The Impact of Competition and Corporate Structure on Productive Efficiency: The Case of the U.S. Electric Utility Industry, 1990-2004

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Abstract

In this study, we present empirical evidence on the productive efficiency of electric utilities in the United States over the period, 1990-2004. This is a period marked by major attempts to introduce competition in the industry with the expectation that it will lead firms to improve their productive efficiency and ultimately to lower consumer prices. The actual experience has been surprising, since electricity prices have either fallen little or even risen sharply in some states. Relying on recent advances in the estimation of productive efficiency, we find that firms in jurisdictions that adopted competitive mechanisms have lower productive efficiency compared to firms in jurisdictions where rate-of-return regulation was retained. Furthermore, we provide evidence that firms in states that adopted competition have experienced decreases in productive efficiency, while firms in states with traditional regulation saw increases in efficiency over time. Since the introduction of deregulation has brought greater discretion to managers, we also examine the impact of various organizational choices on productive efficiency. Interestingly, the separation of the generation function from other functions, a hallmark of the effort to deregulate the industry, is associated with an adverse impact on productive efficiency. These findings question the claim that competition necessarily fosters higher productive efficiency. Alternatively, true competition may have been circumvented.

Key words: Productive efficiency, corporate structure, electricity industry, restructuring
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1. Introduction

The primary purpose of this paper is to empirically examine the impact of deregulation and organizational choices firms on the productive efficiency of the electric utility industry in the United States during the period, 1990-2004. The enactment of the Energy Policy Act of 1992 opened the wholesale power market to competition, bringing many independent power producers (IPPs) into the wholesale markets. Competition was further encouraged by the Federal Energy Regulatory Commission (FERC) through the issuance of its Order 888 in 1996 and Order 2000 in 1999 which approved free access to the transmission network for all participants. These orders also fostered competitive mechanisms in wholesale power markets by promoting the wide-scale development of transmission networks under the regional transmission organizations (RTOs). Indeed, by 2000 nearly half of the states in the U.S. and the District of Columbia had passed legislation adopting competition as envisaged by the FERC (Rose and Meeusen, 2005). The introduction of such substantial deregulation constitutes a natural experiment to study the impact of competition on the productive efficiency of electric utilities.

At the heart of the liberalization effort of the electric power industry is simply a notion that the productivity of the industry will benefit from the introduction of competition. Indeed, Nickell (1996) argues that this is not necessarily so, and that there is in fact little empirical evidence in support of such a claim. He goes on, however, to himself report some supporting evidence based on his large sample of U.K. firms whose productivity improvements are associated with increases in the number of rival firms. In another study, Mizutani and Uranishi (2003) find that exposure to competition from private parcel delivery reportedly had a beneficial effect on the productivity of the Post Office in Japan. In some cases, exposure to market forces can be enhanced in other ways besides an increase in the number of rivals. For example, firms that were previously shielded by government ownership typically face deregulation after privatization. According to Saal and Parker (2001), and Berg, Lin, and Tsaplin (2005), privatization too produced improvements in productivity in their samples of water and sewage companies. Deregulation *per se* contributed to productivity gains for Spanish banks in Kumbhakar and

Lozano-Vivas (2005). Though limited, this literature conforms with and motivates our basic hypothesis that the introduction of greater competition in the electric utility industry should be beneficial to productivity.

Experience from the deregulation of telecommunications, airlines, and trucking industries in the United States seems to support the claim that competition fosters productivity gains. For example, a decade after the introduction of competition, long-distance telephone providers were profitable even after lowering rates by half (*New York Times*, October 15, 2006, p.1). Similarly, it was expected that electric utilities, in response to competitive pressures, will reduce waste, adopt improved technologies, and even restructure to obtain greater productive efficiencies, consequently turing consumers by sharing these gains. The deregulation of the electricity industry did not begin till the early nineties, which was much later than that of other regulated industries. However, it was expected that the economic impact of the restructuring on consumers would be larger than that of the other industries. Under the former rate-of-return regulatory regime, electric utilities had incentives to over-capitalize (the Averch-Johnson Effect), and had recovery procedures that severely limited efforts at cost reduction. Consequently, *a priori* we would hypothesize that (1) electric utilities in jurisdictions that adopted competitive mechanisms will exhibit greater productive efficiencies compared to those in jurisdictions that retained rate-of-return regulation, and (2) electric utilities in jurisdictions that adopted competitive measures will exhibit greater productive efficiencies compared with the same utilities when they were under rate-of-return regulation. Finally, (3) we also examine how the organizational structure of utilities affects their productive efficiency, since part of the effort to deregulate the industry consists of separating out the generation function into a free market setting.

Evidence on the productive efficiencies of electric utilities -- those in deregulated jurisdictions versus those still in rate-of-return regulation, and before and after the introduction of competition—may help explain what has actually transpired in terms of electricity prices. Surprisingly, electricity prices have not decreased to the degree that was expected and may even have increased to levels higher than those before deregulation in some states, even though achieving efficient lower electricity prices was a primary purpose of the deregulation (*New York Times*, October 15, 2006). In addition, rate increases have been higher in states that deregulated compared with those that kept the old regulatory framework (*Washington Post*, March 12, 2006, p.1). With deregulation, managerial discretion has increased, making it possible to undertake various forms of restructuring including venturing into diversified businesses far from the core electricity business. In fact, while there had been little merger activity prior to 1995, many mergers have been filed after deregulation (Joskow, 2000). That trend reflects a major policy change for the Securities and Exchange Commission (SEC), which historically oversaw strict restrictions in merger activities among electric utilities under the 1935 Public Utilities Holding Company Act. In itself, the evidence is not in as to whether greater managerial discretion, with its consequent freedom to restructure and undertake new businesses, has translated into productivity gains and consequently larger benefits to shareholders or consumers. For example, though frequently they are argued to be complements with economies of scale and potential operating synergies, there is little evidence that even the combination of gas and electric businesses has turned out to be valuable[1]. Therefore, in this paper we also examine how various managerial choices regarding organizational structure of firms have affected productive efficiency. In particular, we study the impact of the diversification policy on utility businesses, decision of purchase versus generation of power, and wholesale activity on productive efficiency. The managerial decision to purchase versus generate is influenced by the vertical structure of firms.

Our work is related to a number of strands in the literature. Work on vertical integration/separation has investigated whether vertical separation of functions causes economic loss or not. Most of the previous studies conducted after Kaserman and Mayo (1994) indicate that vertical economies could be lost through vertical separation of electric power utilities. Therefore, vertical separation that accompanies competition, as in generation being separated out after deregulation, should be evaluated in terms of such potential loss of economies (Michaels, 2006). Yet, these studies do not

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[1] Wilson (2002) briefly refers to the similarity of electricity and gas from a perspective of homogeneity of commodities and their transmission systems.

explicitly examine impacts of deregulation and corporate structure (e.g., separation) on productive efficiency. Indeed, Fabrizio, Rose and Wolfram (2004) point out that, "While many of the costs of electricity restructuring have been intensively studied, relatively little effort has been devoted to quantifying any ex post operating efficiency gains of restructuring." Using data on electric power generation plants, Fabrizio, Rose and Wolfram (2004) estimate input demand equations with unobserved inefficiency factors that were caused by a deviation from the cost-minimizing behavior of firms, and indicated that generation efficiency gains were achieved through electricity restructuring. Furthermore, they identified the principal source of efficiency gains to be reduced labor and non-fuel expenses. Their results support previous studies for other industries such as the telecommunication and the airline industries[2], which indicate that increased competition is associated with productivity gains. Several studies on wholesale power markets, such as Borenstein, Bushnell and Wolak (2002), focused on the effects of market power but did not consider productive efficiency nor did they examine the impact of the firm's activities in the wholesale market on its productivity.

