests that a subsidy may lead to inefficient management of power distribution utilities.

Finally, some remarks about further extensions of this work are in order. In this study, we managed to collect panel data from 2005 to 2012 for 13 electricity distribution utilities in three states, including those with the largest and second-largest installed capacity of power generation. Although data availability for electricity distribution utilities in India varies among states, it is worthwhile to collect datasets for more states and periods with the help of central and local governments to enrich the quantitative analysis. Particularly, if we can obtain data for more pre- and post-reform period years, we may be able to explicitly examine the effects of regulatory reform on power industries. In this Chapter, we determined the efficiency advantage of public utilities in the Indian power distribution sector, but the reason for this observation remains an open question. Complex socio-political conditions and the history of the electricity industries may be key factors for such an advantage. Further work should investigate the background of seemingly different efficiencies of public and private enterprises using quantitative and qualitative approaches.

Tables and Figures: Chapter 3

Table 3-1. Year-wise DMUs and ownership structure

Year	Number of DMUs	Private	Public
2005	8	5	3
2006	11	5	6
2007	11	5	6
2008	13	7	6
2009	13	7	6
2010	13	7	6
2011	13	7	6
2012	13	7	6

Table 3-2. Summary of variables

Variables		Models		Mean	Unit
		Model 1	Model 2		
Input variables	Number of employees	√	√	12,479.67	Person
	Distribution line length	√	-	109,555	Circuit km
	Transformer capacity	√	-	14,173.58	MVA
	Total assets (inflation-adjusted)	-	√	3,227.41	Crore Indian Rupees (INR)
Output variables	Number of customers	√	√	2,956.62	1000 person
	Electricity delivered	√	√	11,088.14	GWh
Environmental variables	Tariff ratio	√	√	0.940	(Ratio)
	Consumer structure	√	√	0.304	(Ratio)
	Population density	√	√	13,228.57	Person per square km
	Ownership dummy (public = 1)	√	√	0.526	-
	Subsidy (inflation-adjusted)	√	√	34.79	Lac Indian Rupees (INR)

Note: 1 Crore INR = 100 Lac INR = 10 million INR.

Table 3-3. Test for returns to scale: Model 1

H_0: production set is CRS; H_A: production set is VRS				
Year	Test statistic	Critical value, 5% (10%)	Type I error	Decision
2005	0.9885546	0.9929177 (0.9929762)	0	Reject null hypothesis
2006	0.9767534	0.9900034 (0.9913276)	0	Reject null hypothesis
2007	0.9821714	0.9913447 (0.9933993)	0.0043	Reject null hypothesis
2008	0.9940201	0.9927663 (0.9934711)	0.1443	Fail to reject null hypothesis
2009	0.9937234	0.9927207 (0.9937517)	0.0959	Reject null hypothesis (10% level)
2010	0.9932305	0.9933519 (0.9950785)	0.0478	Reject null hypothesis
2011	0.9928162	0.9908798 (0.9936869)	0.0817	Reject null hypothesis (10% level)
2012	0.9919228	0.9858939 (0.9941538)	0.0827	Reject null hypothesis (10% level)

Table 3-4. Test for returns to scale: Model 2

H_0: production set is CRS; H_A: production set is VRS				
Year	Test statistic	Critical value, 5% (10%)	Type I error	Decision
2005	0.9954672	0.9922629 (0.9930472)	0.3359	Fail to reject null hypothesis
2006	0.9967642	0.989643 (0.9909744)	0.3327	Fail to reject null hypothesis
2007	0.9968784	0.9897278 (0.991144)	0.2296	Fail to reject null hypothesis
2008	0.9962957	0.9921095 (0.9932042)	0.1641	Fail to reject null hypothesis
2009	0.994726	0.9928758 (0.9944875)	0.1115	Fail to reject null hypothesis
2010	0.993336	0.9914518 (0.993014)	0.1155	Fail to reject null hypothesis
2011	0.9919675	0.9883079 (0.9898115)	0.2319	Fail to reject null hypothesis
2012	0.9896937	0.9869493 (0.9886891)	0.1519	Fail to reject null hypothesis

Table 3-5. Second-stage regression results: Model 1

	Bootstrap DEA estimates		Conventional DEA estimates	
	Panel RE	**Pooled OLS**	**Panel RE**	**Pooled OLS**
	(1)	(2)	(3)	(4)
Tariff ratio	0.000021	0.000101	0.000036	0.000164
	(0.00003)	(0.00029)	(0.00004)	(0.000279)
Consumer structure	0.004064**	0.003127	0.004626**	0.004825
	(0.002068)	(0.004127)	(0.002335)	(0.003991)
Population density	0.003934**	0.004864***	0.003194*	0.004280**
	(0.001591)	(0.001734)	(0.001866)	(0.001677)
Ownership dummy	0.081848***	0.0827946***	0.083397***	0.086995***
	(0.015441)	(0.015452)	(0.017927)	(0.014946)
Subsidy	−0.001318***	−0.001269***	−0.001503***	−0.00153***
	(0.000144)	(0.000143)	(0.000168)	(0.000139)
Population density × ownership	−0.008364***	−0.008388***	−0.008776***	−0.009103***
	(0.001655)	(0.001642)	(0.001919)	(0.001588)
Constant	0.95113***	0.942932***	0.96718***	0.956803***
	(0.015456)	(0.017435)	(0.018213)	(0.016864)
Observations	95	95	95	95
R^2	0.59592	0.61908	0.66901	0.69818

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in parentheses.

Table 3-6. Second-stage regression results: Model 2

	Bootstrap DEA estimates		Conventional DEA estimates	
	Panel RE	**Pooled OLS**	**Panel RE**	**Pooled OLS**
	(1)	(2)	(3)	(4)
Tariff ratio	0.000032	0.000187	0.000125***	0.000042
	(0.000038)	(0.000562)	(0.000012)	(0.000582)
Consumer structure	0.007287	0.002786	0.004672**	0.012428
	(0.004633)	(0.008042)	(0.001948)	(0.008331)
Population density	0.008036**	0.0091497***	0.0068543**	0.009231***
	(0.0038504)	(0.00337913)	(0.0034545)	(0.0035005)
Ownership dummy	0.13545***	0.177891***	0.15234***	0.18618***
	(0.036266)	(0.030111)	(0.032479)	(0.031193)
Subsidy	−0.0015255***	−0.0022117***	−0.0021317***	−0.0025677***
	(0.0003118)	(0.0002791)	(0.0002901)	(0.0002891)
Population density × ownership	−0.012935***	−0.018689***	−0.016199***	−0.019922***
	(0.0038667)	(0.0031996)	(0.0034949)	(0.0033146)
Constant	0.90658***	0.89569***	0.92549***	0.90416***
	(0.037675)	(0.033975)	(0.033098)	(0.035195)
Observations	95	95	95	95
R^2	0.38655	0.62089	0.63077	0.65423

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in parentheses.

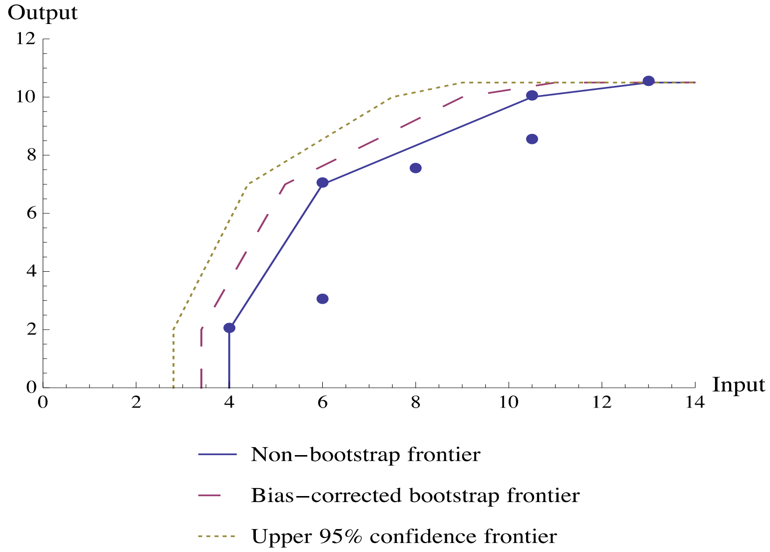

Figure 3-1. Example of bias corrected bootstrap frontier.

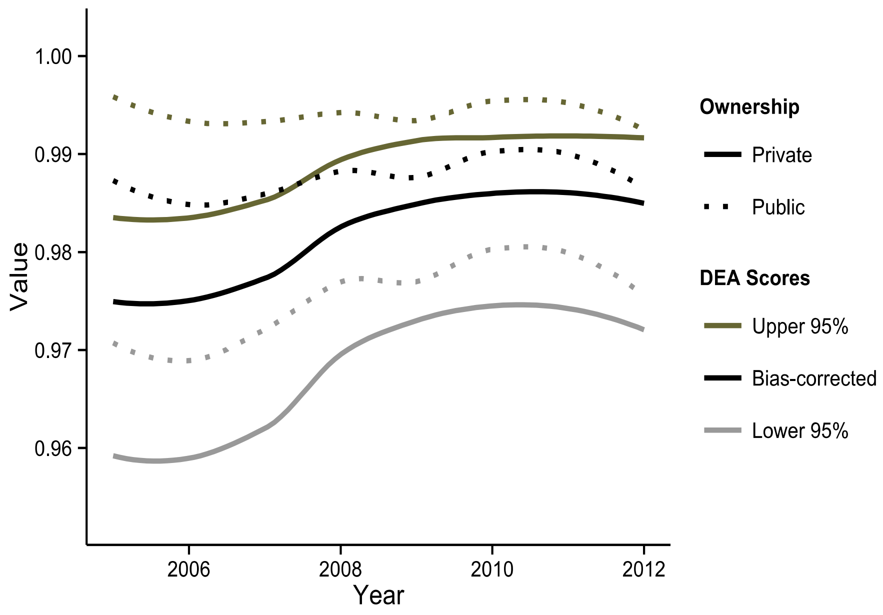

Figure 3-2. Bias-corrected bootstrap DEA estimates (average) with confidence interval: Model 1.

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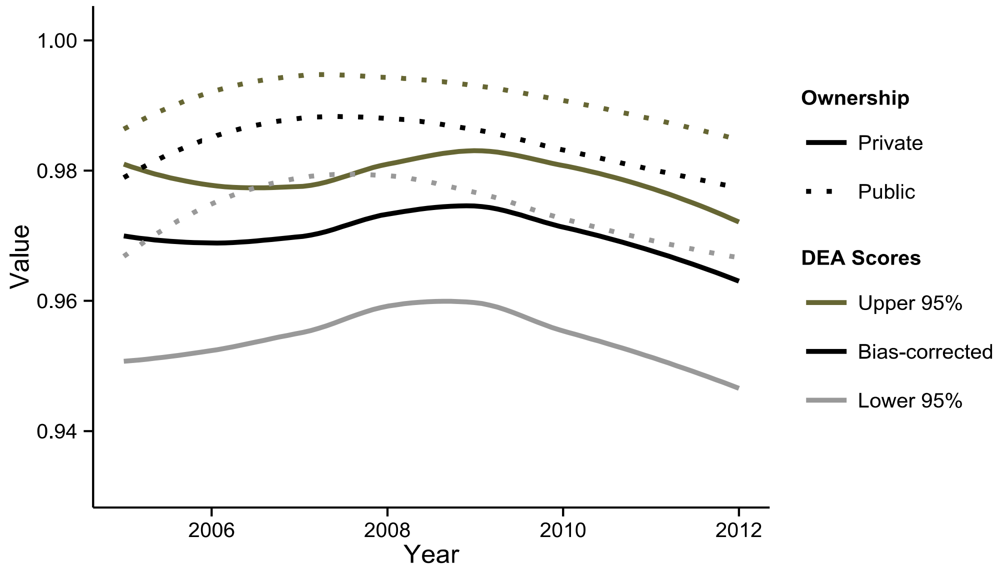

Figure 3-3. Bias-corrected bootstrap DEA estimates (average) with confidence interval: Model 2.

4 Structural Reforms and Technical Efficiency: Empirical Analysis of Indian Electricity Distribution Sector

4.1 Introduction

It has been more than a decade since two landmark legislations initiating structural reforms in the Indian electricity sector were enacted. These legislations aimed to make the electricity sector, in general, and distribution sector, in particular, operationally more efficient. In the past, much attention has been given to evaluate the impact of electricity reforms on various outcomes, including price of electricity and sector efficiency. DEA, a non-parametric benchmarking technique, is being used for productivity analysis in the electricity sector. However, examples of its use for impact evaluation of policy, which call for second-stage estimation, are limited.[18] Existing literature, which makes use of the benchmarking technique for analyzing structures of the Indian electricity sector, is also limited.

In an Indian context, the evaluation of electricity reforms on various performance indicators has started growing. Sen and Jamasb (2012), Vagliasindi and Besant-Jones (2013), and Pargal and Banerjee (2014) are examples of recent publications. However, these publications use parametric applications, and do not specifically look into various forms of structural changes and their relationship to efficiency and/or other outcomes of interest. Other publications such as Cropper et al. (2013) and Sugathan et al. (2013), do look into structural forms and impact of reforms in the electricity sector in India. However, these studies look into the efficiency of generating stations, and also, use parametric and SFA techniques, respectively. In the Indian electricity sector context, Thakur et al. (2006) evaluated the performance of state-owned electricity utilities (SOEUs) for 2001 data using DEA (one input/two inputs and three outputs). They used total cost for the one-input case and number of employees and adjusted

[18] Survey of applications can be seen in Santos et al. 2011.

cost for the two-input case. The three outputs were number of customers, energy sold, and distribution line length. Meenakumari and Kamaraj (2008) evaluated operational efficiency of SOEUs for 2005 data using DEA with three inputs (installed capacity, distribution line length, and technical losses) and two outputs (number of consumers and amount of energy sold). Saxena and Thakur (2011) applied DEA with three inputs (distribution line length, total expenditure, and aggregate technical and commercial losses) and two outputs (number of consumers and energy sold), using data for the year 2008. Yadav et al. (2011) focused on electricity distribution divisions in one state in India, Uttarakhand, for the year 2007. They considered a DEA model with two inputs (number of employees and operating costs) and six outputs (number of customers, energy sold, duration of interruption per feeder, distribution line length, transformer capacity, and total sanctioned load per square kilometer).

The existing literature, however, suffers from various limitations. (a) Most of the DEA papers relating to the Indian electricity sector have a limited time period of analysis and, thus, are not able to capture the dynamic efficiency evolution over a longer period. (b) The literature capturing link between structure of bundling/unbundling and technical efficiency of the Indian electricity distribution sector using a non-parametric frontier technique is nearly non-existent. (c) It is also not clearly established that how electricity reforms, structure of electricity sector, and other external/environmental variables affect the efficiency of the distribution sector. (d) From a methodological viewpoint, existing literature does not provide statistical inference based on nonparametric estimates of efficiency. Nonparametric models, such as conventional DEA, are subject to uncertainty because of sampling variation as observed by Daraio and Simar (2007).

In contrast, this Chapter adds to the literature of efficiency evaluation and to the impact evaluation of electricity reforms in the context of the electricity distribution sector of India in the following ways. (a) We use panel data for the state-level power distribution sector for the years 1995–2012, to track possible changes in efficiency over a longer period. (b) The vertically integrated structure existing before reforms, and partially or fully unbundled structures after the reforms, are explicitly considered in the analysis to compare the technical efficiency of electricity distribution sectors in Indian states. (c) In order to examine the impact of structural reforms policy, and also of the other determinants of efficiency variation, we employ a two-stage DEA, where DEA efficiency estimates obtained in the first-stage are regressed on policy reform variables (including variables representing bundling/unbundling structures) and some external-environmental variables in a second-stage analysis. (d) The bootstrap method is used to analyze the statistical properties of the nonparametric estimates. Specifically, we statistically test a returns-to-scale hypothesis using bootstrapping. Furthermore, we apply bootstrap (bias-corrected) efficiency estimates to the second stage in two-stage DEA. (e) Additionally, we conduct the investigation into the structures of the electricity sector, and their relationship with the size of the distribution sector.