In another strand of the literature pursued by financial economists, diversification is a subject of considerable research. Following Lang and Stulz (1994) and Berger and Ofek (1995), a number of studies have documented that diversified firms sell at a discount relative to the sum of the values of their stand-alone component segments. The implication is that diversification destroys corporate value. Offering an alternative explanation, Campa and Kedia (2002) argue that diversification discounts can be explained by selection bias instead, whereby poorly performing firms elect to undertake diversification. Moreover, Villalonga (2004) presents evidence that suggests that, instead of a diversification discount, there may be a diversification premium if we use better establishment-level data to avoid certain biases in the commonly used segment data. Pertinent to this study, Schoar (2002) approaches diversification by examining its real effects. She estimates the total factor productivities (TFP) for diversified firms and stand-alone firms, and reports that diversified firms were more

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[2] For example, Olley and Pakes (1996) and Ng and Seabright (2001) revealed productivity gains that were associated with deregulation for telecommunications and airlines industries, respectively.

productive than stand-alone firms. Thus, the literature on the impact of diversification on the firm is mixed.

Although most studies do not include firms from the utility industry, a few researchers have examined the impact of diversification on electric utilities. Sing (1987) examines potential synergy effects arising out of natural monopoly, but concludes against economies of scope between electricity and gas supply businesses. Fraquelli, Piacenza and Vannoni (2004) investigate economies of scope for multi-utility companies and find cost advantages for relatively small firms, but no similar evidence for large-scale utilities. Jandik and Makhija (2005) examine diversification premium/discount for the U.S. electric utilities, and contrary to the discounts reported for the other diversifying firms in the finance literature, they find that diversification actually created value because it led to more efficient investment for firms during the period under regulation. However, this advantage disappeared after deregulation.

In this study, we estimate productive efficiency with a Stochastic Frontier Analysis model with Bayesian inference using Markov chain Monte Carlo (MCMC) computational methods (described methodology section) and find that:

(1) Electric utilities in jurisdictions that have adopted competitive measures have significantly lower productive efficiency in comparison with utilities in jurisdictions that have retained rate-of-return regulation.

(2) The evidence is mixed as to whether competition has translated into improved productive efficiencies, based on changes before and after deregulation. Firms in states that adopted deregulation show a trend of decreasing productive efficiency, while those in states under traditional regulation show increases in efficiency.

(3) In terms of organizational structure of the firm, we find that separating generation from other functions has adversely affected productive efficiency. We also find that the extent of joint operation of electricity and gas businesses and the level of wholesale activity of firms do not appear to significantly affect productive efficiency.

In sum, our findings suggest that competition has not translated into benefits in terms of productive efficiency for electric utilities. In turn if productive efficiency is a proxy for profit margin, these results offer one explanation for the recently observed higher, rather than the promised lower, electricity prices in some states.

The rest of the paper is organized as follows. In the next section, we briefly describe a methodology for the measurement of the productive efficiency. Section 3 explains data. Section 4 describes an empirical model and its estimation. Section 5 presents results and findings. The last section (6) concludes.

2. Methodology

The productive efficiency of a firm's activities is an important concept for corporate management because there is a common belief that a higher efficiency is a necessary condition for a firm to survive. Yet, the productivity literature ignored the efficiency component for many years. The traditional approaches to the measurement of the Total Factor Productivity (TFP) generally assume that the observed output is the "best" practice and that all firms are fully efficient. These methods include the standard growth accounting model associated with Solow (1957), and its corresponding nonparametric index number approaches such as the Törnqvist index[3]. The reason for these approaches may lie in the difficulties researchers have in empirically determining the potential that a production unit could achieve. For the sake of such potential, Koopmans (1951) provided a formal definition of technical efficiency: A producer is technically efficient if, and only if, it is impossible to produce more of any output without producing less of some other output or using more of some input. Debreu (1951) and Shephard (1953) introduced a measure of technical efficiency as a radial distance of a producer from a frontier, and Farrell (1957) was the first to empirically measure this productive efficiency. Therefore, if we do not take account of the possible deviation from efficient production for each firm, the resulting measures of

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[3] The Törnqvist index is shown to be exact for the translog technology and superlative since the translog functional form is flexible (Diewert, 1976).

productivity may be biased. Since Farrell's (1957) work, a number of researchers have contributed to the study of productive efficiency.

Technical efficiency, or productive efficiency as it is more commonly called, refers to the ability to avoid waste by producing as much output as input usage allows, or by using as little input as output production allows[4]. Several alternative methods have been proposed for the measurement of productive efficiency, which can be classified into parametric and non-parametric frameworks. Fried, Lovell, and Schmidt (1993) include various such types of methods and their applications to measure efficiency. The common essence of these methods is that productive efficiency is evaluated by the degree of deviation or distance of the observed data from the efficient frontier, which represents the "best practice" production technology and serves as a norm for efficiency evaluation.

This study employs a parametric estimation of the efficient frontier that is referred to as stochastic frontier analysis (SFA). The SFA was initiated by Aigner, Lovell, and Schmidt (1977), Meeusen and van den Broeck (1977), and Battese and Corra (1977). Kumbhakar and Lovell (2000) describe the basic theory of the SFA as well as a wide range of advanced SFA techniques and application models. From a technical viewpoint, the frontier function investigates the "best practice technology" of production with a two-part error term, i.e., normal error term and inefficiency. The SFA model could be specified in the production function, the cost function, or the distance function. Which function we use depends on the purpose of each study and on the availability of data. In this study, we estimate the production function using SFA, based on which we measure the degree of inefficiency that varies not only with each firm but also with each period without imposing the same trajectory for all firms.

The production function with two-part error term can be formulated as follows:

$$Y_{nt} = f\left(R_{nt}\right) + v_{nt} - u_{nt}, \qquad (1.)$$

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[4] In a precise sense, productive efficiency can be defined as consisting of two components; the technical or physical efficiency and allocative or price efficiency. The allocative efficiency component refers to the ability to combine inputs and outputs in optimal proportions in light of prevailing prices. This study does not examine the allocative efficiency.

where Y_{nt} is an output for firm n ($n = 1,...,N$) in period t ($t = 1,...,T$) and R_{nt} is a vector of explanatory variables for firm n ($n = 1,...,N$) in period t ($t = 1,...,T$). v_{nt} is a random error term and u_{nt} is a non-negative random variable assumed to represent productive inefficiency in production. Specifically, the degree of productive efficiency (PE) is measured by $PE_{nt} = \exp(-u_{nt})$, which ranges from larger than 0 to smaller than or equal to 1, which indicates the best practice among firms. Thus, the more the PE approaches 1, the more efficient is the firm.

To estimate the model, we assume (a) the random error term v_{nt} is independently and identically distributed as $N\left(0,\sigma_v^2\right)$, (b) the inefficiency variable u_{nt} is independently (but not identically) distributed as a non-negative truncation of the general normal distribution of the form, $N^+\left(w'_{nt}\eta,\sigma_u^2\right)$, where w_{nt} is a vector of variables for firm n ($n = 1,...,N$) in period t ($t = 1,...,T$)[5] that are firm- and/or period-specific characteristics that affect the mean inefficiency of firms, and η is a vector of constant and slope parameters to be estimated, and (c) v_{nt} and u_{nt} are distributed independently of each other, and of the regressors R_{nt}.

Note that R_{nt} consists of X_{nt}, Z_{nt} and t. X_{nt} is a vector of input variables for firm n ($n = 1,...,N$) in period t ($t = 1,...,T$), Z_{nt} is a vector of control variables for firm n ($n = 1,...,N$) in period t ($t = 1,...,T$) and t is a time trend variable to capture technological changes. It is often discussed that the firm-specific heterogeneity should be controlled in estimating the efficiency of firms. Since our dataset consists of regulated utilities, it is important to control several factors in the production function because operation and management of electric power firms are restricted to some extent by state and federal regulation, demand-side conditions, as well as combination of generation technologies. In other words, their production is inevitably influenced by several constraints that are out of control for them. For example, given the historical service area in which they are the monopolistic supplier with an obligation of to supply electricity, they do not have complete discretion to enhance their customers

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[5] These assumptions are consistent with $u_{it} = w'_{nt}\eta + v_{it}$ where the random variable, v_{it}, is defined by the truncation of the normal distribution with zero mean and variance, σ^2, such that the point of truncation is $-w'_{nt}\eta$ (Battese and Coelli, 1995).

outside their service area or it may be practically difficult to sell their product only to some specific groups of customers within their service area to achieve higher profit margins.

3. Data

3.1. Variables for estimating production frontier

Our data consists of investor-owned electric power utilities (IOUs) in the U.S. during the period from 1990 to 2004. To avoid excessive dispersion in size for our sample data (and avoid incomparable small firms), we screened out firms using a minimum threshold value of the total retail sales of 100,000 Mega Watt hours (MWhs). Therefore, firms that sell electricity less than or equal to 100,000 MWh to final customers are not included in our dataset. This procedure not only restricts the size of firms to above the threshold, but also restricts the dataset to include utility firms that are involved in the retail sales business along with other functions. In other words, firms that are only involved in generation and wholesale business are excluded from our dataset. After deleting firms that have missing data required in our estimation of productive efficiency, our final annual-based balanced panel dataset is comprised of 104 firms in total that cover the period from 1990 to 2004.

Approximately one third of the firms included in our sample provide gas and other utility services as well as core electricity supply services. This mix of services within our sample firms provides us with an opportunity to measure the effects of diversification on productive efficiency. However, it simultaneously leads to a problem with respect to how we should define the output in this study. This problem is apparent if we consider firms that operate gas and other businesses, because it is not appropriate to simply measure the output by volume of electricity sold to customers because that does not reflect any outputs produced by gas and other businesses. To circumvent this problem, we define the output by total operating revenues measured in financial terms. Yet, it is desirable in theory that the production function be defined with quantity data, because in a usual definition, productive efficiency is measured as real output produced per unit of real total input employed such as labor, capital, and materials. Consequently, we use financial data that is converted into real terms by a deflator (as being a proxy for quantity data). Specifically, we define revenue as output, but after it is converted into real terms using state-level discount rates as deflators.

As in the case of output, we use financial data on O&M cost that is converted into real terms as proxy for the consolidated quantity of inputs that include labor, fuel and purchased power[6]. These three terms are the usual components of inputs for producing electricity[7]. Fuel and the purchased power are the equivalent of materials in production theory. Meanwhile, capital is measured by capital stock that is constructed by applying a commonly used procedure of perpetual inventory method (See Appendix 1 for construction of the capital stock data). These definitions of inputs are consistent with the perspective of production economics, in which we often distinguish between two types of inputs in the short run; (1) variable part of inputs that are represented by O&M cost in this study, and (2) quasi-fixed inputs measured by the capital stock. Note that all the data used in this study are restricted to those associated with the utility business of the firm, electricity, gas and others, and do not include non-utility businesses. Consequently, in our study a combination of the electricity and gas businesses is the basis of our diversification measure.

In addition to the basic variables employed in formulating the production function described above, this study utilizes the following control variables:

(1) Residential Customer Ratio (RCR): Ratio of residential customers to total customers, which is calculated by electricity sold to residential customers divided by the electricity sold to all customers, represented in percentage terms.

(2) Environmental Protection Ratio (EPR): The firm's expenses for environmental protection, which are

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[6] As a deflator for the revenue and O&M cost, this study uses the ratio of the nominal (current price) and the real (2000 constant price) gross state product that is provided by the U.S. Department of Commerce, Bureau of Economic Analysis. The advantage of using this deflator is that we can obtain different time-series deflators for each state.

[7] Although the reason for this definition for the consolidated input is primarily due to the fact that our dataset includes firms other than electricity-specialized firms, it is also related to the fact that constructing quantity data for fuel use often requires cumbersome calculations based on additional technical assumptions for each plant. This is because each firm uses several types of fuel that differ in source, such as gas, coal and even nuclear. In addition, a thermal efficiency is different for each plant. A promising way to obtain a consistent quantity of fuel is to calculate a heat-equivalent quantity of the fuel measured in calories for each plant and then added up to the firm-level.

required for utility firms to follow based on state legislation that stipulates standards for environmental protection. Specifically, the ratio is calculated as the cost expensed for environmental protection facilities divided by the book value of the total utility plant, represented in percentage terms.

(3) Nuclear Ratio (NCR): Ratio of nuclear generation to total generation, which is calculated by electricity generated by nuclear technology divided by the total volume of electricity generated by all types of generation technology in use, such as that based on fossil-fuel and others, represented in percentage terms. This factor is expected to affect firm's production through the impact of selection and the combination of different types of generation technologies, which cannot be instantaneously adjusted once the specific technology is installed. For example, the firm cannot readily change in the short-run from nuclear generation once it has invested in this technology. Therefore, this study uses this variable as a control variable.