This Chapter has the following major findings. First, we find positive impacts of the population density on the efficiency of utilities. This result is in line with existing studies. Second, we discover that partially unbundled structure of the electricity sector, wherein generation and distribution sectors are together, but transmission sector is separate (i.e., transmission sector only unbundled), has a significant positive impact on the technical efficiency of the distribution sector in India, as compared to the fully vertically, integrated monopoly. This indicates potentially higher "economies of scope" in the "transmission sector unbundling" structure than of a fully integrated one. Third, we find that Indian electricity reforms legislation has caused efficiency disadvantages for the Indian power distribution sector. Fourth, we ascertain that "small-sized" electricity distribution sectors/states experience significant positive gain in technical efficiency if they are partially or fully unbundled. Conversely, "medium-sized" states, post-unbundling, experience efficiency disadvantages, but these are not statistically different from zero. This result sheds some light on the "size advantage" for the small states, as they are able to adjust scale of operations when faced with "diseconomies of scope" after unbundling. Fifth, we find that the issuance of tariff order by the SERCs under rate of return regulation (RoR regulation) has a negative, but statistically insignificant, impact on the technical efficiency of the distribution sector. Last, we determine that real GDP per capita of the state and the consumer structure of the electricity sector has a positive but insignificant impact on the technical efficiency of its distribution sector. As existing literature lacks analytical quantitative studies regarding the effects of Indian electricity reforms on the distribution sector, our results add empirical evidence in this direction.

The rest of the Chapter is organized as follows. Section 4.2 presents the background of Indian electricity reforms. Section 4.3 details literature review, while in Section 4.4 we report the methodology of the two-stage DEA with bootstrap estimation. Section 4.5 covers the dataset and variable selection for this study. Section 4.6 reports our estimation results. And, Section 4.7 concludes with policy implications recommendations for future research.

4.2 Background of Indian Electricity Distribution Sector Reforms

Though we have given brief background of Indian power sectoral reforms in Section 2.2; for the sake of convenience and continuity of arguments we reproduce the same here in this Section. Since independence, the Indian electricity sector was governed by the Electricity (supply) Act 1948 which established vertically integrated monopolies in each State for generation (G), transmission (T), and distribution (D) of electricity. These were monopolies were known as State Electricity Boards (SEBs) and in some states as State Electricity Departments (SEDs). The constitution of India, adopted in 1950, included "electricity" as a subject in the concurrent list (Sugathan et al. 2013). Although this arrangement gave both the federal/central government and the state government simultaneous jurisdiction for legislation in this sector, the federal government has more controlling powers over this sector. However, it also provides sufficient autonomy to the regional state governments in the routine governance and administration of the electricity sector in the state. All three pillars (G, T, and D) of the electricity sector were dominated by the state, as observed by Tongia (2003). The performance of the electricity sector, until the early 1990s, and the causes for initiating reforms are well elaborated in Dubash and Rajan (2001), Tongia (2003), and Sharma et al. (2005). Since establishment of SEBs, the process of tariff determination by the SEBs was marred by the political-economy, and hence, tariffs failed to cover costs. In turn, the revenue shortfalls were backed up by the state governments as observed by Chan et al. (2014). A few of the main reasons for reform, as cited in the existing literature, were (a) inadequate generation capacity, (b) high technical losses, and (c) poor financial conditions of SEBs, leading to the financial burden on the State governments, etc. All these reasons amounted to “inefficient operations” of SEBs, in general, and of the distribution sector, in particular.

The power sector in India witnessed the reforms, beginning in 1991. The early reforms were focused on the generation sector to attract private investment, according to Tongia (2003). However, the distribution sector, in particular, was shifted to a “new paradigm,” according to Reddy (2002), with the enactment of The Electricity Regulatory Commissions Act, 1998, which led to the establishment of Central Electricity Regulatory Commissions (CERCs), and also allowed for establishment of State Electricity Regulatory Commissions (SERCs). This act also provided for the determination of tariff by both CERCs and SERCs for supply of electricity. However, the eastern state of Orissa started reforms in 1996, with World Bank’s initiative, before enactment of 1998 legislation. And, it allowed participation of private sector in distribution. Between 1998 and 2003, many state governments established SERCs. A few of these states also unbundled the vertical monopolies of SEBs and corporatized three pillars (G, T, and D), adopting various combinations of organizational structures of G, T, and D. Almost all these states also retained the State ownership of these structures, with the exception of Delhi and Orissa (which had already allowed private participation in distribution in 1997).

The second most important step in the reforms process was enactment of The Electricity Act, 2003. This act replaced all the previous existing legislation. This act is now pivotal in all policy decisions applicable to the electricity sector in India. The 2003 act made establishment of SERCs and unbundling and corporatization of SEBs/SEDs mandatory. It also aimed to (a) rationalize the tariffs by cost-coverage and removal of subsidies, (b) provide open access of networks to third parties, and (c) allow private participation in the distribution sector. Sen and Jamasb (2012) observed that the purpose of the 2003 act was not only to structurally and institutionally reform the electricity sector, but also to make it competitive and efficient. The establishment of SERCs, after both the 1998 and 2003 Acts, also marked the beginning of the Rate on Return (RoR) Regulation regime. Table 4-1 shows the State-wise date (year for purposes of the analysis in this Chapter) of the establishment of SERCs, the date/year of the first tariff order for the distribution sector issued by the SERC under RoR regime, and date/year of enactment of the state legislation for electricity reforms (which can be different from federally promulgated “The Electricity Regulatory Commissions Act, 1998” and/or “The Electricity Act 2003”).

[Table 4-1 here]

The state-level enactments are either adoption of the Central Act as it is, or a slight modification of the same which suits a particular state. For the most part, all the legislations of different states mandate not only establishment of SERCs and unbundling of vertically integrated structures, but also includes provisions for establishment of Appellate authority to

SERCs, establishment of state grid code, provisions for supply of electricity by distribution licensee, and other measures for protection of consumer interests and quality of supply.

Similarly, Table 4-2 shows the post-unbundling structures of the electricity sector adopted by a state, and how these structures changed from vertically integrated monopoly to a partially or fully separate distribution sector. We can see a variety of modes/forms of unbundling across Indian states. (a) States Andhra Pradesh, Haryana, Karnataka, Orissa, Uttar Pradesh, and Uttarakhand adopted the transmission and distribution (TD) as an intermediate corporate structure immediately after vertical unbundling, and before making distribution totally independent from both the generation and transmission (i.e., G-TD before G-T-D). (b) States Assam, Chhattisgarh, Delhi, Gujarat, Madhya Pradesh, Maharashtra, and Rajasthan made the distribution sector totally separate and stand-alone right after unbundling (i.e., directly G-T-D). (c) States of Himachal Pradesh, Punjab, Tamil Nadu, and West Bengal adopted the structural form of keeping the generation and distribution together after the unbundling (i.e., GD-T). (d) Bihar, Jharkhand, and Kerala integrated a monopoly structure during the relevant panel period (i.e., GTD). However, both Bihar and Jharkhand moved to unbundled structures in 2013 and 2014, respectively, which is beyond the scope of the panel data analysis for this Chapter. (e) Jammu and Kashmir are the only states which has a structure of TD, separate from the generation, since the first year of the relevant panel period. (f) A scenario did not exist in any state, at any time just after unbundling, in which there was the generation and transmission structure together (GT), with a totally separate distribution sector (i.e., GT-D).

Though, there exists temporal variation across India in both the timing and the forms of unbundling, Cropper et al. (2013) did not find any evidence of reasons for such preference by states to adopt a particular time and/or a particular structure of reforms, either between 1998-2003, or after 2003.

[Table 4-2 here]

By comparing and analyzing Table 4-1 and Table 4-2, we can observe the following salient features of the structural reforms in the Indian electricity sector, so far as it relates to establishment of SERCs, tariff orders, and unbundling of vertical monopolies. (a) The distribution sector of every state has either started operations under the system’s annual tariff orders (being issued by SERCs under Rate of Return regulation), or experienced such a system before the concerned state had implemented the policy of partial or full unbundling. (b) There exists variation (across the states) in the period required for complete separation of the distribution sector from the partially or fully integrated structures after the legislation related to unbundling was enacted by the state. This required time may be related to state-specific, political-economy factors and/or historical factors. (c) For the distribution sector, full-unbundling or total separation may not be a binary event. There can exist stages of a gradual unbundling process (or partially unbundled stages) from total vertical integration to the total separate/stand-alone distribution sector. (d) There exists regional and temporal diversity in the adopted structures for the electricity distribution sector in India.

India is a typical example of geo-climatic and socio-eco-political diversity among the developing countries. During this study, we control these time-invariant (or very slow time-variant), observed and unobserved, regional and state specific diversities in our panel-data analysis. In India, region-specific diversity is also observed in the electricity sector. The diversity was observed in terms of peak-load, consumer structure, etc., according to Shukla and Thampy (2011). As such, we also try to capture and control for this variation during our analysis. In addition to the mentioned salient features of the unbundling, many states have holding-companies for unbundled, corporatized, single or multiple, distribution companies (DISCOMs). Pargal and Banerjee (2014) interpreted this arrangement as a structure under which only partial operational and financial independence was allowed, even for the totally independent stand-alone DISCOMs.

In our analysis, we make use of the temporal and group-wise variations in post-unbundled, state-level, structures of the distribution sector to evaluate the impact of reforms and of specific structural forms on the technical efficiency of the electricity distribution sector. However, we neither go into analyzing whether the distribution sector has one or multiple DISCOMs, nor do we analyze the impact of ownership aspects of DISCOMs.

4.3 Literature Review

This Section reviews the existing literature, first in relation to the evaluation of the electrical sector reforms using DEA, and then with regard to the evaluation of the Indian electrical reforms.

4.3.1 Literature Review: Evaluation of electricity sector reforms using DEA

Jamasb et al. (2005) categorizes study of electricity reforms, based on DEA methodology, into an “efficiency and productivity analysis method”. There are also other methods of investigation, most notably the “econometric method”. The existing literature for the application of DEA in the electricity distribution sector is rich. Santos et al. (2011), for example, has provided the details about the studies of efficiency measurement of the electricity distribution utilities using DEA methodology.

However, one direction of existing studies is to measure the impact of power sector reforms based on the “econometric method.” Steiner (2001), Hattori and Tsutsui (2004), Ernst and Young (2006),[19] Fiorio et al. (2007), Florio M. (2007), Nagayama and Kashiwagi (2007),

[19] http://www.dti.gov.uk/files/file28401.pdf

Nagayama (2007), Zhang et al. (2008), Nagayama (2009), and Erdogdu (2011) are prominent examples in this field. They have investigated the impact of reforms in the electricity sector, by evaluating changes in the prices of electricity, using the econometric method for panel data. These studies include Organisation for Economic Co-operation and Development (OECD) countries, EU member countries, Latin American countries, Pan-Asian countries, and a few developing countries.

However, in the other direction, literature related to evaluating the impact of structural reforms in the electricity sector on the performance of the distribution utilities/sector, is limited, but continuously growing. Furthermore, as observed by Vagliasindi (2012), the literature with specific use of DEA and bootstrap-DEA for investigating the impact of unbundling of vertically integrated monopolies of the electricity sector (as a part of the reforms), is negligible.

Kwoka (2002), Nemoto and Goto (2004), Jara-Dıaz et al. (2004), Fraquelli et al. (2005), Piacenza and Vannoni (2009), and Goto et al. (2013) are the examples of specific investigation into the impact of vertically integrated of electricity monopolies on the cost efficiency gains, to test the existence of economies of scope. These studies are related to the electricity utilities in the US, Japan, Spain, and Italy, and are based on multi-product cost functions. However, critics of this approach argue that these cost-functions are estimated by non-frontier techniques under the assumption of firms are efficient (e.g., Arocena (2008)). Another critique is that the firms under this approach are also assumed to follow cost minimizing behavior; and the cost functions for integrated and separate firms are assumed to be the same, which may not be true (e.g., Meyer (2011)). In a recent study, Vagliasindi (2012) has analyzed the links between alternative market structures of the electricity sector on the various performance indicators. Her study includes 22 developing countries for the period of 1989-2009, and is based on "econometric" and "case-study comparison" methods. She found that partial forms of unbundling do not appear to improve performance of the power sector.

To the best of this author's knowledge, only two studies in the existing literature are related to empirical analysis of vertical unbundling using DEA. In the first study, Arocena (2008) has analyzed the degree of economies of vertical integration in the Spanish electricity industry using DEA. He has taken into consideration the gains from the quality of supply, along with the cost for evaluating alternative structures. He has used variable returns to scale (VRS) to compute the scale efficiency and to estimate the impact of firm size. The drawback of this approach is that with DEA being deterministic, one cannot statistically test the underlying assumption about the "returns to scale" while estimating underlying technology. This study used 1989-1997 Spanish data, with the method of creating hypothetical composite companies for construction of additive technologies to serve as a benchmark for costs when production is done by separate specialized firms. However, Arocena has also observed that some of the hypothetical composite companies do not truly represent the vertically integrated companies, which may undervalue the estimates.

The second, and perhaps the only study based on *bootstrap*-DEA (*B*-DEA), is by Meyer (2011). He has compared different frontiers for integrated and separate provision of electricity. He has investigated only two specific cases of unbundling, generation unbundling (i.e., G-TD), and transmission unbundling (i.e., GD-T). Furthermore, he has estimated one-input (total expenditure) and four-outputs (MWhr generated, transmitted, distributed, and transmission line length) for VRS model with *super efficiency*,[20]and compared one integrated frontier with two additive frontiers. He created two additive frontiers, one each for G-TD and GD-T, respectively.

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[20] Firms' efficiency are calculated relative to reference technology, hence *super efficiency* scores can be less than or more than unity.

While creating the additive frontier for G-TD, he combined a single generation (G) company with integrated transmission and distribution (TD) company by pairwise, adding outputs and costs. Though he has used bootstrapped estimates of DEA scores to remove the bias, he has not tested the underlying assumption of VRS technology.

In this Chapter, we follow the bootstrap-DEA estimation of only “technical efficiency” scores (and not “allocative efficiency” and/or “total efficiency”) for a three-input, two-output input-oriented model for both VRS and CRS technologies for the electricity distribution sector. We statistically test the “returns to scale” for underlying technology for the Indian electricity distribution sector. We also do not use either super efficiency or additive frontier creation. We take three inputs, one to represent labor and two for representing capital used, in the distribution sector. While choosing input and output variables, we follow the most commonly used variables in the existing literature. Labour is represented by number of employees; and, capital is represented by network length and transformation capacity of the distribution sector. While including labor, we consider only those personnel who are associated with the distribution sector in the vertically integrated monopoly (irrespective of whether it is partially or fully integrated) for both pre- and post-reform periods. Similarly, distribution network length and distribution transformation capacity are only those network characteristics, representing the capital, which are totally associated with the distribution sector only. Our two outputs are number of customers served and amount of electricity sold by the distribution sector of an Indian state. In some states, after the reforms, multiple stand-alone DISCOMs were created by horizontal unbundling of the distribution sector of the state. In these states, we create a post-reform hypothetical single distribution sector for the entire state by adding inputs and outputs of these multiple DISCOMs so that we are able to compare pre-reform and post-reform efficiencies of the distribution sector without changing the reference technology. Our method is thus in contrast to the one used by Arocena (2008) and Meyer (2011). We are also treating reforms legislation, issuance of tariff orders by SERCs, and unbundling of the electricity sector (whether fully/ partially unbundled), as exogenous environmental variables affecting the distribution sector, and as decisions made by the policy maker, meaning variables which are beyond control of managers of the distribution sector. We then evaluate the impact of these environmental variables (as independent variables) on the "technical efficiency" (a dependent variable) of the distribution sector. In our study, we do not take into account costs associated with the inputs; therefore, we also do not consider allocative efficiency in the distribution sector.

4.3.2 Literature review: Evaluation of Indian power sector reforms

Post Electricity Act 2003, the earlier scholarly literature qualitatively evaluated the Indian electricity sector reforms. Ranganathan (2004), Sankar (2004), Bhattacharyya (2006), Sharma et al. (2005), Singh (2006), and Thakur et al. (2005) belong to these kind of qualitative studies. Thakur et al. (2006) has conducted evaluation of State Owned Electricity Utilities (SOEUs) in India using DEA for 26 SOEUs, for the years 2001-2002, and did not really reflect the evaluation of the electricity reforms act of 2003. Dubash and Rao (2008) have qualitatively evaluated the regulatory reforms in the electricity sector in India, and particularly focused on the regulation in practice in an institutional and political context. Meenakumari and Kamaraj (2008) have studied the performance of 29 SOEUs using DEA, for the year 2005. However, they focused on the efficiency part of the SOEUs, rather than evaluation of the electricity sector reforms per se. Kodwani (2009) has analyzed the tariff determination process for electricity consumers by the State Electricity Regulatory Commissions (SERCs) in four different states in India covering 12 DISCOMs. He examined if regulatory regime has resulted in reduction of the operational costs for the DISCOMs, and if, consequently, it has reduced the prices of electricity for consumers. However, his approach is non-econometric and solely based on the analysis of the tariff orders issued by the regulators. Joseph (2010) has econometrically evaluated Indian electricity reforms in a political-economy context. He used panel data for 35 Indian states, for the period 1994-2005. Installed capacity of captive power plants has been used as a dependent variable with agriculture pump-set consumption, transmission and distribution losses, agriculture tariff, industry tariff, and State industrial GDP as independent variables. He has used a fixed effects model to explain the need for significant distribution sector reforms from a political-economy angle. Saxena and Thakur (2010) have used a balanced score card technique with the two-stage Delphi method for comparison of service, operational efficiencies, and financial efficiencies of the SOEUs of 31 Indian states, for the period 2006-2007. Their results are not linked to the electricity reforms and are merely aimed at management of SOEUs in efficiency terms.

After 2010, there was growth in the literature which, both parametrically and non-parametrically, has tried to evaluate Indian Electricity reforms. (Yadav et al. 2011b) has analyzed 29 electricity distribution divisions (EDDs) of the northern, hilly state of Uttarakhand in India, for the year 2007-2008, using DEA approach. The result is at micro-level, with state-specific focus, and merely focused on the operational efficiencies of the EDDs within a state, and not related to electricity reforms. A major study by Sen and Jamasb (2012) has evaluated causal effect of regulatory reforms on various performance indicators using a dynamic panel data estimator, for years 1991-2007, for 19 states. Their results show that each individual state has different outcomes based on the nature of reform due to the political-economy factor. Reform outcomes have been found to be adverse in the beginning, due to revelation of hidden distortions. The authors have used plant load factor (PLF), gross generation, and transmission and distribution losses, as indicators of outcome/performance measures. They have tried to find the causal linkage between these three indicators as a function of six regulatory dummy variables and state and year fixed effects. Their results show that PLF is strongly positively affected by the unbundling and tariff order dummy variables. Similarly, the ratio of industrial to agricultural electricity prices also affects PLF strongly positively. They have concluded that the establishment of SERCs, unbundling of the vertically integrated monopolies, and privatization dummies have led to an increase in transmission and distribution losses, the probable reason being the revelation of previously hidden existing losses before reforms.

Cropper et al. (2013) has used the difference-in-difference (D-i-D) method for panel data of 82 thermal power plants, during the period 1994-2008. In contrast to state-level data as used by Sen and Jamasb (2012), they have used plant-level data to examine the causal link between unbundling and performance of state-owned power plants. They assumed that conditional on plant-level fixed effects, state-level time trend and year fixed effects (and other controls), unbundling of generation (G) from transmission and distribution (TD) is exogenous. Their study solely focused on the generation sector and found that unbundling did not result in improvement of thermal efficiency of power plants, but resulted in improvements in capacity utilization and reduction in forced outage.

Sugathan et al. (2013) has used stochastic frontier analysis (SFA), a parametric model, and separated unobserved, firm-level heterogeneity from technical inefficiency to empirically investigate the nature of productivity changes. They used panel data, for the period 2000-2009, for 98 firms in the Indian electricity sector, with the transformed fixed-effect SFA method. Their sample consisted of 51 generation (G) firms, 38 transmission and distribution (TD) firms, and 9 vertically integrated (GTD) utilities. They used 542 firm-time observations in an un-balanced panel with ownership of both public and private sector. Using translog production specification, they separated total factor productivity (TFP) into various components, thus analyzing dynamic changes in the efficiency at the firm-level. They found that post-Electricity Act 2003, there had been no improvements in firm level productivity. They also found that most of the productivity change was due to the effect of technology change (newer capacity addition). They observed that the efficiency component of productivity was generally declining after the reforms, including that for the distribution firms and unbundling, as such, had no significant impact on efficiency.

In a recent book by Vagliasindi and Besant-Jones (2013), three Indian states (viz., Andhra Pradesh, Gujarat, and West Bengal) have been investigated to analyze the impact of power sector reforms. They concluded that partial forms of vertical unbundling do not appear to improve the distribution sector, and has no impact on tariffs. They found no significant link between vertical unbundling and operational efficiency for the Gujarat and West Bengal electricity sector. Another very recent book, authored by Pargal and Banerjee (2014), has analyzed in depth the Indian electricity sector and effects of reforms. They identified multiple sources of weakness in distribution sector. They found that, even after nearly two decades of first starting original reforms, the distribution sector is still inefficient and loss making. They also observed in Chapter 6 that unbundled utilities operating still as a part of holding companies may be one of the reasons for unbundled utilities' worst performance. However, their observation is not supported by sound empirical evidence. In a recent publication of Khurana and Banerjee (2014), they have used DEA to find the best and worst performing utilities in the Indian electricity sector. They observed that the decision to unbundle rests on the economies of scope that may be achieved by unbundling. They cited the example of the southern Indian state of Kerala performing best, even though it was vertically integrated after reforms legislation, based on both operational and financial criteria. They also concluded that differences in performance of unbundled versus bundled utilities are empirically ambiguous.

All of these recent World Bank publications about the Indian electricity sector, may be correctly identifying ills of the Indian electricity reforms, but perhaps they are not backed by robust empirical evidence based on economic theory. This Chapter tries to fill this gap and creates empirical study for the evaluation of Indian electricity reforms.

4.3.3 Motivation and Contribution of this Chapter

We contribute to the existing literature in following ways:

1. We add a unique example of diversity among the developing countries in the form of Indian experience. We evaluate the impact of electricity reforms and, also, of various forms of unbundling on the technical efficiency of the electricity distribution sector.

2. Unlike the existing literature on the Indian electricity sector in which reforms focus on evaluating the impact of unbundling on the generation sector, we exclusively focus on the distribution sector, which is the key link for successful reforms as observed by Pargal and Banerjee (2014).

3. In contrast to the existing literature, which mostly uses a parametric approach for policy impact evaluation, we adopt a mixed and computationally intensive approach. (a) We use two-stage approach, non-parametric in the first stage and parametric in the second stage. (b) In the first stage, we calculate the unbiased bootstrap-DEA efficiency scores of the distribution sector of each state, relative to their own technology, both before and after reforms. We use estimate three-input and two-output, input-oriented model with VRS and CRS technology. (c) We construct the test-statistics for the assumption of underlying technology, and statistically test the assumption about "returns to scale." (d) We then choose those efficiency scores associated with underlying technology, which are found to be statistically significant for the distribution sector, and use the same as the dependent variable for parametric estimation of impact of reforms during the second stage of analysis. Thus, we contribute to the existing literature in terms of methodology.

4. Unlike existing literature which uses additive frontier and super efficiency concept in DEA, we keep the frontier creation in the first-stage very simple. We do not use cost of inputs,

additive frontiers, or super efficiency. We look at actual performance of the distribution sector when it is part of vertically integrated monopoly, and compare the same with that of the distribution sector existing after the reforms. Only in the case of those states where multiple DISCOMs are created after the reforms, have we created a virtual distribution sector for the state by adding inputs and outputs of all these DISCOMs. Thus, we do not need to calculate the efficiencies of the "post-reform distribution sectors" with reference to technology of "pre-reform integrated structure."

5. We additionally explore the relationship between the size of the distribution sector and the unbundling structure of the electricity market, in which the distribution sector is operating. We investigate how structure-size combinations affect technical efficiency of the distribution sector. This helps shed some light on how managers of distribution sectors of different sizes dynamically act to deal with cost-gain trade-off between "diseconomies of scope" and "economies of scale" after unbundling.

4.4 Methodology

This Section describes the methodology used in this Chapter.

4.4.1 Conventional-DEA and Bootstrap-DEA

This Chapter uses the same methodology as used in Chapter 3 (i.e., two-stage DEA with bootstrap estimation). In this Chapter, technical efficiency scores of each state (as DMUs in this Chapter represent the state-level distribution sector) for each year is estimated using bootstrap-DEA in the first stage. And, these estimates are, subsequently, regressed on some external environmental variables in the second stage.

As the methodology is identical to that of Chapter 3, one can refer to Subsections 3.2.1 and 3.2.2 for the theoretical background of Conventional-DEA and Bootstrap-DEA, respectively. However, for recapitulation, we do reproduce the diagram showing the difference between conventional-DEA and bootstrap-DEA frontiers for one-input and one-output firms in Figure 4-1.

[Figure 4-1 HERE]

4.4.2 Second Stage Regression

In a typical two-stage DEA model, efficiency estimates in the first stage are regressed on external-environmental variables in the second-stage analysis. The purpose is to determine what factors have significant impacts on efficiency. Here, we consider a panel data setting.

Before giving details of models, we would reiterate the approach mentioned (in contrast to existing literature) in Subsection 4.3.1. We aim to make use of (a) temporal variation across the Indian states in enactment of legislation and total unbundling of the distribution sector, (b) variation in the group-wise structural forms of unbundling across the states' scope, and (c) group-wise variation in the size of states/distribution sectors. This is likely to give us insight about the (a) impact of reforms legislation and structural forms of unbundling on the technical efficiency of the distribution sector, and (b) relationship of size with structural forms of unbundling like the model.

This approach is expected to reveal whether distribution sectors, after the reforms, are able to recover loss in efficiency caused by decrease in economies of scope. Through interaction terms of "size" of states/distribution sectors (size is fixed and represent group variation) with "different structures of unbundling" (which is both group and temporal variation); we expect to gain insight whether efficiency advantages attributable to firm size (i.e., "economies of scale") and loss in efficiency attributable to "diseconomies of scope" after unbundling matter or not.

Fraunhoffer and Schiereck (2012) have mentioned three sources of synergies in the electricity market: scale and scope energies, operational synergies, and financial synergies. They advanced empirical discussions about energy related synergy effects in Germany through an interview methodology. Their findings, through interviews with industry experts, confirm the existence of scale and scope economies in the certain segments of the value chain, particularly in distribution and generation. Their findings are in line with the existing empirical literature of Christensen and Greene (1976) and Piacenza and Vannoni (2009). Hence, we expect that partial unbundling, where only the transmission sector is unbundled (i.e., generation and distribution sectors remain together after unbundling), is likely to have a strong positive synergetic impact on technical efficiency of distribution sector after the unbundling.

(A) Model for effect of reforms and different structural forms on technical efficiency

Let $\boldsymbol{z_{it}}$ denote a vector of K external-environmental variables for distribution sector/ state/ DMU i at period t. We regress bias-corrected estimates $\widetilde{\theta}_{it}$ on $\boldsymbol{z_{it}}$. Our $\boldsymbol{z_{it}}$ consists of consumer structure, population density, and real gross domestic product (GDP) per capita. In addition to $\boldsymbol{z_{it}}$ we have binary variable "$Legislation$" representing enactment of reforms legislation and unbundling dummy. In first sub-model, we treat unbundling dummy as binary; then, in the second sub-model, we consider various structure of unbundling.[21]

(i) When bundling is binary (stand-alone distribution sector means bundling = 0)

$$\widetilde{\theta}_{ijt} = \alpha_i + \lambda_t + \gamma * Unbundling_{it} + \delta * Legislation_{it} + \boldsymbol{z}_{\boldsymbol{it}}^{'}\boldsymbol{\beta} + \epsilon_{it} \quad \text{....(5)}$$

Here, $\widetilde{\theta}_{ijt}$ is bias-corrected efficiency score of distribution sector/ state i in region j at year ; α_i is state fixed effect and also absorbs fixed effects of region j. α_i controls for unobserved time-invariant determinants of distribution sector performance (e.g., work culture, traditions, location), λ_t is time-fixed effect, $Unbundling_{it}$ has value 1 if in year t distribution sector of state i is fully or partially integrated with generation and/or transmission (i.e., for G-TD, GD-

[21] Our models are based on the Aghion et al. 2008 study of delicensing industries and labor regulation in India.

T, and G-T-D structures). If it is stand-alone/separate from both (i.e., GTD structure), then it has value 0. $Legislation_{it}$ represents[22] whether state i has enacted reforms legislation in year t as indicated in Table 4-1. It has value unity in the year a state adopted the legislation, and remains one thereafter. $\boldsymbol{z}_{it}^{'}$is transpose of vector of covariates and ϵ_{it} is a stochastic error term. We have two coefficients of interest γ and δ. First coefficient γ gives the effects of unbundling the distribution sector irrespective of treatment as compared with totally bundled/ vertically integrated distribution sector. Our second coefficient of interest δ is identified by interaction of state-year variation in enactment of the reforms law and gives the impact of legislation on the technical efficiency of the distribution sector.

(ii) When dummies for various forms of bundling structures are used

$$\widetilde{\theta}_{ijt} = \alpha_i + \lambda_t + \sum\nolimits_3 \gamma_k * Unbundling_{it,k} + \delta * Legislation_{it} + \boldsymbol{z}_{it}^{'}\boldsymbol{\beta} + \epsilon_{it} \quad \text{............ (6)}$$

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[22] The variable "Legislation" refers to "enactment of the relevant Act applicable to a State/prefecture in India." It represents the policy change and includes a reforms package for electricity sector of the State. As a reforms package encompasses (a) mandatory establishment of state-level regulatory commission (SERC) and start of issue of tariff order by SERC, this event is represented by variable "Tariff Order," (b) mandatory unbundling of vertically integrated electric monopolies. This event is represented by variables related to "Unbundling Structures," (c) various measures related to consumer satisfaction, (d) open access for transmission (i.e., third party access); (e) establishment of Appellate Tribunals against SERCs, and (f) establishment of power trading as a distinct activity, etc. Thus, "Legislation" as a variable represents a broad reforms policy signal. It indicates the start of reforms, but actual timing and structure adopted for "unbundling" differs from state to state. Thus, variable "Unbundling" represents the actual occurrence of event of unbundling. In this sense "Legislation" introduces uncertainty regarding timing and structure of unbundling. And, "Unbundling" variable represents event with certainty with regard to timing and type of structure adopted by state while unbundling its vertical electric monopoly.

In this model $Unbundling_{it,1}$= GD-T sector, where distribution sector is integrated with generation sector; and this is base case. $Unbundling_{it,2}$= G-TD sector, wherein transmission and distribution sectors are integrated. $Unbundling_{it,3}$= G-T-D sector, wherein distribution sector is stand-alone and is completely unbundled from both generation and transmission sectors. In this model, our base-case for unbundling is GTD sector, which represents fully integrated monopoly. Hence, compared to this base-case of GTD, our coefficients of interest are γ_1 , γ_2 and γ_3.