It is important to note that a different combination of generation technology influences total productive efficiency at least through two paths: influences stemming from, one, different fuel costs, and, two, capacity factors of plants. The latter effect is expected to be measured by productive efficiency. While the former effect is partly controlled for by the nuclear ratio, the effect may be more directly controlled for by introducing a fuel cost variable. In addition, since our output variable is defined by total revenue in real terms, it may be influenced by the beginning of retail competition (that was generally accompanied by rate reductions for customers). To avoid these factors' influence on productive efficiency, we estimated the model using other control variables than the nuclear ratio, such as a fuel cost variable and a dummy variable for each state (with a variable that takes a value of 1 after the states introduced retail competition and 0 otherwise).

3.2. Variables for estimating mean efficiency

We assume that four variables affect the productive efficiency of firms from a perspective of the deregulation of the industry and its organizational restructuring. All of them with the exception of the state dummy variable, directly or indirectly, depend on management's decision-making as to which businesses they should be actively involved in to achieve optimal operations. Specifically, those variables are described as follows:

(1) Electricity Ratio (ER): Ratio of electricity business to firm's total operations, which is calculated by electricity revenue divided by utility total revenue, represented in percentage terms. This ratio indicates the degree of business concentration in the electricity business. Most firms that jointly operate electricity and gas businesses have inherited such joint structures since their foundation. However, this ratio is expected to change as a result of deregulation of the industry. Hence, to capture such dynamic changes in business concentration that occurred during the period covered in this study, we also use this ratio for each year.

(2) Purchased Power Ratio (PPR): Ratio of purchased power to total sales, which is calculated by the amount of purchased power divided by the amount of total sales of electricity in Mega Watt hours (MWhs), represented in percentage terms. If this ratio is large, the management of the firm has decided to buy electricity from other firms through power exchange markets and long- and/or short-term over the counter trading without generating electricity by its own plants. Hence, if the ratio is large, it implies that the firm has adopted a more separated form of vertical structure between generation and other functions.

(3) Wholesale Ratio (WSR): Ratio of wholesale power to total sales, which is calculated by the amount of wholesale power divided by the amount of total sales in MWhs, represented in percentage terms. This ratio reflects a management strategy with respect to the firm's degree of activity in the wholesale business. If this ratio is large, it implies that the firm is actively involved in the wholesale power business by providing relatively large amounts of electricity to other firms. Consequently, as a corporate structure, it becomes an organization which is more focused on the generation and trading functions.

In addition to the organizational variables described above, this study also considers two other direct effects of deregulation on productive efficiency. One of them is a cross-sectional effect that may be different for firms in states under traditional regulation and for those that adopted deregulation. Another interesting effect is a temporal effect of deregulation, particularly the effect since the issuance of FERC Orders 888 and 889. As a result of these Orders, there has been greater restructuring and retail competition. These effects are captured through the following variables:

(4) State-level Deregulation Dummy (DRST): A state dummy variable based on the regulatory policy for each state (traditional regulation versus adoption of deregulation): Our classification is derived from the "Map of State Electricity Markets" in Potter (NRRI), December 2005 version, which indicates the status of deregulation for each state. It takes the value one if the state belongs to "traditionally regulated states (27 states)" or "states with formally reversed, suspended, or delayed restructuring (4 states)", and zero if the state belongs to "states with full restructuring (17 states)" or "states with limited restructuring (3 states)".

(5) Progress of Deregulation Dummy (DRP): In 1996, FERC Orders 888 and 889 were issued. By this issuance, open access to the transmission network was assured to all market participants. Some states immediately began to implement restructuring of the electricity industry by promoting competition in retail markets. In 1996, California and Rhode Island passed landmark legislation to restructure their electric power industry and gave their consumers the right to choose among alternative suppliers for providing electricity. To examine the impact of deregulation since 1996 on productive efficiency, this dummy variable takes the value one over the period from 1996 to 2004, and zero otherwise.

All data for the production frontier are obtained from FERC Form 1 and those compiled by Platts. Deflators are obtained from Bureau of Economic Analysis of U.S. Department of Commerce. The list of firms in our sample, their states and status of deregulation of each state, and descriptive statistics of the data are indicated in Tables 1 and 2, respectively.

Insert Tables 1 and 2 here.

The average output increased by 68% from $1.296 b. in 1990 to $2.172 b. in 2004. Meanwhile input 1 (fuel, labor and purchased power in O&M cost) increased by 100% from $0.785 b. in 1990 to $1.566 b. in 2004, and input 2 (capital stock) increased by 68% from $44.426 m. in 1990 to $74.778 m. in 2004. The growth rates of output and input 2 are almost parallel, but the growth rate of input 1 is larger than that of output, implying that decreasing efficiency is expected. Environmental protection ratio, nuclear ratio, and electricity ratio decreased by 40%, 49% and 3%, respectively, for each, while purchased power ratio and wholesale ratio increased by 91% and 39% over the period, respectively.

4. Empirical model and estimation

We specify the production function by the translog functional form, which makes a production function flexible using a second-order approximation to an unknown function. The translog function allows representation of various substitution possibilities without restrictive assumptions about the shape of the technological relationship.

Let us consider production with I inputs ($i, j = 1,\dots,I$). The general formulation of the production function under the variable returns-to-scale (RTS) production technology can be mathematically expressed as follows:

$$\begin{aligned} ln Y_{nt} &= \beta_0 + \sum_{i=1}^{I} \beta_i \, ln\, x_{int} + \frac{1}{2}\sum_{i=1}^{I}\sum_{j=1}^{I} \gamma_{ij} \, ln\, x_{int} \, ln\, x_{jnt} \\ &\quad + \theta_t t + \theta_{tt} t^2 + \sum_{i=1}^{I} \delta_{it} \, ln\, x_{int} t \qquad (2.) \\ &\quad + v_{nt} - u_{nt}, \end{aligned}$$

where Y_{nt} is an output for firm *n* ($n = 1,\dots,N$) in period *t* ($t = 1,\dots,T$), x_{int} is an *i*th ($i = 1,\dots,I$) input for firm *n* ($n = 1,\dots,N$) in period *t* ($t = 1,\dots,T$) and *t* is a time trend. Distributional assumptions on the error term, v_{nt} and u_{nt}, have been defined in the previous section. Conditions for symmetry of the cross-effects are imposed by restricting the parameters as $\gamma_{ij} = \gamma_{ji}, \forall i, j$ and $\delta_{it} = \delta_{ti}, \forall i, t$.

Including the control variables and omitting subscripts of variables for conciseness of description, our empirical model of the production function is specified as follows:

$$\begin{aligned}\ln Y = {} & \beta_0 + \beta_v \ln x_v + \beta_f \ln x_f + \frac{1}{2}\beta_{vv}(\ln x_v)^2 + \beta_{vf} \ln x_v \ln x_f \\ & + \frac{1}{2}\beta_{ff}(\ln x_f)^2 + \beta_t t + \frac{1}{2}\beta_{tt} t + \beta_{vt} \ln x_v t + \beta_{ft} \ln x_f t \\ & + \beta_{h1} \cdot RCR + \beta_{h2} \cdot EPR + \beta_{h3} \cdot NCR \\ & + v_{nt} - u_{nt},\end{aligned} \tag{3.}$$

where Y is an output measured by the revenue converted to real terms, x_v is a consolidated input consisting of fuel, labor and purchased power that is measured by the O&M costs in real terms, and x_f is a capital input measured by the capital stock. The mean of the inefficiency (μ_{it}) is specified as follows:

$$\mu_{nt} = \eta_0 + \eta_1 \cdot ER + \eta_2 \cdot PPR + \eta_3 \cdot WSR + \eta_4 \cdot DRST + \eta_5 \cdot DRP + \eta_6 \cdot DRST \cdot DRP\,, \tag{4.}$$

where the productive efficiency for each firm and period is measured by $PE_{nt} = \exp(-\mu_{nt})$.