We estimate both above models (5) and (6) as Fixed Effect[23] models, wherein we allow the correlation between individual state effect and other regressors. We check for the robustness of estimation by initially estimating models without introduction of covariates, and then adding each covariate separately. Finally, we also cluster the standard errors by one-way clustering by state to account for serial correlation. While clustering by state, (a) we assume no intragroup serial correlation between errors, and allow for heteroskedasticity across groups, and (b) we estimate Arellano-type standard errors which allow a fully general structure with respect to heteroskedasticity and serial correlation. These clustered robust estimations address serial correlation concerns (and allow for heteroskedasticity).

(B) <u>Model for effect of structural forms and size of state on efficiency</u>

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[23] It is true that every state in India has its own political-economy factors. These factors, in turn, may affect the timing and mode of "legislation" and "unbundling." These political-economy factors are unobserved in our state-level data in this Chapter. We estimated panel data Fixed Effect (FE) model in this Chapter. Hence to reduce the endogeneity concerns with regard to these variables we have to make two assumptions: (a) the value of the unobserved political-economy factors in a particular state remain constant across all period under consideration (i.e., 1995-2012), and (b) the effect of this state specific, individual unobserved heterogeneity also remains constant throughout panel period.

In this model, we alter model (6) to include the size of the state, and its interaction with dummy variables representing structures of unbundling, and also with that of the legislation:

$$\widetilde{\theta}_{ijt} = \alpha_i + \lambda_t + \sum_3 \gamma_k * Unbundling_{it,k} + \delta * Legislation_{it} + \sum_3(\sum_2 \tau_s * size_{i,s}) * Unbundling_{it,k} + \sum_2 \pi_s * size_{i,s} * Legislation_{it} + \boldsymbol{z}_{\boldsymbol{it}}^{'}\boldsymbol{\beta} + \epsilon_{it} \quad \ldots\ldots (7)$$

In this model, we introduce $size_{i,s}$ as distribution sector/ state specific time-invariant fixed size. $\widetilde{\theta}_{ijst}$is bias-corrected technical efficiency of distribution sector of state i with fixed size s in region j in year t. α_i is the unobserved, time-invariant, fixed effect for state i which now absorbs fixed effect related to region j and also absorbs those time-invariant effects attributable to size s of the state. We have divided states into 3 sizes; $size_{i,1}$= large, $size_{i,2}$= medium, and $size_{i,3}$ = small. Our base case is "large" for "$size$" dummy variable. Our coefficients of interest $\gamma_1, \gamma_2, , \gamma_3$ and δ are same as in model (5). Additional coefficients of interest are τ_1,.., τ_6 and π_1, π_2. All τ_s are identified by mix of state-size variation with state-year variation in unbundling dummy, and both π_s are identified by interaction of state-size variation, state-year variation in binary dummy variable $Legislation$.

4.5 Data and Variables

In this Section, we explain the data source, definition of variables, and method of calculation of some specific variables.

4.5.1 Data

Our data set consists of data on 21 state-level electricity distribution sectors for the period of 18 years, from 1995-2012. Data for year 1995 means data for the year 1st April, 1994-31st March, 1995. During the period 1995-1999, 18 states' data is available. In 1999-2000 three new states were carved out of the then existing 18 states.[24] However, the data for these new

[24] Madhya Pradesh (MP) divided into MP and Chhattisgarh. Uttar Pradesh (UP) was divided into UP and Uttarakhand. Bihar was divided into Bihar and Jharkhand.

states is available from the year 2002 (i.e., from 1st April, 2001-31st March, 2002). This made our panel unbalanced, amounting to a total 357 state-year observations. We collected data from various distribution companies across all the Indian states and from SERCs at the state-level. The data before unbundling was taken from Annual Statistical Reports and annual administrative reports published by respective SEBs or SEDs. These data were confirmed by crosschecking with "Annual report on working of state power utilities and electricity department 2001-02," published by the planning commission Government of India, data published by Central Electricity Authority (CEA) under Ministry of Power, Government of India, and Annual publication TERI Energy & Environment Data Diary and Yearbook (TEDDY) by Tata Energy Research Institute (TERI), New Delhi. The data required for calculation of labor actually associated with the distribution sector before unbundling, was collected with personal interaction at headquarters of erstwhile SEBs. The actual calculation was determined by analyzing function wise income and expenditure from Annual Account of Statement of erstwhile State Electricity Boards. Please see Data Appendix-Chapter 4 for more details about state-wise calculation of actual labor associated with the distribution sector during the vertically integrated monopoly period.[25] Post-reform data for each DISCOM was available at the DISCOM headquarters, annual SERC tariff orders, state government and Central government Ministry of Power, CEA, and other institutions associated with the electricity sector.

In as many as 10 states, post-reforms horizontal unbundling of the distribution sector was also implemented. These states are Andhra Pradesh, Assam, Delhi, Gujarat, Haryana, Karnataka, Madhya Pradesh, Orissa, Rajasthan, and Uttar Pradesh. In these states, after

[25] Data Appendix-Chapter 4 also shows the definition and source of other data variables.

vertically unbundling of the distribution sector, multiple distribution companies (DISCOMs) were corporatized. These companies are mostly formed on a geographical basis. The sum of the areas served by these multiple DISCOMs, matches with the areas served by erstwhile distribution sectors. For these states, we created a post-reform, hypothetical, state-level distribution sector. This virtual distribution sector is analogous with the distribution sector that existed as a part of erstwhile vertically integrated monopoly, in terms of area, customers served, and population covered. We added respective input variables and output variables of the multiple DISCOMs to obtain a single value of the respective input and output variables for this virtual post-reform distribution sector at the state-level. This method facilitated the comparison of the pre-reform and post-reform performance of the electricity distribution sector at the state-level. This also helps to maintain uniformity and consistency in many observed and unobserved state-level characteristics, both pre-reform and post-reform, that may affect operations of the distribution sector of the state.

Our data covers nearly 80% to 96% of electricity sold per year throughout panel period in terms of GWhr or Million Units (MU) by the distribution sector in India. This represents mostly the supply of electricity through the public sector. For example,[26] in year 1995-1996, a total of 277,029 MU was distributed. Our data covers 264,933 MU (95.63%) in 1996. For year 1999-2000, a total of 312,841 MU electricity was distributed; our data for year 2000 covers 290,370 MU (92.81%). Similarly, in year 2005-2006, throughout India a total of 411,887 MU was sold; our data for 2006 covers 359,498 MU, amounting to 87.28%. In year 2009-2010, against total sales of 620,251 MU, our data covers 508,478 MU, amounting to 81.98%. And for year 2011-2012, against total sales of 755,847 MU of electricity throughout India, our data

[26] Data collected from annual publication "All India Electricity Statistics- General Review," published by CEA. Ministry of Power Government of India.

covers 605,815 MUs in year 2012, which is 80.15%. This also shows that, although the role of the public sector ownership in distribution sector is decreasing, it is still dominant.

4.5.2 Variables

Here, we discuss the variables used. During the first-stage, variables used are for the purpose of estimating bootstrap-DEA scores, representing the technical efficiency of the sector. In the second-stage regressions, we use both environmental and other policy related variables, as well as other explanatory variables which may affect the performance scores estimated in the first-stage.

(A) Input and Output Variables in the First Stage

Santos et al. (2011) surveyed the existing literature on DEA models for the electricity distribution utilities in detail. Common inputs for the evaluation of the electricity distribution utilities include labor (e.g., number of employees and wages) and physical assets (e.g., distribution network and transformer capacity). Commonly used outputs are number of customers and electricity delivered. We follow the same trend that exists in literature and choose three inputs, namely, number of employees, distribution line length (in circuit kilometers), and transformer capacity (in MVA). Two outputs commonly used, as found in the literature, are number of customers and total electricity delivered (in GWhr/Million Units). Our set of variables is similar to, for example, those in Pombo and Taborda (2006) and Çelen (2013), who examined panel data for the power distribution sectors in Colombia and Turkey, respectively. The power distribution sector in each state has to meet the electricity demand of its consumers in each geographical area by efficiently using its inputs. Input-oriented DEA would be suitable for this case. Table 4-3 shows descriptive statistics for input and output variables of the first-stage bootstrap-DEA.

[Table 4-3 HERE]

(B) Environmental and other Explanatory Variables in the Second Stage

While discussing external-environmental variables, it needs to be noticed that these are the variables that may potentially affect the efficiency of the electricity distribution sector, but are mostly beyond the direct control of managers selecting combinations of inputs to provide demanded output. Our set of variables is similar to that in Çelen (2013), Vagliasindi (2012), and Fiorio and Florio (2011), who used environmental variables such as customer structure, customer density/population density, and GDP per capita. In addition, we also include one binary treatment variable to evaluate the impact of legislation regarding reforms and a categorical variable to indicate the structural form of unbundling of the vertically integrated monopoly.

The first environmental variable is the customer structure of the distribution sector. This is measured by the ratio of high-voltage electricity sales to total electricity sales. A similar variable representing the consumer structure was also used, for example, by Kwoka and Pollitt (2010) and Çelen (2013). Kwoka and Pollitt (2010) discussed that residential sales are more costly because of the increased service requirement and higher infrastructure costs, possibly resulting in lower efficiency. Thus, we expect that an increase in the ratio positively influences the efficiency of utilities.

The second environmental variable is the population density of the state where the distribution sector is operating, and is measured by person per square kilometer. The population density is usually considered to have a positive relationship with efficiency. For example, Çelen (2013) also used a variable for customer density with an expectation for its positive influence on efficiency. Fiorio and Florio (2011), too, used population density to reflect regional, time-varying heterogeneity and state-level, macro-economic variable.

The third variable we are including is the real per capita GDP of the state, measured in Rupees (Rs.) Crore. The real GDP per capita represents state-level, time-varying heterogeneity and, also, acts as a control for macro-economic conditions. Fiorio and Florio (2011) used this variable and did not find any impact on the outcome. Similarly, Vagliasindi (2012) also used this variable and expected a positive impact on performance. Given the mixed outcomes for this variable, we *a priori* do not make any expectation for the sign.

Our next two variables are reform-related. Our first reform-related variable is a binary variable representing the enactment of legislation. As discussed in Section 4.2 and Subsection 4.4.2, electricity reforms enactment not only includes intention of unbundling but also many other aspects affecting the regulatory operations, like establishment of Appellate Authority to SERCs, establishment of grid code, and other measures for consumer protection and quality of supply. For every state, for all the years before enactment, this variable "$Legislation$" has value zero, and from the beginning with the year of enactment until the last year of our panel period (i.e., 2012), this variable has value one. In our panel, the states of Bihar and Jharkhand did not pass the legislation until 2012. Hence, they have value zero for this variable throughout the panel period. Table 4-4 shows the summary statistics of environmental variables of the second stage.

[Table 4-4 HERE]

Our second reform-related variable represents unbundling. We have two ways of using this structural reform's variable. First, we use it in binary form. In this first method, we use this variable as having value zero if distribution sector is part of the fully vertically integrated structure (i.e., fully bundled with the generation and transmission sectors, representing structure GTD). If the distribution sector is partially or fully separate, then this variable will have value one. (For example, in case of GD-T, G-TD, or G-T-D structures, this binary variable will have value 1.) In India, we did not have a case of GT-D structure, so this particular structure is not represented in this Chapter. In the second approach, which is a detailed approach for analyzing specific effect related to specific partially or fully unbundled structures, we use a dummy variable to represent each of the structures and conduct the second-stage regression. We use dummies for GTD (vertically integrated), G-TD (only generation sector unbundled), GD-T (generation and distribution together, and only transmission sector unbundled), and G-T-D (all three sectors totally separate). In the case of GTD, where the distribution sector is a part of the fully vertically integrated structure, it is the base case for this second method.

We also use time-invariant heterogeneity represented by "region" in which the state is located. The "region" represents the work culture, management practices, and similar historical, social, cultural and geo-climatic affinity. These regions are indicated in Table 4-2. In our analysis, East region acts as base case for "region" variable. We specifically use this variable to analyze the impact of regional variation in population density, GDP per capita, and consumer structure on the technical efficiency of the states belonging to a particular "region," as compared with "base-case East region."

Lastly, for additional analysis, we use a variable representing the time-invariant size of the distribution sector. The size depends on the amount of energy distributed by the state. The sizes mostly correspond to the state and/or economic activity size. We have Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Uttar Pradesh, and Tamil Nadu, as six "large" states. Assam, Chhattisgarh, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Orissa and Uttarakhand, are seen as our seven "small" states. And, the remaining eight states of Bihar, Delhi, Haryana, Kerala, Madhya Pradesh, Punjab, Rajasthan, and West Bengal, are categorized as "medium" size states. The size is also a time-invariant, observed characteristic of the distribution sector; and "large" size acts as the base case in our analysis.

4.6 Empirical Analysis, Estimation Results and Discussions

This Section presents the estimation results of the first- and second-stage methodology, which is described in Section 4.4. The bootstrap (bias-corrected) efficiency estimates in the first-stage are derived along with the test for the returns-to-scale hypothesis using bootstrapping. We then discuss the external factors, including legislation of reforms and actual unbundling, which have significant effects on the efficiency of the power distribution sector in India by using bias-corrected efficiency estimates as dependent variable in the second-stage regression. We used R statistical software for all the estimations.[27]

4.6.1 First-Stage Bootstrap DEA Estimation and Returns to Scale

Figure 4-2 and Figure 4-3 show the density plots of bias-corrected DEA Efficiency scores for VRS and CRS technologies, respectively, for all state-year observations.

[Figure 4-2 HERE]

[Figure 4-3 HERE]

Next, we test the returns-to-scale assumption following the method proposed by Bogetoft and Otto (2011 Chap.6). As stated in Section 3.4, the test statistic, $\widehat{S} = \sum_{i=1}^{I} \widehat{\theta}_{i,CRS} \,/\, \sum_{i=1}^{I} \widehat{\theta}_{i,VRS} \leq 1$, is calculated. We bootstrap the distribution of $\widehat{S}$ using the approach of Bogetoft and Otto. The 5% critical thresholds of $\widehat{S}$ is then calculated. For example, the 5% threshold implies that 5% of the observations are found above this value. If the test statistic $\widehat{S}$ is less than the critical threshold, we reject the null hypothesis of the CRS assumption. As in Bogetoft and Otto (2011), we also derive the probability of a type-I error, which is the probability of rejecting the null hypothesis if it is true. If the value of the type-I error is sufficiently low, it is less likely to mistakenly reject the hypothesis. Table 4-5 shows the year-wise results of test statistic $\widehat{S}$ and the decision thereon. As is evidenced in Table 4-5, the test statistics are greater than the critical value (5%) for all years, except 1999. The values of the type-I error, range from 5.37% to

[27] Particularly, the R package *Benchmarking*, Bogetoft, Otto (2011), is used for bootstrapping DEA estimates (20,000 repetitions for bootstrapping).

24.77%, which suggest a relatively high possibility of mistakenly rejecting the null hypothesis. Thus, we fail to reject the null hypothesis of the CRS assumption about the underlying technology. Hence, we use input-oriented, bias-corrected efficiency scores estimated on the CRS production technology for all the years. From microeconomic theoretical standpoint, CRS technology means firms are able to change the size over the long term; and, when used in benchmarking/frontier analysis, it also means that firms of different sizes are compared to each other to get the relative efficiency. Hence, it appears logical to think that the CRS efficiency scores may be affected by the size of the firms, which we can check in the second-stage regression.

[Table 4-5 HERE]

4.6.2 Second-stage Regression

This Subsection discusses model fitting for the second-stage regression. First, we estimate the impact of mix of state-year variation in reform legislation and state-year variation in structures of unbundling. We use unbiased CRS-efficiency from the first stage as a dependent variable. We use logarithm of population density and logarithm of real gross domestic product (GDP) per capita of the state as independent environmental variables, in addition to consumer structure of the state.

(1) Unbundling as binary variable

Table 4-6 shows the results of Fixed Effect estimation[28] (with clustered-robust variance: Arellano-type) for model-equation (6) in Subsection 4.4.2. We start our analysis with very simple model estimation in column (A) of Table 4-6. In this estimation, we have an unbundling dummy (a binary variable) and another binary term for legislation variable. We control for time fixed effect. The results show that making the distribution sector a part of unbundled structure

[28] “within” estimation using *plm* package in R.

(either with generation, transmission, or fully stand-alone), irrespective of reform legislation, has a positive impact on efficiency (as compared to when it is part of a fully vertically integrated structure), but is not significantly different from zero. This result points to the likelihood of existence of higher economies of scope in the unbundled structural form of the electricity sector, as compared with a fully vertically integrated structure. In the next result under column (B), we estimate the same model as in (A), but controlling for both year fixed effects and region-year fixed effects (regional impact of some unobserved characteristics in some years). This result shows the same results as those under column (A). Thus, the first two results under columns (A) and (B) clearly indicate the likelihood of presence of economies of scope in the partially or fully unbundled electricity monopoly.

In both of these results, the variable "Legislation" shows highly significant negative impact (-0.00502 at 95% confidence interval in column (A) and -0.00616 at p-value < 0.01 in column (B)) on the technical efficiency of the distribution sector. We interpret that the reforms legislation of the electrical sector in an Indian state has negatively affected the technical efficiency of its distribution sector. The legislation, as discussed earlier, not only includes unbundling, but also other aspects which affect the operations of the electric supply in a state and has a much broader range of policy reform.

[Table 4-6 HERE]

In the next two results under columns (C) and (D), we include another independent variable, specifically logarithm of real gross domestic product (GDP) per capita. In estimation under column (C) we control for year fixed effects only, while in (D) we also control for region-year interaction fixed effects. In the results of both columns, the significance and sign of both unbundling (binary variable) and legislation (binary variable) remain the same as that in results under columns (A) and (B). The real GDP per capita shows a positive impact on efficiency, and is not a significant result in estimation under column (C). However, in estimation (D), after controlling for region-year fixed effects, we find that real GDP per capita now shows a significant result (+0.00795 at 95% confidence interval).

In the next estimation result under column (E), we add the interaction term for region-real GDP per capita variables to the estimation model in (D). These interaction variables represent regional GDP variation across India, and show how they impact efficiency of the distribution sector. Our base case for variable "region" is East region. In column (D) estimation, we controlled for region-year fixed effects. However, we control only for year-fixed effects in the estimation (E) (and not region-year fixed effects) because inclusion of regional interaction with both year and real GDP per capita gave rise to multicollinearity. The results in column (E) indicate consistency in the sign and value of coefficients of "unbundling" dummy, "Legislation" dummy, and logarithm of real GDP per capita, with those in earlier estimations. However, significance is changed for unbundling dummy and, also, for GDP per capita. Now the result for "unbundling" dummy is significant at 90% confidence level, while coefficient for GDP per capita is now not significantly different from zero. We can also see that North-East region and West region show significance for its interaction terms with real GDP per capita. As our base case region is East region, we can interpret this result that, in comparison with the impact of increase in real GDP per capita of the states in the base-case East-region, the north-eastern states have a significantly higher positive impact on the efficiency of the distribution sector. On the other hand, increase in GDP per capita in states belonging to the West-region has less impact on the efficiency of their distribution sector, as compared to the impact of increase in GDP per capita of the states in Eastern-region.

For estimation in column (F), we added another independent variable, specifically logarithm of population density along with its regional interaction terms in the previous model

(E). These variables represent impact of population density (which also acts as a proxy for consumer density) and regional variation on the technical efficiency of the distribution sector, respectively. We now find that the binary dummy variable for unbundling is highly significant (0.00549 at 99% confidence interval). Legislation and real GDP per capita coefficients have consistent sign and significance as compared to those in column (E). The newly added variable population density shows significantly positive impact (0.02643 at p-value <0.05) on the efficiency of the distribution sector. If we look at the region-population density interaction variables, we see that the states belonging to North, North-East, and West regions have a negative impact of increase in their population density on the efficiency of the distribution sector as compared to impact of increase in population density of the states in base-case Eastern region. This may be due to the fact that Eastern region states in India have the highest population densities. However, this result is not significantly different from zero for Southern states. Another important observation in the estimation in column (F) is that the region-interaction terms of real GDP per capita show that sign reversal and significance change have occurred for North region, as compared with the result in estimation (E). Similarly, the sign reversal (but not significance change) has also occurred for South region. The signs and significance of the North-East region-real GDP per capita interactions have not changed. Although for West region, the sign of coefficient is not changed, but the significance is increased from estimation (E). Prima facie, it seems that region-real GDP per capita interaction terms may not be able to clearly capture the impact of regional variation in real GDP per capita on the efficiency of the distribution sector, after inclusion of population density related covariates in the model. Hence, we dropped the region-real capita interaction in estimation (G).

Estimation (G) represents the estimation for fully specified model (5) with dropped region-real GDP per capita interaction terms as compared to estimation (E). However, we did include an additional variable representing consumer structure of the distribution sector. Consumer structure represents the ratio of high voltage sales (in GWhr) to total sales (in GWhr). We have also included its region interaction terms to investigate the impact of inter-regional variation in the consumer structure on the efficiency of the distribution sector. The results show that unbundling dummy has consistent sign when compared to all estimations (A)-(F), but the statistical significance is lost compared to estimations (E)-(F). The variable "Legislation" has consistent sign and significance in all estimations (A)-(F). Similarly, the coefficient for population density in all the estimations of (E), (F), and (G) is consistent in terms of both sign and significance. Real GDP per capita also has same sign and significance as that in (E)-(F) estimations, even after dropping its regional interaction variables. Coefficients of regional interaction terms of population density also have same sign and significance for all the regions to those in estimation (F), except for North-East region where sign reversal has occurred, but not change in level of significance. This may be due to the fact that only one state represents North-East region in our sample. The newly included variable consumer structure does not show any statistical significance, but has a positive sign indicating direction of impact. The regional interaction terms for consumer density shows high significance only for regions South and West. The positive value of coefficient of consumer structure (0.00791) indicates that the higher the high-voltage sales (out of total sales), the higher is the efficiency of the distribution sector, but it is not statistically significantly different from zero.

The above discussions about our estimation results of model (5) in Subsection 4.4.2 (second stage regressions) show that the partially or fully unbundled electricity distribution sector in India is likely to have more technical efficiency, compared to the one under a fully vertically integrated structure, irrespective of structural reforms in the electricity sector. However, we also found empirical evidence that Indian electricity reforms legislation resulted in negative significant impact (based on model (G), -0.00595 at 99% confidence level) on the technical efficiency of the electricity distribution sector. In addition, we discovered that population density has highly significant positive impact on the technical efficiency of the electricity distribution sector; and, our findings are in line with those of Çelen (2013) and Fiorio and Florio (2011). Our findings, with regard to direction of impact of consumer structure, are also in line with those found in existing literature of Kwoka and Pollitt (2010), but the value of coefficient is not significantly different from zero. Real GDP per capita was ascertained to have positive impact on technical efficiency, although it is not significant in the models where we have included population density. This finding of positive impact of GDP per capita is also in line with existing literature of Vagliasindi (2012).

(2) Unbundling in different structures as dummy variables

In the analysis of estimations of model (6) in Subsection 4.4.2, we further investigate impact of different forms of unbundling structures of the electricity sector on the technical efficiency of the distribution sector in India. Table 4-7 shows the results of Fixed Effect estimation of model (6). Our previous analysis of all column-wise estimations and inclusion of variables and their region interaction terms for model (5), is also applicable here for model (6). The structure of estimation results under columns (A)-(G) in Table 4-7, are the same as those in Table 4-6, except that now in Table 4-7, the unbundling variables represent dummy for each structure. For sake of non-repetition, here in the analysis of Table 4-7, we focus only on the analysis of the terms which are different from the previous one. Our “Legislation” variable represents enactment of broader electricity reforms by the policy maker of a state, of which unbundling is one part. However, “unbundling” variable represents the actual implementation (i.e., occurrence of event with certainty about timing of unbundling and type of structure for unbundling adopted by the state, as a part of this legislation).

[Table 4-7 HERE]

In estimation results under columns (A) and (B) of Table 4-7, is a basic model with control for only year fixed effects in (A), and additional control for region-year fixed effects in (B). The results show, in estimation (A), that only GD-T structure has a significant positive impact on the technical efficiency of the distribution sector compared to base case GTD (fully vertically integrated distribution sector), irrespective of reforms legislation. For both G-TD structure (i.e., partially integrated structure of transmission and distribution together) and G-T-D structure, the coefficient is positive, but it is not significantly different from zero. If we control for region-year fixed effects, as in estimation (B), we find that GD-T structure has same sign and significance of the coefficient as in (A). Although now G-TD and G-T-D coefficients have sign reversal compared to (A), they are not statistically significant. Thus, both estimations (A) and (B) empirically indicate the potential for existence of higher economies of scope in the partially unbundled electricity structure GD-T (where generation and distribution are together but transmission is separate), as compared to a fully vertically integrated structure of GTD in India. This result remains consistent in the next estimation results under column (C), (D), and (E), even after inclusion of GDP per capita, with columns (C) and (E) results matching with those in (A), and column (D) matching with (B). In column (D), we have controlled for region-year fixed effects; and, in column (E), we have included region-GDP interaction terms. Real GDP per capita is significant in column (D) results, but not significantly different from zero in columns (C) and (E). The result shown under column (F), after inclusion of population density, gives highest R-squared value of 52.93%. Here, “GD-T” and “Legislation” coefficients have same sign and significance. Additionally, now under column (F), “G-TD” and “G-D-T” are also significant at p-values 0.05 and 0.1, respectively; however, in column (G), both these variables again lose their significance. We also observe that after including consumer structure and its region-interaction terms, under column (G), the R-squared value has decreased as compared to column (F), but “GD-T” and “Legislation” coefficients have maintained their sign and significance. The other coefficients, related to GDP per capita, population density, and consumer structure, in Table 4-7 display same sign and significance as those in Table 4-6.

Summing up results of Table 4-7, we observe that partial unbundling structure “GD-T” has consistent and significant impact on the technical efficiency of the distribution sector, as compared to base-case “GTD” that is vertically integrated. The other partial unbundled structure “G-TD” and fully unbundled structure “G-T-D” do not show consistent positive significant impact on the efficiency across all estimations. In fact, in the models with controlled region-year fixed effects, they even show negative signs. The coefficient of “Legislation” shows significant negative impact, implying that the electricity reforms package of each state has an overall negative effect on the technical efficiency of its electricity distribution sector, irrespective of the structure under which it operates. This result is also consistent with that in Table 4-6, along with those for variables representing GDP per capita, population density, and consumer structure.

The consistent and significant impact of “GD-T” structure on the technical efficiency of the distribution sector can be attributed to the synergetic effect of the generation and distribution sectors being combined. The synergy sources in “GD-T” (distribution and generation together) can be as follows: (a) Scale and scope synergy: firms specialized either solely in serving group of customers, or solely involved in power generation, have higher costs; (b) Operational and financial synergy: distribution segment has unforeseen peak demand or breakdowns. In such contingent operational situations, the combined firm (with distribution and generation together) are likely to have functional and cost advantages over distribution companies that are either under unbundled structure or as a part of a fully vertically integrated structure.

(3) Additional Analysis of Table 4-7 Results

Additional analysis is performed of Table 4-7 in two manners. First, we include a binary dummy variable "Tariff Order," which indicates whether the electricity distribution sector is under the operations of annual "tariff orders" being issued by SERC of a state under rate of return (RoR) regulation regime. We see from Table 4-1 that there exists temporal variation across states for this variable. "Tariff Order", is a binary variable having value unity for all the years beginning with the year of first tariff order, as indicated in Table 4-1, and has value 0 for all years before that. Thus we modify our model in equation (6), in Subsection 4.4.2, for this purpose and write it as:

$$\widetilde{\theta}_{ijt} = \alpha_i + \lambda_t + \sum_3 \gamma_k * Unbundling_{it,k} + \sigma * Tariff\ Order_{it} + \delta * Legislation_{it} + \boldsymbol{z}_{it}^{'}\boldsymbol{\beta} + \epsilon_{it} \quad .... (8)$$

Our new coefficient of interest σ, is identified by state-year variation in the beginning of "rate of return regulation" (RoR) regime for the distribution sector of each state. It gives us impact of another precise policy reform of "establishing SERC and issuing tariff order"; which is an event experienced by the electricity distribution sector of a state with a certainty and is an important part of a broader package of electricity reforms in India.

[Table 4-8 HERE]

The results in Table 4-8 show the estimations for this model equation (8) under columns (A)-(G), with variable inclusion similar to those in Table 4-6 and Table 4-7. We observe that "tariff order" coefficient has a consistently negative sign, but is not significantly different from zero. Thus, indicating that operations of the distribution sector under "rate of return regulation" have a negative impact on technical efficiency, but it is not significant. This result may be attributed to the disadvantage of RoR regulation, as ROR regulation gives more incentive to managers of the distribution sector for over-investment in capital. If managers know for certain that the regulator is going to give them minimum return on the capital, they may tend to reduce labour and over-invest in capital. The result is not significant and can be explained by the fact that India's demand for energy is continuously increasing, both in terms of GWhr and number of consumers (which are the output variables in the first-stage of DEA); hence, every state needed investment in the distribution transformers and distribution lines (which are the inputs in the first-stage of DEA). So, even though tariff orders have built-in incentives over-capitalization, the efficiency could not be significantly negatively impacted due to the demand for output also increasing simultaneously. The other cause for non-significance could be, even though capital may have been increased due to the built-in incentive of tariff order, the labour associated with distribution sector was continuously reduced at the same time; therefore, for the same multiple-output level, the efficiency is negatively affected but not significantly. The other results of Table 4-8, which relates to unbundling structures, legislation, GDP per capita, population density, and consumer structures, shows similar and consistent results with those in Table 4-6 and Table 4-7.

The second manner in which we further analyze the results of Table 4-7 is by estimating model in equation (7) in Subsection 4.4.2. As mentioned earlier, we now investigate the interaction of size of the electrical distribution sector with unbundling structures, as well as with legislation, and their impacts on the technical efficiency of the distribution sector.

[Table 4-9 HERE]

Table 4-9 shows the results for various estimation of equation (7) under columns (A)-(G). These columns are the same as the ones in previous Table 4-6, Table 4-7, and Table 4-8, except for added variable "size." We also have controlled for the fixed effects related to time-invariant observed "size" of the distribution sector. We only analyze the results related to interaction of terms of "size," because the results for other terms are in line with those in all previous tables. Our base-case for "size" is "large-sized" states/ distribution sectors. If we observe "small-size" (Size-S) interaction terms with various unbundling structures, we notice that nearly all the columns show significant positive coefficients for "GD-T" and "G-T-D" structures. Columns (A) and (C) show significance for "G-TD" structure, also.

These results indicate that "small-sized" states have experienced significant positive impact on the technical efficiency of their distribution sectors if they have a partially or fully unbundled electricity sector, as compared to a fully vertically integrated structure. This may indicate that when small states are faced with "decrease in economies of scope" due to partial or full unbundling from the fully vertically integrated structures, they are then some-how able to quickly compensate over and above these "diseconomies" through efficiency increase by "economies of scale" attributed to their "size." Thus, it appears that "small-sized" states are able to move quickly towards "optimal size" of operations of the distribution sector after partial or full unbundling. However, the same cannot be said for the "medium-sized" states, as the concerned variables indicate negative, but statistically insignificant, coefficients for all structures of unbundling across all columns, except columns (E) and (F). Negative sign of the coefficients for "medium-sized" states may mean that partial or full unbundling of the electricity sector for "medium-sized" states causes a decrease in technical efficiency of the distribution sector. This decrease may be attributed to "diseconomies of scope" and, perhaps, to the managers of the distribution sectors of these states if they are unable to compensate this efficiency loss significantly by adjusting scale of operations quickly enough.