To deal with the statistical complexity of the SFA model, we apply Bayesian inference using Markov chain Monte Carlo (MCMC) computational methods for the estimation of the production frontier of electric power utilities (See Koop (2003) for Bayesian methods and applied econometric models and computational techniques). Consequently, we use the Bayesian SFA that was first proposed by van den Broeck, Koop, Osiewalski and Steel (1994) and enhanced with respect to the numerical technique by Koop, Osiewalski and Steel (1994) and Koop, Steel and Osiewalski (1995) using Gibbs sampler[8]. This study uses WinBUGS, which is a powerful and a flexible tool to implement MCMC

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[8] A recent example that applied the Bayesian SFA to the electric power utilities is Kleit and Terrell (2001). Using data on generation plants fueled by natural gas, they estimated a degree of potential cost reduction through increased efficiency. Other recent Bayesian papers using MCMC techniques to estimate SFA models include Fernández, Koop and Steel (2000), Kurkalova and Carriquiry (2002), Tsionas (2002), and Kumbhakar and Tsionas (2005). Kumbhakar and Tsionas (2005) measure

techniques, to perform inferences for the Bayesian SFA model using MCMC techniques (Griffin and Steel, 2006). The prior specification is based on Section 6 of van den Broeck *et al.* (1994). They specify the model for the case with no covariates in the efficiency distribution while our model incorporates covariate information in the efficiency distribution by modeling the underlying mean of a truncated normal inefficiency distribution. Yet the basic structure of their prior specification is applicable to our model and WinBUGS implements the estimation of such an extended model as described in Griffin and Steel (2006), footnote 11 and the Appendix.

The Bayesian approach requires choosing a prior parameter. For example, β are assigned priors of a multivariate normal as $\beta \sim N(0,\Sigma)$. A gamma distribution with shape parameter a_0 and mean a_0/b_0 is assigned to the usual error term as $\sigma_v^{-2} \sim Ga(a_0,b_0)$. We set parameters a_0 and b_0 of this prior distribution at 0.001. In addition, the specification uses a particular right-skewed skew-normal prior for the standardized underlying mean $\varphi_0 = \eta_0\sigma_u^{-1}$ and an independent gamma prior for σ_u^{-2}. In particular, it is written as:

$$p(\varphi_0,\sigma_u^{-2}) = 2\Phi(\varphi_0)\phi(\varphi_0)\, f_G(\sigma_u^{-2}|5,5\log^2 r^*), \qquad (5.)$$

where $\Phi(\cdot)$ and $\phi(\cdot)$ denote the cdf and pdf of a standard normal, and $f_G(\cdot|a,b)$ denotes the pdf of a gamma distribution of $Ga(a,b)$. The prior median efficiency is equal to r^* that we set at 0.75 in this study. In the more general case with multiple (*P*) covariates in mean inefficiency, which is employed in this study, the above specification (Eq. (5)) is extended by adopting vague priors centered over zero for the other element of the vector $\varphi = \eta\sigma_u^{-1}$ as:

$$\varphi_p \sim N(0,10),\ p = 1,\ldots,P, \qquad (6.)$$

after normalizing any continuous covariates to have zero mean and unitary standard deviation (Griffin and Steel, 2006).

All data pertaining to the production function are normalized by their means for the estimation.

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allocative efficiency as well as technical efficiency using the translog cost system.

5. Results

The results of the estimation of Eqs. (3) and (4) are described in Table 3, which shows means of posterior distributions and *t*-ratios of parameters. We estimated four models that are slightly different from each other with respect to deregulation dummies that are used as explanatory variables of mean inefficiency. Model 1 is a base-case estimation that only includes the cross-sectional impact of deregulation (DRST). Meanwhile, Models 2, 3 and 4 include temporal effect of deregulation without and with the cross-sectional impact and a cross-term. We generated three chains using the Gibbs sampler. Each chain was run with a burn-in of 5,000 iterations with 20,000 retained draws. All three chains converged to almost the same values so that it is credibly considered that the convergence to posterior distribution was achieved.

Insert Tables 3 here.

Technology parameters of the production function are all statistically significant except for that of the time trend (*t*) variable. The parameters mildly indicate economies of scale at the sample average. Variance parameters related to normal error term and inefficiency term, σ_v^2 and σ_u^2, are both significant so that the model provides reasonable estimates of productive efficiencies. All parameters of time trend and its related variables are estimated to reveal negative signs with the exception of the cross-term parameter with x_v, which implies that there is no technological progress with respect to this production function. Parameters of all control variables are statistically significant. Specifically, the parameter of the residential customer ratio (RCR) is positive, which indicates that production increases when the firms supply more electricity to residential customers. This ratio can be interpreted as a proxy for the economies of density over the service area of electricity as discussed in Roberts (1986), because the ratio of residential customers is higher in cities with higher population density[9]. Therefore, the positive sign of this parameter reveals the effect of economies of density on total production. The parameter of the environmental protection variable is positive, which indicates that production increases when the firms spend more on environmental protection facilities. This variable works as a proxy for the firm's proactive employment of new generation technology such as highly efficient combined-cycle gas turbines. Introduction of these technologies may be the result of relatively strict environmental standards, which paradoxically lead firms to achieve more production using the same level of inputs compared to firms with a lower environmental protection ratio. The sign of the parameter of the nuclear power ratio is also positive, which indicates that a higher ratio of nuclear generation contributes to a higher level of productivity. This is consistent with our expectations because nuclear generation is used to provide base-load power, which constantly operates under higher capacity usage ratio if it is soundly managed, compared to other generation technologies for non-base-load power. There are frequently political issues surrounding nuclear generation, and the importance of nuclear generation varies depending on the natural resources available to a nation. Our findings show that nuclear generation positively influences productivity, an element that is overlooked in these debates.

In addition to Table 3, we present results of estimations with other control variables in Appendix 2 (as discussed in Section 3.1). The results indicate that parameters of these other control variables, fuel cost variable (FUELC) and the introduction of retail competition (RComp), are not significant except for RComp in Model 2A. Thus, we do not employ these additional control variables further. Note also that the estimated parameters for the other variables are almost the same as those described in Table 3, so that the results serve as a robustness check.