Thus, it appears that post-unbundling, the managers of the "medium-sized" states/ distribution sectors move the operations towards "optimal size" sluggishly; hence, their distribution sectors experience negative, but statistically insignificant, impact on its technical efficiency. When we observe the interaction terms of "size" and "legislation," we do not notice statistically significant results for either "medium-sized" or "small-sized" states; but, the signs of the coefficients are positive and negative, respectively. Thus, "true impact of legislation" on the "medium- and small-sized" states, irrespective of the structure of the electricity sector, is not significantly different from zero. But, as we have discussed in the analysis of Table 4-6, Table 4-7 and Table 4-8, the coefficient of "Legislation" is consistent in all columns in Table 4-9 (as also in other Tables) and shows significant negative impact on the technical efficiency of the distribution sector of a state, irrespective of the structure of its electricity sector, and also, irrespective of its size.

4.7 Policy Implications and Conclusions

We started this Chapter with two aims. First, we wanted to find the impact of Indian electricity reforms legislation and various structures of the electricity sector, on the technical efficiency of the electricity distribution sector. Second, we wanted to check the impact of other time-variant and time-invariant factors related to individual states and their electricity sectors, on the technical efficiency. Based on the findings and discussions in Section 4.6, our conclusions, with policy implications, are as follows.

(A) While investigating the first aim, we discussed and deduced in Subsection 4.6.1 that the underlying technology of the Indian electricity distribution sector exhibits constant returns to scale (CRS). In India, the state-level SERCs and federal CERC evaluate the distribution utilities more on the basis of financial performance, and less on operational efficiency parameters, according to Khurana and Banerjee (2014). Hence, we can recommend that central-level CERC, the Government of India, and other national level institutions that monitor the electricity sector in India, adopt input-oriented CRS-DEA techniques to evaluate operational efficiencies of the state distribution sectors.

(B) We found in various estimations of second stage regressions in Subsection 4.6.2, that there exists strong empirical evidence in favor of a partially unbundled structure of generation and distribution sectors, together with a separate transmission sector (i.e., GD-T), having significant positive impact on the technical efficiency of the electricity distribution sector in India. This result is irrespective of the size of the state and, also, irrespective of whether a state has adopted the reforms legislation. It appears that generation and distribution, which have an all-together separate nature of activities, have synergetic effect together on the technical efficiency of the distribution sector under such a structure. At present, GD-T structure exists in Tamil Nadu (a large state), in the medium-sized states of Punjab and West Bengal, and in the small-sized state of Himachal Pradesh. The policy makers of other states should consider combining the distribution sector with the generation sector, giving it operational independence to increase both technical and allocative efficiencies. However, state-specific political-economy related factors (i.e., subsidies, etc.) will have to be taken into consideration before this policy change.

(C) When we analyzed the unbundling structure and size relationship, we found that partially-unbundled structure (GD-T), or fully unbundled structure (G-T-D), for “small states” has a significant positive impact on the technical efficiency of their distribution sector. This result gives alternative policy options for those small states, which still remain either fully vertically integrated (GTD, e.g., Jharkhand) or partially unbundled (G-TD, e.g., Jammu-Kashmir), for modifying the structure of the electricity sector in order to increase the technical efficiency of their distribution sectors.

(D) The impact of state-level electricity reforms legislation as a package is found to be significantly negative on the technical efficiency of the distribution sector of a state. This confirms the observation made by Pargal and Banerjee (2014) about the Indian distribution sector being still inefficient and loss-making, even after two decades of reforms. The reforms package appears to give a signal about policy makers' intention and commitment to the structural reforms, which gives rise to uncertainty about structural form of the electricity sector. This uncertainty affects in two ways. First, perhaps this policy signal and uncertainty results in disincentive to the managers of the distribution sector. Second, the policy signal also results in the revelation of previously hidden distortions in the distribution sector (when it was under vertical monopolies) as Sen and Jamasb (2012) have pointed out. Only when the two events, (a) tariff orders under rate of return regulation and (b) partial or full unbundling of distribution sector, occur do the managers of the distribution sector then have certainty about the unbundled structure to which they belong and about boundary conditions affecting their operations. Only after this certainty, can they act in response to the revealed information and, perhaps, adopt over-capitalization behavior under RoR regime and try to increase technical efficiency.

(E) During the analysis of estimations of model (7) in Subsection 4.6.2, we found strong evidence that size of the distribution sector, which affects "economies of scale," does matter in terms of the "diseconomies of scope" that the distribution sector faces after the partial or full unbundling of vertically integrated electric monopolies. First, we found that partial unbundled structures (GD-T) in India have potential for higher economies of scope, irrespective of size, as compared to fully vertically integrated structures GTD. Second, we found that "medium-sized" states face efficiency loss in their distribution sector through "diseconomies of scope" after partial or full unbundling of their vertical monopolies; and, they are sluggish in raising the efficiency through "economies of scale" by adjusting towards "optimal size." On the other hand, "small-sized" states are quickly able to adjust the scale of operations of their distribution sector towards "optimal size," increasing the efficiency gains more and above the efficiency loss faced due to "diseconomies of scope" after unbundling of vertically integrated electric monopolies. This result has two policy implications. First, managers of the medium-sized distribution sector, CERC, SERCs, and federal/state-level policy makers can now critically analyze and identify the factors which can rapidly cause the shift of operations' scale of distribution sector towards "optimal size" to benefit from the increase in efficiency due to "economies of scale." Second, medium-sized states can now consider horizontally unbundling its distribution sector into "small-sizes" and give them full operational independence for adjusting scale to "optimal size." However, the second policy alternative will also involve cost-benefit analysis for such a horizontal unbundling of the distribution sector. We know from Section 4.5.1 and 4.5.2 that, at present, out of the eight "medium-sized" states of Bihar, Delhi, Haryana, Kerala, Madhya Pradesh, Punjab, Rajasthan, and West Bengal, four of those states (Delhi, Haryana, Madhya Pradesh, and Rajasthan) have already horizontally unbundled their distribution sectors. Hence, policy makers of remaining medium-sized states (Bihar, Kerala, Punjab, and West Bengal) can also evaluate this policy option of "horizontal unbundling" to increase technical efficiency of their distribution sectors through "economies of scale."

(F) As we have seen in our analysis, "medium-sized" states have negative but insignificant impact on the technical efficiency after partial or full unbundling of a vertical monopoly. This means that the vertically integrated structure for "medium-sized" states may, perhaps, be better from the point of view of technical efficiency of the distribution sector. Thus, our analysis is also able to explain the recent observation made in the World Bank publication by Khurana and Banerjee (2014) of why the state of Kerala (a medium-sized state), who has retained the fully vertically integrated structure even after reforms legislation, shows better performance in the distribution sector compared to other states who have vertically and horizontally unbundled their distribution sectors.

(G) We also found that population density, which represents customer density, has a significant positive impact on the technical efficiency of the distribution sector. This result also has policy implications. India has witnessed, in many states, that in urban, densely populated areas, private participation in the distribution of electricity is being adopted as a policy measure. While designing contracts for such private participation, the policy makers and the regulators can recognize the natural advantage of population/customer density on the technical efficiency of the distribution sector, and have suitable cost-benefit provisions for the state-exchequer and the consumers.

Finally, we would also like to highlight areas for future research. Although we could not include "quality of supply" indicators in our analysis, future research can be helpful in this direction. Our research is primarily based on DEA and can be re-examined and/or reconfirmed using a parametric frontier technique like SFA. The program-impact evaluation part of the second-stage regressions can also be re-examined through techniques like propensity scores.

Data Appendix- Chapter 4

(1) *Labour in distribution sector of erstwhile SEBs*: Our main aim was to account for the number of employees that were actually associated with the distribution sector in erstwhile vertically integrated State Electricity Boards (SEBs). To achieve this goal, we collected function wise income and expenditure from the Annual Statement of Accounts available at the headquarters of erstwhile SEBs of the states Rajasthan, Punjab, Bihar, Uttar Pradesh, Madhya Pradesh, Maharashtra, Kerala, Karnataka, Gujarat, Orissa, and West Bengal. For Delhi, we analyzed annual reports of Delhi Electricity Board (DEB) 1998-2001, and for Haryana, we studied Haryana Vidyut Prasar Nigam (HVPN) annual reports 1999-2000, and Planning Commission Government of India (GoI) publications. For Himachal Pradesh, tariff orders from 2001-2012 separately mentioned labor cost for each generation, distribution, and transmission part of the SEB. For Andhra Pradesh, we collected and studied information published by Planning Commission GoI 2001-2002. For Jharkhand, function wise employee cost was collected from human resources department of Jharkhand State Electricity Board (JSEB). For Tamil Nadu, tariff orders for 2001-2012, and tariff orders for wheeling were analyzed. For Uttarakhand, Profit & Loss Account of Uttarakhand Power Corporation Ltd (UPCL) from 2002-2005 was studied.

We noticed that in erstwhile SEBs, in the Annual Statement of Accounts, function wise employee cost is mentioned for six areas (viz., generation, transmission, distribution, stores, construction, and management). It was observed that, on an average, 60% to 80% of employee cost—of the three functional areas of stores, purchase, and management together—is associated with distribution. However, this percentage varies from state to state based on the historical practice. (e.g., Rajasthan- 80%, Punjab- 65% for 1995-2005 and 70% for 2006-2010, Gujarat- 60-70%, Orissa- 60%, Karnataka- 60%, Madhya Pradesh - 60%, West Bengal - 75%, Uttar Pradesh - 100% stores and purchase and 60% management). We calculated employee cost associated with the distribution as follows.

(a) Employee Cost of Distribution Sector in SEB = Employee cost of distribution function + (State-Specific %) of employee cost of (stores, purchase, and management)

(b) Employee associated with distribution sector of SEB (L1) = Total Employees of SEB (L0) *[(a)/Total Employee Cost of SEB]

For Delhi, Haryana, Himachal Pradesh, Kerala, and Tamil Nadu, the employee cost associated with the distribution sector is separately mentioned in the relevant records. We used this cost to estimate L1 for these states. In three newly carved out states, Chhattisgarh, Jharkhand, and Uttarakhand, the employee cost associated with distribution cost is separately accounted for. We used this figure to calculate the number of personnel associated in the distribution sector of the integrated monopoly. For Assam, we used the tariff order 2004-2006, and calculated the percentage of labor involved only in the distribution sector. We applied this percentage for all of the years before unbundling. For Andhra Pradesh, we separately calculated percentage of employee cost for distribution sector for both fully and partially integrated monopoly. For Maharashtra, the actual personnel involved in generation, transmission, and distribution during MSEB regime was found to be 28%, 7%, and 65%, respectively, for period 1995-2004, on the basis of relevant records. For Bihar SEB, we found that, historically, employee cost is divided into four functional areas only (viz., generation, transmission, distribution, and power purchase). Employee cost of power purchase was never associated with the distribution sector, even partially. Hence, we took the employee cost of the distribution functional area to calculate the number of employees associated with the distribution sector only from total Bihar SEB employees. Finally, Jammu and Kashmir required completely separate methods as separate data was kept by the State Electricity Department, and data was destroyed in the floods of 2014. Jammu and Kashmir, since the beginning, had a structure of separate generation and bundled transmission-distribution sector (i.e., G-TD). In our dataset, we have G-TD structure for Andhra Pradesh (1999-2001), Haryana (1999-2004), Uttar Pradesh (2001-2003), Uttarakhand (2002-2004), Orissa (1997-1999), and Karnataka (1999-2002). We found that the percentage of employees actually associated with distribution in these states (from bundled TD sector), to be during these periods, as 80%, 79%, 76%, 86%, 81%, and 81%, respectively. Out of these states, Uttarakhand and Orissa have the same size, in terms of energy sold, as Jammu and Kashmir. Hence, we took an average of Uttarakhand 86% and Orissa 81% (i.e., 83%) as the labor actually associated with the distribution sector out of the bundled TD sector for Jammu and Kashmir, for period 1995-2012.

(2) *Distribution Network Line Length*: This is total network line length in circuit kilometer (Ckt-Km), which is under the control of the distribution sector of a state. In all the states, it is the sum of HT Lines (33kv, 22kv, and 11kv lines) and LT Lines (Below 11kv Lines). In Gujarat, HT Lines of 66kv are also under the distribution sector. The source of this data is the annual administrative reports published by SEBs, DISCOMs, State and Central government agencies, Annual Revenue Requirements (ARRs) filed by the DISCOMs with the SERCs, SERC tariff orders, Year book TEDDY published by TERI, etc.

(3) *Distribution Transformation Capacity*: This represents transformation capacity installed Mega Volt-Ampere (MVA) in the distribution sector in a state below 11kv level. Theoretically, we should take transformation capacity below 33kv level. However, due to the unavailability of data for installed transformation capacity between 11kv and 33kv, we focused on the 11kv, and below, transformation capacity. This transformation capacity is also the one which is directly relevant to customers from the operational and management point of views of the distribution sector.

(4) *Total Number of Consumers*: This represents the actual number of total customers who are given connection of electricity supply. We collected category wise (viz., residential, commercial, industrial, agricultural, and others) consumer numbers and added them to arrive at the total consumer numbers. However, in this Chapter, we have used only total number of consumers as one of the output variables. The source of this data is the same as all of the annual publications mentioned above.

(5) *Total Energy Sold*: We collected consumer category wise energy sold (in Million Units [MU] / Giga Watt Hour [GWhr]) and revenue collected (in Rs. Crore; Rs. 1 Crore = Rs. 10 Million) for each DISCOM in each state. However, for the purpose of this Chapter, we used only total energy sold in MU/GWhr for each distribution sector at state-level. This data is collected from all annual publications mentioned above.

(6) *Area of distribution sector/State*: Area of state (in square Km) matches with the area of SEBs before reforms and with that of corporatized DISCOMs after the reforms. In case of multiple DISCOMs after the reforms, it matches the sum of the areas served by individual DISCOMs. The source of the data is State-level Statistical departments and also the SEBs and DISCOM's annual publications.

(7) *Population of the State*: This represents total population of the state. The source of the data is Census Commissioner Office, Government of India. Census data is available every 10 years for 1991, 2001, and 2011, for each state. We interpolated the state population for the years in between.

(8) *State Gross Domestic Product (SGDP)*: This data is collected from the Planning Commission, GoI. It represents state-level GDP for each state, for each year in Rs. Crore (Rs. 1 Crore = Rs. 100 Lac = Ra. 10 million). We collected SGDP at current price; and then, used consumer price index (CPI) of the state to construct SGDP in real terms.

(9) *Consumer Price Index (CPI)*: We collected consumer price index data from the Labour Bureau of India. It maintains CPI data for many important places in each state. We took an average of all places within a state, in order to arrive at CPI for that state. In collected data, we found that for 1995-2005, the CPI data was based on year 1982; while from the year 2005, it was based on year 2001. We re-constructed CPI on the data collected so that the base year is 1995.