Meanwhile, variables related to organizational choices that are expected to affect productive efficiency reveal mixed results. First, electricity ratio shows a negative impact on productive efficiency, but it is not statistically significant. This implies that a joint operation of electricity and gas are neutral

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[9] Alternatively we used an industrial customer ratio instead of the residential customer ratio. The estimated parameter of the industrial customer ratio was negative and significant.

to the productive efficiency of utility firms. Consequently, there is no evidence of the economic synergy of the joint operation of electricity and gas supply businesses. Second, purchased power ratio (PPR) has a positive and statistically significant parameter. Hence, productive efficiency decreases when firms buy more electricity from outside firms instead of generating it by themselves. This negative effect of PPR may be partly caused by an inefficient or non-competitive pricing of electricity in the wholesale power markets due to a possible exertion of market power. This ratio can be interpreted as a proxy for the degree of vertical disintegration of the organization. Therefore, the result implies that vertical separation is not good strategy for improving productive efficiency, at least under the current situation of wholesale power markets. This result is consistent with results of most previous studies that investigate economies of vertical integration for electric power utilities. Third, the parameter of wholesale power ratio (WSR) is positive such that the degree of efficiency decreases when the ratio increases. However, the parameter is not significant with the exception of Model 2. Therefore, this ratio is also mostly neutral in its impact on productive efficiency.

Further, regarding cross-sectional impacts on productive efficiency through deregulation (DRST), all the results of Model 1, Model 3 and Model 4 indicate that firms in states under traditional regulation are more efficient compared to those exposed to deregulation. Since one of the motives for deregulation was to improve efficiency and reduce the costs of electric utilities, this result is disappointing. The difference in the efficiencies between the two groups of firms is also confirmed by a statistical test in terms of means of productive efficiencies for each group. The second and the third columns of Table 4 show means and other descriptive statistics for productive efficiency as well as the statistical tests for the null hypothesis that both groups belong to the same population with respect to productive efficiency. The productive efficiency is calculated based on Model 4, because the DIC (Spiegelhalter et al., 2002) model comparison criterion indicates support for Model 4 over the other models. The null hypothesis of equal means for those two groups of firms is rejected by Welch’s *t*-test with a 1% significance level (*t* ratio: 7.34).

Insert Table 4 here.

Meanwhile, the temporal effects of deregulation (DRP) are not clear from the estimated parameters because they are not statistically significant (Model 2, Model 3 and Model 4). In addition, the cross-term of DRST with DRP --which captures temporal effects of efficiency only for the regulated group of firms-- is not significant as well. Such an ambiguous result regarding the temporal impact of deregulation on productive efficiency can be also confirmed by an ex post statistical test as described in the fourth and the fifth columns of Table 4. The null hypothesis that both groups of productive efficiencies, before and after 1996, belong to the same population, cannot be rejected (*t* ratio: 1.05). Figure 1 shows temporal developments of the mean, the maximum, and minimum productive efficiencies over the period from 1990 to 2004. Compared to changes in the highest and the lowest levels, it is confirmed that the level of the mean is relatively stable.

In order to further examine the above results, we conducted statistical tests of the temporal impacts of deregulation on productive efficiency with respect to each group of firms in the regulated and deregulated states. The null hypotheses of these tests are that productive efficiencies of firms before and after 1996 belong to the same population. The results of tests for these two groups are indicated in the sixth and the seventh columns (the regulated group), and the eighth and the ninth columns (the deregulated group) in Table 4, respectively. Regarding the regulated group, the productive efficiency increases over time with statistical significance (*t*-ratio: -2.32), while the level of efficiency decreases over time for the deregulated group (*t*-ratio: 2.96). These findings are also surprising since deregulation was expected to lead to improvements in productive efficiency.

Figure 2 describes central tendencies of efficiencies for the full sample, regulated group of firms, and our deregulated group of firms. Consistent with the statistical tests in Table 4, the average efficiency for the regulated group is higher than the overall average for all years except for 1994, while that for the deregulated group is lower than the overall average. Both of them (regulated and deregulated) decrease toward 1994 to become almost the same level, after which they turn to an increasing trend toward 1997. Then after 1997, the average efficiency for the regulated group slightly increases till 2004, while the average efficiency for the deregulated group deteriorates till 2004. These trends of average efficiencies for each group of firms offset each other, which explains the relatively flat average plot in Figure 1.

The results of this study are not consistent with those of most previous studies that find evidence of efficiency improvement as a result of competition for other industries as well as for electricity plants. Furthermore, our results are different from our ex ante hypotheses described in Section 1. This may suggest that the effects of competition may not be apparent for the electric power utilities in the short-term. While plant efficiency can be achieved in the relatively short-term, because it is purely technical matter, productive efficiency of a firm's total operation is not so straightforward. The productive efficiency of a firm entails many factors that influence operations, various costs, organizational choices, and the performance of wholesale power markets, etc. Indeed, as indicated in our estimation results, described in Table 3, higher PPR is associated with lower productive efficiency, which implies that higher exposure to wholesale markets results in lower efficiency. This result is also seen in the data because the average PPR for the regulated group of firms is 38.4% over the period, while that for the deregulated group of firms is 53.9%. In other words, productive efficiency of electric power utilities more and more depends on the performance of power markets under vertical separation.

6. Conclusion

In this study, we empirically examine the productive efficiencies of large electric utilities in the United States over the period, 1990 to 2004. This period constitutes a natural experiment to study the impact of competition on productive efficiency because it is marked by major deregulatory actions by the Federal Energy Regulatory Commissions, state-level easing of regulation, and even the softening of SEC oversight over M & A activity. While the deregulation was motivated by the improvements in productive efficiency and subsequent lower consumer prices that competition will engender, actual electric prices have in fact either fallen too little or have even risen in some states. This is contrary to the prior experience in other industries, such as telecommunications, airlines and trucking. It is, however, consistent with our findings. We find that the productive efficiency of firms in deregulated jurisdictions is in fact lower than that for electric utilities in jurisdictions with rate-of-return regulation. Furthermore, the evidence is mixed regarding changes in productive efficiency before and after the introduction of competition. These results both lead us to questions about the relationship between competition and productive efficiency, and to whether true competition may in fact have been circumvented. Thus, the experience of the electricity industry after the deregulation is different from that of the other formerly regulated industries in the U.S. An interesting research question is what has led to such different outcomes in these industries.

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Table 1: List of electric utility firms

No.	Company Name	State	DRST
1	Alabama Power Co.	AL	1
2	Alaska Electric Light & Power Co.	AK	1
3	Aquila Inc.	MO	1
4	Arizona Public Service Co.	AZ	0
5	Atlantic City Electric Co.	NJ	0
6	Avista Corp.	WA	1
7	Baltimore Gas & Electric Co.	MD	0
8	Black Hills Power Inc.	SD	1
9	Boston Edison Co.	MA	0
10	Cambridge Electric Light Co.	MA	0
11	Carolina Power & Light Co.	NC	1
12	Central Hudson Gas & Electric Corp.	NY	0
13	Central Illinois Light Co.	IL	0
14	Central Illinois Public Services Co.	IL	0
15	Central Vermont Public Service Corp.	VT	1
16	Cincinnati Gas & Electric Co.	OH	0
17	Cleco Power LLC	LA	1
18	Commonwealth Edison Co.	IL	0
19	Commonwealth Electric Co.	MA	0
20	Connecticut Light & Power Co.	CT	0
21	Consolidated Edison Co. Of New York Inc.	NY	0
22	Consumers Energy Co.	MI	0
23	Dayton Power & Light Co.	OH	0
24	Delmarva Power & Light Co.	DE	0
25	Detroit Edison Co.	MI	0
26	Duke Power Co.	NC	1
27	Duquesne Light Co.	PA	0
28	Edison Sault Electric Co.	MI	0
29	El Paso Electric Co.	TX	0
30	Electric Energy, Inc.	IL	0
31	Empire District Electric Co.	MO	1
32	Entergy Arkansas, Inc.	AR	1
33	Entergy Gulf States, Inc.	TX	0
34	Entergy Louisiana, Inc.	LA	1
35	Entergy Mississippi, Inc.	MS	1
36	Entergy New Orleans, Inc.	LA	1
37	Fitchburg Gas & Electric Light Co.	MA	0
38	Florida Power & Light Co.	FL	1
39	Florida Power Corp.	FL	1
40	Georgia Power Co.	GA	1
41	Granite State Electric Co.	NH	0
42	Green Mountain Power Corp.	VT	1
43	Gulf Power Co.	FL	1
44	Hawaiian Electric Co., Inc.	HI	1
45	Idaho Power Co.	ID	1
46	Illinois Power Co.	IL	0
47	Indianapolis Power & Light Co.	IN	1
48	Jersey Central Power & Light Co.	OH	0
49	Kansas City Power & Light Co.	MO	1
50	Kentucky Utilities Co.	KY	1
51	KGE, A Westar Energy Co.	KS	1
52	Kingsport Power Co.	TN	1
53	Louisville Gas & Electric Co.	KY	1
54	Madison Gas & Electric Co.	WI	1
55	Massachusetts Electric Co.	MA	0
56	Maui Electric Co., Ltd.	HI	1
57	Metropolitan Edison Co.	OH	0
58	Minnesota Power, Inc.	MN	1
59	Mississippi Power Co.	MS	1
60	Monongahela Power Co.	PA	0
61	Mount Carmel Public Utility Co.	IL	0
62	Nevada Power Co.	NV	0
63	New York State Electric & Gas Corp.	NY	0
64	Niagara Mohawk, a National Grid Co.	NY	0
65	Northern Indiana Public Service Co.	IN	1
66	Northern States Power Co.	MN	1
67	Northern States Power Co. Wisconsin	WI	1
68	Ohio Edison Co.	OH	0
69	Oklahoma Gas & Electric Co. (OG&E)	OK	1
70	Orange & Rockland Utilities, Inc.	NY	0
71	Otter Tail Power Co.	MN	1
72	Pacific Gas and Electric Co.	CA	1
73	PacifiCorp	OR	0
74	Pennsylvania Electric Co.	PA	0
75	Portland General Electric Co.	OR	0
76	Potomac Edison Co.	MD	0
77	Potomac Electric Power Co.	DC	0
78	PPL Electric Utilities Corp.	PA	0
79	PSC of Colorado	CO	1
80	PSC of New Hampshire	NH	0
81	Public Service Electric and Gas Co.	NJ	0
82	Puget Sound Energy, Inc.	WA	1
83	Rochester Gas & Electric Corp.	NY	0
84	Rockland Electric Co.	NJ	0
85	San Diego Gas & Electric Co.	CA	1
86	Savannah Electric & Power Co.	GA	1
87	Sierra Pacific Power Co.	NV	0
88	South Carolina Electric & Gas Co.	SC	1
89	Southern California Edison Co.	CA	1
90	Southwestern Public Service Co.	TX	0
91	Superior Water, Light & Power Co.	WI	1
92	Texas-New Mexico Power Co.	TX	0
93	Tucson Electric Power Co	AZ	0
94	Union Electric Co.	MO	1
95	Union Light, Heat & Power Co.	KY	1
96	United Illuminating Co.	CT	0
97	Upper Peninsula Power Co.	MI	0
98	Virginia Electric & Power Co.	VA	0
99	West Penn Power Co.	PA	0
100	Western Massachusetts Electric Co.	MA	0
101	Wheeling Power Co.	OH	0
102	Wisconsin Electric Power Co.	WI	1
103	Wisconsin Power & Light Co.	WI	1
104	Wisconsin Public Service Corp.	WI	1