(10) *Aggregate Technical and Commercial Loss (ATC Loss)*: This represents the technical and commercial loss associated with the distribution sector of the state. For the period 1995-1999, this represents only transmission and distribution loss (T & D Loss) of the distribution sectors for most of the SEBs. For Delhi, Haryana, and Orissa, ATC data was available from 1995. Gujarat and Andhra Pradesh's ATC data was available from 1997; before that, T&D Loss is shown. Similarly, for Assam from 1999, for Uttar Pradesh (UP), Punjab and Jammu and Kashmir (JK) from 2000, for Rajasthan and West Bengal from 2001, for Chhattisgarh, Jharkhand, Uttarakhand, Kerala, and Bihar from 2002, for Maharashtra, Himachal Pradesh, and Karnataka from 2003, and finally, for Tamil Nadu, ATC data is available from 2004. For all the previous years for each state, T&D Loss data is available and is used the same. This data is in percentage and reflects amount of energy lost as a result of transmission and distribution (technical) loss, billing, and collecting efficiency. We collected this data from the annual reports of SEBs, CEA, Planning Commission GoI, and SERC tariff orders. This data is most rigorously monitored by DISCOMs, SERCs, and government agencies at the state and central levels. Though we collected this data, we have not used this data in this Chapter.

Tables and Figures: Chapter 4

Table 4-1.State-level Electricity Regulatory Commissions in Electricity Distribution Sector.

Sr. No.	State	Date of Establishment of SERC (Year)	Date of First Tariff Order (Year)	Date of Legislation of Electricity Reforms (Year)
1	Andhra Pradesh	02-04-1999 (2000)	27-05-2000 (2001)	29-10-1998 (1999)
2	Assam	01-08-2001 (2002)	26-03-2003 (2003)	10-12-2004 (2005)
3	Bihar	20-05-2005 (2006)	29-04-2006 (2007)	30-10-2012 (2013)
4	Chhattisgarh	01-07-2004 (2005)	15-06-2005 (2006)	19-12-2008 (2009)
5	Delhi	09-12-1999 (2000)	23-05-2001 (2002)	11-03-2001 (2001)
6	Gujarat	12-11-1998 (1999)	10-10-2000 (2001)	August2003(2004)
7	Haryana	17-08-1998 (1999)	29-11-1999 (2000)	14-08-1998 (1999)
8	Himachal Pradesh	06-01-2001 (2001)	01-11-2001 (2002)	06-10-2010 (2011)
9	Jammu-Kashmir	23-06-2004 (2005)	28-03-2007 (2007)	28-04-2010 (2011)
10	Jharkhand	24-04-2003 (2004)	26-12-2003 (2004)	June 2013 (2014)
11	Karnataka	15-11-1999 (2000)	18-12-2000 (2001)	01-06-1999 (2000)
12	Kerala	29-11-2002 (2003)	31-12-2003 (2004)	25-09-2008 (2009)
13	Madhya Pradesh	29-01-1999 (1999)	26-09-2001 (2002)	20-02-2001 (2001)
14	Maharashtra	05-08-1999 (2000)	05-05-2000 (2001)	04-06-2005 (2006)
15	Orissa	01-08-1996 (1997)	12-03-1997 (1997)	10-01-1996 (1996)
16	Punjab	18-01-2002 (2002)	06-09-2002 (2003)	16-04-2010 (2011)
17	Rajasthan	02-01-2000 (2000)	24-03-2001 (2001)	19-07-2000 (2001)
18	Tamil Nadu	01-07-1999 (2000)	15-03-2003 (2003)	19-10-2010 (2011)
19	Uttar Pradesh	10-09-1998 (1999)	27-07-2000 (2001)	14-01-2000 (2000)
20	Uttarakhand	05-09-2002 (2003)	08-09-2003 (2004)	01-01-2002 (2002)
21	West Bengal	31-03-1999 (1999)	07-12-2001 (2002)	25-01-2007 (2007)

Table 4-2.State-wise post-unbundling structures of the electricity sector in India (1995-2012).

Sr. No.	Region	State	Year of Establishment of Structure of Electricity Sector (Panel Period 1995-2012)			
			GTD	**G-TD**	**G-T-D**	**GD-T**
1	South	Andhra Pradesh	1995-1998	1999-2001	2002-2012	---
2	North-East	Assam	1995-2005	---	2006-2012	---
3	East	Bihar	1995-2012	---	---	---
4	West	Chhattisgarh	1995-2008	---	2009-2012	---
5	North	Delhi	1995-2001	---	2002-2012	---
6	West	Gujarat	1995-2005	---	2006-2012	---
7	North	Haryana	1995-1998	1999-2004	2005-2012	---
8	North	Himachal Pradesh	1995-2010	---	---	2011-2012
9	North	Jammu-Kashmir	---	1995-2012	---	---
10	East	Jharkhand	1995-2012	---	---	---
11	South	Karnataka	1995-1998	1999-2002	2003-2012	---
12	South	Kerala	1995-2012	---	---	---
13	West	Madhya Pradesh	1995-2005	---	2006-2012	---
14	West	Maharashtra	1995-2005	---	2006-2012	---
15	East	Orissa	1995-1996	1997-1999	2000-2012	---
16	North	Punjab	1995-2010	---	---	2011-2012
17	North	Rajasthan	1995-2000	---	2001-2012	---
18	South	Tamil Nadu	1995-2010	---	---	2011-2012
19	North	Uttar Pradesh	1995-2000	2001-2003	2004-2012	---
20	North	Uttarakhand	---	2002-2004	2005-2012	---
21	East	West Bengal	1995-2007	---	---	2008-2012

Table 4-3. Summary statistics for input-output variables of the first-stage DEA.

Type	Variable	N	Mean	Std. Dev.	Unit
Input	No. of Employees (distribution sector)	357	33,762.36	19,386.74	persons
	Distribution Line Length	357	337,238.2	313,723.6	Ckt. Km
	Distribution Transformation Capacity	357	10,949.35	12,423.53	MVA
Output	Number of Consumers	357	6,260.074	5,277.791	1000 persons
	Amount of Energy sold	357	18,109.79	15,089.65	GWhr

Table 4-4. Summary statistics of environmental variables in the second-stage.

Environmental Variable	N	Mean	Std. Dev.	Unit
Log (Real GDP per Capita)	357	4.9635	5.4602	Crore Indian Rupees (INR) [1Crore INR = 10 Million INR]
Log (Population Density)	357	5.9484	1.0324	Person per square km
Consumer Structure	357	0.38027	0.18889	(Ratio)
Tariff Order Dummy (Order by SERC = 1)	357	0.61904	0.48630	-
Legislation Dummy (Legislation of reforms by state = 1)	357	0.47059	0.49983	-

Table 4-5. Test for returns to scale.

H_0: T is CRS; Ha: T is VRS				
Year	**Test Statistic**	**Critical Value (5%)**	**Type-I Error (p-value)**	**Decision**
1995	0.9850513	0.9839686	0.07141702	Fail to reject Null at 5% level but Reject Null at 10% confidence level.
1996	0.9940479	0.9914054	0.1823513	Fail to reject Null Hypothesis.
1997	0.9915719	0.9900503	0.1159653	Fail to reject Null Hypothesis.
1998	0.9911818	0.9898918	0.09671963	Fail to reject Null at 5% level but Reject Null at 10% confidence level.
1999	0.9859849	0.9878514	0.0284159	**Reject Null Hypothesis at 5% level**
2000	0.9889761	0.9880557	0.0787522	Fail to reject Null at 5% level but Reject Null at 10% confidence level.
2001	0.9908345	0.9882061	0.1594083	Fail to reject Null Hypothesis.
2002	0.9918892	0.9897067	0.1507054	Fail to reject Null Hypothesis.
2003	0.9905895	0.9892966	0.0945614	Fail to reject Null at 5% level but Reject Null at 10% confidence level.
2004	0.9906879	0.9887911	0.1247697	Fail to reject Null Hypothesis.
2005	0.9903459	0.9880102	0.1368764	Fail to reject Null Hypothesis.
2006	0.9906171	0.9883292	0.1393032	Fail to reject Null Hypothesis.
2007	0.9921956	0.9883176	0.2477855	Fail to reject Null Hypothesis.
2008	0.9891991	0.9873482	0.1133484	Fail to reject Null Hypothesis.
2009	0.9884177	0.9868525	0.09435042	Fail to reject Null at 5% level but Reject Null at 10% confidence level.
2010	0.9892524	0.9878808	0.09169047	Fail to reject Null at 5% level but Reject Null at 10% confidence level.
2011	0.9883507	0.9875085	0.0735385	Fail to reject Null at 5% level but Reject Null at 10% confidence level.
2012	0.9884647	0.9883022	0.05376802	Fail to reject Null at 5% level but Reject Null at 10% confidence level.

Table 4-6. Results for Unbundling as Dummy (Base Case GTD = 0)- Clustered SE: Arellano

	Dependent variable:						
	Bias-corrected Efficiency						
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
Unbundling	0.00286	0.00191	0.00299	0.00215	0.00414*	0.00549***	0.00303
	(0.00311)	(0.00216)	(0.00307)	(0.00205)	(0.00215)	(0.00202)	(0.00210)
Legislation	−0.00502**	−0.00616***	−0.00510**	−0.00635***	−0.00618***	−0.00601***	−0.00595***
	(0.00208)	(0.00149)	(0.00207)	(0.00144)	(0.00183)	(0.00188)	(0.00188)
Log(Real GDP per Capita)			0.00553	0.00795**	0.00601	0.00144	0.00327
			(0.00513)	(0.00382)	(0.00490)	(0.00328)	(0.00450)
Log(Population Density)						0.02643**	0.03455**
						(0.01320)	(0.01550)
Consumer Structure							0.00791
							(0.00648)
North X Log(Real GDP per Capita)					−0.00195	0.01070*	
					(0.00601)	(0.00575)	
North-East X Log(Real GDP per Capita)					0.04416***	0.08065***	
					(0.00399)	(0.01092)	
South X Log(Real GDP per Capita)					0.00632	−0.00058	
					(0.00418)	(0.00682)	
West X Log(Real GDP per Capita)					−0.01120**	−0.01141***	
					(0.00466)	(0.00422)	
North X Log(Population Density)						−0.06396***	−0.04293**
						(0.01495)	(0.01728)
North-East X Log(Population Density)						−0.15121***	0.10422***
						(0.03484)	(0.01598)
South X Log(Population Density)						0.00155	0.00335
						(0.02951)	(0.01319)
West X Log(Population Density)						−0.03191**	−0.04022**
						(0.01394)	(0.01598)
North X Consumer Structure							−0.00851
							(0.01050)
North-East X Consumer Structure							−0.00448
							(0.01171)
South X Consumer Structure							−0.01686***
							(0.00626)
West X Consumer Structure							−0.03083**
							(0.01229)
State Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Region X Year Fixed Effects	NO	YES	NO	YES	NO	NO	NO
Observations	357	357	357	357	357	357	357
R^2	0.31164	0.58887	0.32216	0.60610	0.47265	0.52510	0.47534
Adjusted R^2	0.27672	0.41072	0.28516	0.42104	0.41307	0.45156	0.40744
F Statistic	7.55333***	4.09935***	7.50930***	4.33638***	11.65140***	11.70547***	9.24130***

Note: *p<0.1; **p<0.05; ***p<0.01

Table 4-7. Results for Various Structures of Unbundling (Base Case GTD) and Legislation-Clustered SE: Arellano

	Dependent variable:						
	Bias-corrected Efficiency						
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
Unbundling (GD-T)	0.00607**	0.00628**	0.00591**	0.00604**	0.00728***	0.00754***	0.00667**
	(0.00259)	(0.00262)	(0.00255)	(0.00259)	(0.00244)	(0.00280)	(0.00279)
Unbundling (G-TD)	0.00182	−0.00133	0.00204	−0.00073	0.00321	0.00521**	0.00130
	(0.00279)	(0.00215)	(0.00278)	(0.00204)	(0.00236)	(0.00251)	(0.00240)
Unbundling (G-T-D)	0.00151	−0.00166	0.00173	−0.00108	0.00231	0.00407*	0.00151
	(0.00396)	(0.00283)	(0.00390)	(0.00254)	(0.00277)	(0.00232)	(0.00251)
Legislation	−0.00466**	−0.00540***	−0.00477**	−0.00565***	−0.00595***	−0.00596***	−0.00556***
	(0.00199)	(0.00117)	(0.00198)	(0.00115)	(0.00178)	(0.00183)	(0.00180)
Log(Real GDP per Capita)			0.00517	0.00707**	0.00523	0.00116	0.00291
			(0.00503)	(0.00345)	(0.00482)	(0.00321)	(0.00420)
Log(Population Density)						0.02548*	0.02995**
						(0.01305)	(0.01463)
Consumer Structure							0.00570
							(0.00650)
North X Log(Real GDP per Capita)					−0.00119	0.01049*	
					(0.00626)	(0.00576)	
North-East X Log(Real GDP per Capita)					0.04681***	0.08400***	
					(0.00513)	(0.01175)	
South X Log(Real GDP per Capita)					0.00739	−0.00197	
					(0.00448)	(0.00559)	
West X Log(Real GDP per Capita)					−0.00853	−0.00938**	
					(0.00566)	(0.00475)	
North X Log(Population Density)						−0.06026***	−0.03853**
						(0.01487)	(0.01691)
North-East X Log(Population Density)						−0.15418***	0.11009***
						(0.03459)	(0.01581)
South X Log(Population Density)						0.01104	0.00710
						(0.02305)	(0.01219)
West X Log(Population Density)						−0.03151**	−0.03633**
						(0.01368)	(0.01465)
North X Consumer Structure							−0.00754
							(0.01031)
North-East X Consumer Structure							0.00017
							(0.01347)
South X Consumer Structure							−0.01063
							(0.01009)
West X Consumer Structure							−0.03119**
							(0.01235)
State Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Region X Year Fixed Effects	NO	YES	NO	YES	NO	NO	NO
Observations	357	357	357	357	357	357	357
R^2	0.31985	0.60701	0.32900	0.62043	0.48134	0.52926	0.48496
Adjusted R^2	0.28222	0.41997	0.28937	0.42752	0.41797	0.45217	0.41297
F Statistic	7.05406***	4.28660***	6.99808***	4.46784***	11.06496***	11.06189***	8.94527***

Note: *p<0.1; **p<0.05; ***p<0.01

Table 4-8. Results for Various Structures of Unbundling (Base Case GTD), Tariff Order and Legislation- Clustered SE: Arellano

	Dependent variable:						
	Bias-corrected Efficiency						
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
Unbundling (GD-T)	0.00607**	0.00627***	0.00592**	0.00605***	0.00733***	0.00766***	0.00675***
	(0.00244)	(0.00228)	(0.00243)	(0.00225)	(0.00221)	(0.00225)	(0.00239)
Unbundling (G-TD)	0.00201	−0.00149	0.00231	−0.00057	0.00373	0.00607**	0.00193
	(0.00252)	(0.00274)	(0.00251)	(0.00271)	(0.00236)	(0.00241)	(0.00247)
Unbundling (G-T-D)	0.00156	−0.00172	0.00181	−0.00102	0.00249	0.00443**	0.00173
	(0.00197)	(0.00219)	(0.00196)	(0.00217)	(0.00190)	(0.00199)	(0.00200)
Tariff Order	−0.00053	0.00033	−0.00074	−0.00032	−0.00130	−0.00200	−0.00164
	(0.00167)	(0.00157)	(0.00166)	(0.00156)	(0.00148)	(0.00145)	(0.00157)
Legislation	−0.00467***	−0.00537***	−0.00478***	−0.00568***	−0.00599***	−0.00610***	−0.00568***
	(0.00175)	(0.00168)	(0.00174)	(0.00166)	(0.00156)	(0.00161)	(0.00170)
Log(Real GDP per Capita)			0.00524**	0.00714***	0.00532**	0.00113	0.00299
			(0.00251)	(0.00243)	(0.00236)	(0.00243)	(0.00227)
Log(Population Density)						0.02859**	0.03101***
						(0.01178)	(0.01141)
Consumer Structure							0.00323
							(0.00936)
North X Log(Ral GDp per Capita)					−0.00104	0.01110***	
					(0.00301)	(0.00376)	
North-East X Log(Ral GDP per Capita)					0.04691***	0.08405***	
					(0.00610)	(0.02292)	
South X Log(Ral GDP per Capita)					0.00762**	−0.00162	
					(0.00359)	(0.00932)	
West X Log(Ral GDP per Capita)					−0.00862**	−0.00909**	
					(0.00404)	(0.00449)	
North X Log(Population Density)						−0.06309***	−0.03939***
						(0.01345)	(0.01123)
North-East X Log(Population Density)						−0.15536**	0.10571**
						(0.07269)	(0.04751)
South X Log(Population Density)						0.00986	0.00710
						(0.03537)	(0.01464)
West X Log(Population Density)						−0.03405***	−0.03706***
						(0.01251)	(0.01207)
North X Consumer Structure							−0.00505
							(0.00979)
North-East X Consumer Structure							0.00633
							(0.04399)
South X Consumer Structure							−0.00847
							(0.01273)
West X Consumer Structure							−0.02966*
							(0.01758)
State Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Region X Year Fixed Effects	NO	YES	NO	YES	NO	NO	NO
Observations	357	357	357	357	357	357	357
R^2	0.32007	0.60708	0.32943	0.62050	0.48264	0.53221	0.48683
Adjusted R^2	0.28152	0.41832	0.28883	0.42583	0.41774	0.45320	0.41319
F Statistic	6.71879***	4.22307***	6.68547***	4.40196***	10.67628***	10.80833***	8.71037***
Note:							*p<0.1; **p<0.05; ***p<0.01

Table 4-9. Results for Various Structures of Unbundling, Legislation, and Size- Clustered SE: Arellano

	Dependent variable:						
	Bias-corrected Efficiency						
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
Unbundling (GD-T)	0.00422**	0.00486**	0.00429***	0.00484**	0.00591***	0.00977***	0.00904***
	(0.00169)	(0.00198)	(0.00154)	(0.00192)	(0.00176)	(0.00232)	(0.00265)
Unbundling (G-TD)	−0.00003	−0.00024	−0.00009	0.00002	0.00338	0.00744**	0.00624**
	(0.00240)	(0.00184)	(0.00243)	(0.00188)	(0.00237)	(0.00326)	(0.00290)
Unbundling (G-T-D)	−0.00426	−0.00476*	−0.00384	−0.00370	−0.00084	0.00376	0.00046
	(0.00296)	(0.00265)	(0.00265)	(0.00228)	(0.00278)	(0.00269)	(0.00251)
Legislation	−0.00457***	−0.00611***	−0.00481***	−0.00650***	−0.00684***	−0.00758***	−0.00800***
	(0.00155)	(0.00131)	(0.00157)	(0.00133)	(0.00111)	(0.00177)	(0.00146)
Log(Real GDP per Capita)			0.00347	0.00566**	0.00378	0.00063	0.00147
			(0.00391)	(0.00220)	(0.00384)	(0.00282)	(0.00336)
Log(Population Density)						0.02628*	0.02617*
						(0.01338)	(0.01538)
Consumer Structure							0.00061
							(0.00615)
Unbundling (GD-T) X Size-M	−0.00282	−0.00337	−0.00307	−0.00356	−0.00275	−0.00960**	−0.00829*
	(0.00468)	(0.00258)	(0.00452)	(0.00273)	(0.00389)	(0.00410)	(0.00463)
Unbundling (G-TD) X Size-M	−0.00204	−0.00271	−0.00167	−0.00187	−0.00414	−0.00762*	−0.00839*
	(0.00451)	(0.00289)	(0.00449)	(0.00299)	(0.00354)	(0.00398)	(0.00448)
Unbundling (G-T-D) X Size-M	0.00165	0.00232	0.00133	0.00163	0.00152	−0.00305	−0.00131
	(0.00432)	(0.00230)	(0.00407)	(0.00199)	(0.00330)	(0.00408)	(0.00348)
Unbundling (GD-T) X Size-S	0.01075***	0.01394***	0.01041***	0.01351***	0.01086***	0.00500	0.00814***
	(0.00199)	(0.00279)	(0.00183)	(0.00268)	(0.00257)	(0.00341)	(0.00294)
Unbundling (G-TD) X Size-S	0.01370***	0.00182	0.01416***	0.00191	0.00529	0.00121	0.00050
	(0.00449)	(0.00296)	(0.00460)	(0.00317)	(0.00332)	(0.00495)	(0.00534)
Unbundling (G-T-D) X Size-S	0.02603***	0.01162***	0.02554***	0.01007***	0.01402***	0.00734	0.01254**
	(0.00631)	(0.00355)	(0.00631)	(0.00312)	(0.00404)	(0.00480)	(0.00634)
Legislation X Size-M	0.00229	0.00343	0.00248	0.00357	0.00352	0.00556*	0.00581
	(0.00492)	(0.00240)	(0.00481)	(0.00242)	(0.00357)	(0.00335)	(0.00364)
Legislation X Size-S	−0.00389**	−0.00219	−0.00372**	−0.00189	−0.00183	−0.00068	0.00039
	(0.00185)	(0.00174)	(0.00179)	(0.00168)	(0.00214)	(0.00287)	(0.00244)
North X Log(Real GDP per Capita)					−0.00222	0.00859	
					(0.00612)	(0.00595)	
North-East X Log(Real GDP per Capita)					0.03387***	0.07253***	
					(0.00500)	(0.01191)	
South X Log(Real GDP per Capita)					0.00941**	−0.00054	
					(0.00432)	(0.00494)	
West X Log(Real GDP per Capita)					−0.00465	−0.00746	
					(0.00559)	(0.00515)	
North X Log(Population Density)						−0.05794***	−0.03726**
						(0.01712)	(0.01873)
North-East X Log(Population Density)						−0.14315***	0.08859***
						(0.03260)	(0.02501)
South X Log(Population Density)						0.00639	0.00994
						(0.02222)	(0.01622)
West X Log(Population Density)						−0.03511**	−0.03339**
						(0.01449)	(0.01585)
North X Consumer Structure							−0.00311
							(0.01035)
North-East X Consumer Structure							−0.01779
							(0.01709)
South X Consumer Structure							0.00805
							(0.01090)
West X Consumer Structure							−0.01682
							(0.01463)
State Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES
Region X Year Fixed Effects	NO	YES	NO	YES	NO	NO	NO
Observations	357	357	357	357	357	357	357
R^2	0.44729	0.63685	0.45126	0.64506	0.51264	0.55043	0.52718
Adjusted R^2	0.38465	0.42635	0.38680	0.43004	0.43366	0.45792	0.43710
F Statistic	8.56722***	4.32093***	8.38816***	4.41365***	9.34308***	9.32387***	8.25087***

Note: *p<0.1; **p<0.05; ***p<0.01

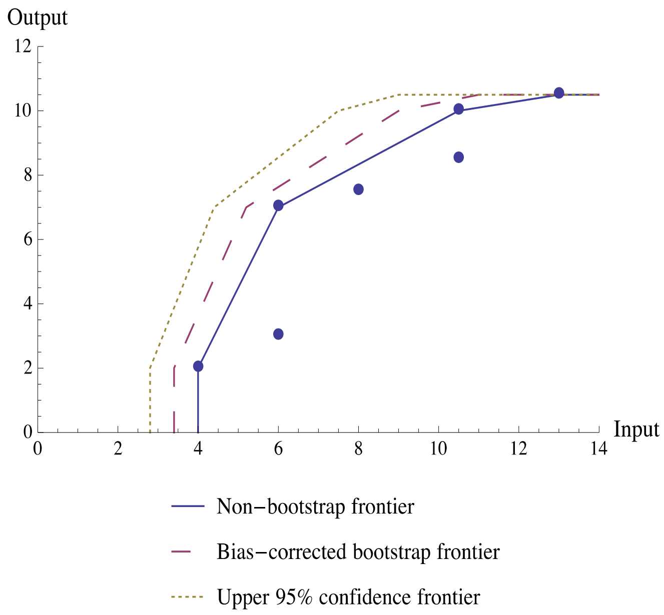

Figure 4-1. Example of bias-corrected bootstrap frontier.

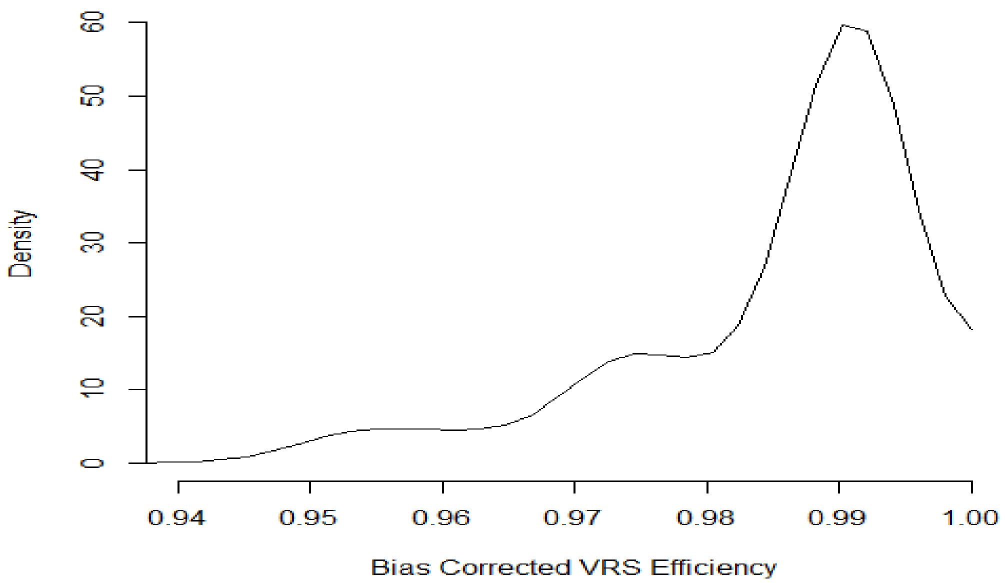

Figure 4-2.Density plot of bias-corrected VRS efficiency scores for all state-year observations.

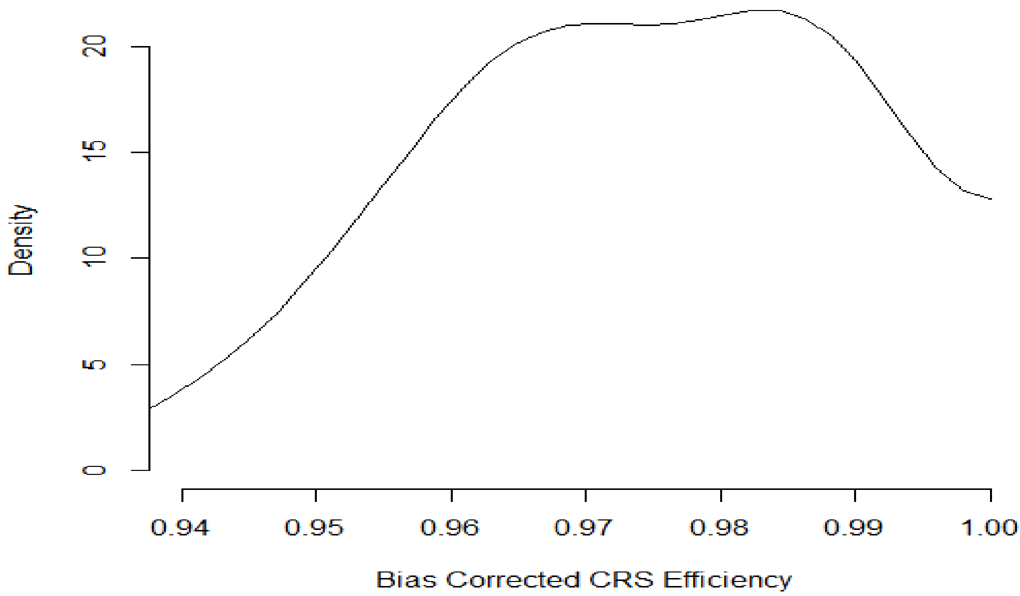

Figure 4-3.Density plot for bias-corrected CRS efficiency scores for all state-year observations.

5 Policy Implication and Conclusions

In this research, we investigated the efficiency of the Indian electrical distribution utilities/sectors, focusing on panel data. We used two-stage DEA with first-stage being an estimation of bias-corrected DEA efficiency scores using bootstrap technique. In the second-stage, these scores were then regressed on various external-environmental variables. In Chapter 3, we considered ownership, population density, consumer structure, and subsidy as environmental variables; while in Chapter 4, we considered reforms legislation, tariff order, various unbundling structures, real GDP per capita, and size, in addition to population density and consumer structure.

We found consistently in Chapter 3 and Chapter 4 that population density, which also acts as proxy for consumer density, has a significant positive impact on the technical efficiency of the electricity distribution sector. With regard to consumer structure, our results show that it has positive significant impact on technical efficiency when considering individual distribution utilities at micro-level in Chapter 3. But, the same significance is lost when considering distribution sectors at macro-level, although the positive sign remains the same. The results for these two variables are in line with existing literature.

We also found statistically significant and positive effects of public ownership of distribution utilities on their technical efficiency in India. This advantage to the Public sector may be due to size of the distribution utilities that we consider in our sample of three states in Chapter 3. Future research in this direction should be worthwhile, as the results on the effects of ownership structure have been mixed in the productivity/ efficiency literature. The reason for the found result of efficiency advantage to public utilities is an open research question. The complex socio-eco-political setup and history may be a key factor for such an advantage. This empirical evidence from India may be tested against the results of other developing countries, with similar backgrounds, before crystallizing the conclusions in favor of public sector. However, we also found that public utilities are less efficient in high population density areas than their private counterparts. This result has significant policy implications, as many states across India are slowly taking initiative of private participation in the distribution of electricity supply in urban populated areas.

We also found in Chapter 3 that subsidy is negatively related to technical efficiency and may lead to inefficient management of utilities. Although, subsidy support to a particular class or group of consumers in a state/prefecture depends on state-specific political-economy factors, the administration of this subsidy to utilities is overseen by the policy makers and regulators. If use of subsidy towards technical efficiency improving measures, such as bringing new technology, is ensured, then this negative impact of subsidy can be mitigated to a certain extent.

Findings of Chapter 4 are broader, both in nature and perspective, from the view of policy implications. First, we found that real gross domestic product of a state has positive, but statistically insignificant, impact on the technical efficiency. This result is in conformity with the finding in existing literature. Next, we found that the Indian electricity reforms legislation has significant and negative impact on the technical efficiency of the distribution sector. This result confirmed the observations made in the recent publication of World Bank. However, our results show that only transmission unbundling (i.e., keeping generation and distribution sectors together) has a consistent and significant impact on the technical efficiency of the distribution sector as compared to a fully vertically integrated structure. This result has major policy implications, not only for various states in India, but also for other developing countries which are considering the electricity reforms.

Our next result further showed that size of distribution sector does matter when unbundling of vertically integrated electric monopolies are considered. Indian experience shows that “small-sized” states experience significant positive impact on the technical efficiency of their distribution sector after unbundling, irrespective of whether this unbundling is partial or full. On the other hand, “medium-sized” Indian states experience negative, but insignificant, impact on their distribution sector’s efficiency. This result also has many policy implications, as discussed in Chapter 4, for various Indian states. These policy implications range from further structural change for the distribution sector, either in the form of partial vertical integration with the generation sector, horizontal bundling of the distribution sector, or horizontal unbundling of the distribution sector, depending on the size of the sector and cost-gains associated with such a policy decision. This result should also be beneficial to many developing countries, or least developed countries, who are evaluating alternative policy options for structural reforms of the electricity sector. Our findings also partially shed light on the observation made in a recent World Bank publication about some Indian states performing well, even without unbundling after reforms legislation.

This thesis can be extended for future work in at least three ways. First, this study can be replicated using a parametric method for efficiency analysis, like Stochastic Frontier Analysis. Second, the first-stage DEA results can be used for replicating second-stage regressions, using propensity score methodology. Third, the same methodology can be used for other developing countries for cross-country comparison among them.

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