Table 2: Descriptive statistics of data

Variables	Statistics	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total
Output (Total Revenue) (1,000$)	Average	1,296,421	1,352,705	1,380,639	1,439,635	1,465,659	1,499,147	1,545,997	1,599,703	1,643,213	1,640,494	1,780,110	1,864,345	1,752,610	1,839,909	2,172,247	1,618,189
	Max.	10,062,883	10,143,058	10,341,272	10,306,718	10,121,649	9,348,288	9,065,855	9,591,783	9,010,297	9,280,011	9,685,976	10,546,336	10,581,740	10,630,539	11,888,609	11,888,609
	Min.	12,351	11,713	10,802	12,336	12,755	12,722	13,471	11,881	12,219	12,083	12,786	13,816	14,307	14,807	15,949	10,802
	S.D.	1,596,216	1,656,568	1,683,979	1,690,568	1,728,350	1,736,438	1,744,663	1,808,779	1,837,259	1,796,639	1,881,445	1,979,671	1,955,973	2,052,807	2,450,771	1,856,854
Variable Input (O&M) (1,000$)	Average	784,605	812,431	826,465	861,299	879,342	863,674	920,708	967,830	1,020,225	1,015,438	1,231,126	1,295,001	1,138,178	1,262,076	1,566,161	1,029,637
	Max.	6,254,421	6,233,423	6,240,879	6,081,679	6,056,963	5,015,195	5,580,057	5,626,258	5,386,502	5,528,167	10,754,943	7,407,964	4,969,750	6,653,593	10,346,257	10,754,943
	Min.	10,460	9,509	8,921	10,228	10,948	10,850	11,476	9,907	9,856	9,180	10,038	10,959	11,524	12,644	14,478	8,921
	S.D.	951,672	980,451	983,411	985,129	1,013,044	949,706	1,013,518	1,071,049	1,140,207	1,082,154	1,482,862	1,360,886	1,147,319	1,372,195	1,795,259	1,193,655
Capital Stock (1,000$)	Average	44,426	46,929	49,533	52,127	54,534	56,507	58,378	60,252	62,119	64,121	66,237	68,331	70,382	72,404	74,778	60,071
	Max.	291,805	304,391	327,355	345,227	357,852	368,108	381,662	398,413	412,981	425,087	437,327	449,986	463,764	478,334	493,040	493,040
	Min.	106	131	167	178	189	200	212	221	227	235	241	249	256	264	274	106
	S.D.	55,312	58,439	61,668	64,601	67,106	69,233	71,362	73,655	75,829	78,191	80,714	83,040	85,431	87,827	90,469	74,491
Residential Customer Ratio (%)	Average	32.84	33.28	32.49	33.13	32.63	32.73	32.78	32.22	32.41	33.41	33.70	33.63	35.18	35.86	36.42	33.51
	Max.	51.34	51.58	51.52	52.07	52.60	53.19	53.41	52.41	53.43	59.08	57.40	52.75	55.39	54.86	55.43	59.08
	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	S.D.	8.11	8.00	7.97	7.99	8.00	7.89	8.02	7.85	7.82	8.54	8.72	8.04	8.43	8.88	9.71	8.34
Environmental Protection Ratio (facility, %)	Average	6.27	6.35	6.13	6.00	5.98	5.77	5.88	5.57	5.37	4.27	3.90	3.74	3.74	3.74	3.74	5.10
	Max.	23.91	23.36	22.91	22.25	23.73	25.08	29.86	25.62	25.02	24.65	31.87	33.33	33.33	33.33	33.33	33.33
	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	S.D.	6.91	6.91	6.60	6.46	6.58	6.55	6.88	6.48	6.40	5.80	6.15	6.20	6.20	6.20	6.20	6.50
Nuclear Ratio (%)	Average	12.49	12.10	12.44	12.07	12.00	11.96	10.72	9.45	10.63	11.62	9.75	7.99	7.31	6.72	6.42	10.24
	Max.	78.02	74.35	80.88	74.18	69.11	70.91	63.17	60.89	60.93	66.53	66.66	55.55	52.14	50.04	49.14	80.88
	Min.	0.00	0.00	0.00	-0.16	-0.16	0.00	0.00	-0.47	-0.28	0.00	0.00	0.00	0.00	0.00	0.00	-0.47
	S.D.	16.76	15.84	16.09	16.23	15.80	15.82	14.40	13.97	14.65	15.28	14.21	13.32	13.29	12.52	12.11	14.84
Electricity Ratio (%)	Average	91.97	92.11	91.89	91.65	91.73	91.89	91.30	91.11	92.33	92.18	91.18	90.60	91.25	90.15	89.26	91.37
	Max.	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	Min.	31.65	37.98	45.27	40.11	43.49	44.49	41.60	42.04	49.76	50.95	45.39	42.80	47.33	42.02	41.76	31.65
	S.D.	12.84	12.51	12.59	12.94	12.70	12.37	13.22	13.24	11.42	11.60	13.20	14.08	13.21	14.79	16.14	13.14
Purchased Power Ratio (%)	Average	34.02	37.29	38.23	39.88	40.04	40.89	43.28	44.50	43.74	45.96	53.03	58.99	61.45	63.55	65.06	47.33
	Max.	118.50	128.04	107.31	106.55	105.90	106.20	106.33	105.62	105.98	107.05	118.75	122.42	144.74	156.45	173.25	173.25
	Min.	0.02	1.33	1.06	1.43	1.22	1.91	1.49	1.04	1.23	1.69	1.36	1.32	2.03	1.66	1.73	0.02
	S.D.	32.69	32.64	31.35	30.82	30.87	30.68	31.45	31.28	31.01	31.62	34.19	36.83	37.76	39.80	41.55	35.11
Wholesale Power Ratio (%)	Average	11.94	14.00	15.38	15.61	15.10	15.66	17.09	18.70	19.76	20.44	20.32	17.98	18.12	17.27	16.55	16.93
	Max.	47.52	51.11	51.18	47.10	49.46	44.63	59.07	67.83	70.75	70.80	65.70	76.56	86.08	90.42	93.09	93.09
	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	S.D.	11.64	11.96	11.95	11.69	11.27	11.08	12.88	14.99	15.55	15.73	16.26	16.39	17.42	16.67	17.44	14.51

Table 3: MCMC Parameter Results (Posterior Means and *t*-ratios)

		Model 1		Model 2		Model 3		Model 4	
Variables	Parameters	Mean	*t*-ratio	Mean	*t*-ratio	Mean	*t*-ratio	Mean	*t*-ratio
Production Technology									
Constant	β_0	0.3417	5.43 **	0.3233	8.03 **	0.3479	6.91 **	0.3919	4.43 **
$\ln x_v$	β_v	0.6982	53.96 **	0.6976	53.13 **	0.6962	54.35 **	0.6962	52.54 **
$\ln x_f$	β_f	0.3150	26.88 **	0.3130	26.30 **	0.3166	27.27 **	0.3168	26.33 **
$1/2(\ln x_v)^2$	β_{vv}	0.1370	10.86 **	0.1388	10.97 **	0.1380	11.21 **	0.1377	10.95 **
$1/2(\ln x_f)^2$	β_{ff}	0.1377	14.32 **	0.1376	14.19 **	0.1386	14.87 **	0.1388	14.31 **
$\ln x_v \ln x_f$	β_{vf}	-0.1342	-12.67 **	-0.1351	-12.67 **	-0.1352	-13.15 **	-0.1351	-12.73 **
t	β_t	-0.0029	-1.51	-0.0039	-1.58	-0.0041	-1.73	-0.0043	-1.75
$1/2t^2$	β_{tt}	-0.0013	-5.84 **	-0.0012	-5.01 **	-0.0012	-5.14 **	-0.0012	-5.05 **
$\ln x_v t$	β_{vt}	0.0031	2.78 **	0.0032	2.92 **	0.0032	2.92 **	0.0032	2.88 **
$\ln x_f t$	β_{ft}	-0.0045	-4.81 **	-0.0045	-4.85 **	-0.0046	-4.95 **	-0.0046	-4.86 **
Control Variables									
RCR	β_{h1}	0.0017	6.66 **	0.0017	6.88 **	0.0017	6.72 **	0.0017	6.81 **
EPR	β_{h2}	0.0010	2.73 **	0.0011	3.16 **	0.0010	2.86 **	0.0010	2.84 **
NCR	β_{h3}	0.0006	3.90 **	0.0006	3.69 **	0.0006	3.87 **	0.0006	3.92 **
Deregulation/Organizational Variables									
Constant	γ_0	0.2867	4.69 **	0.2544	6.53 **	0.2879	5.69 **	0.3109	4.03 **
ER	γ_1	0.0024	1.15	0.0035	1.73	0.0028	1.32	0.0026	1.20
PPR	γ_2	0.0110	9.40 **	0.0121	10.39 **	0.0110	9.39 **	0.0110	9.22 **
WSR	γ_3	0.0031	1.51	0.0041	2.04 *	0.0031	1.54	0.0030	1.49
DRST	γ_4	-0.1820	-3.17 **			-0.1784	-3.13 **	-0.1828	-3.18 **
DRP	γ_5			-0.0905	-0.86	-0.0861	-0.82	-0.0994	-0.93
DRST*DRP	γ_6							0.3183	0.94
Variances									
σ_u^2		0.0048	24.50 **	0.0048	24.89 **	0.0048	24.03 **	0.0048	24.33 **
σ_v^2		0.0003	3.13 **	0.0002	2.73 **	0.0002	3.03 **	0.0002	2.96 **
DIC		-6892.01		-6906.81		-6944.58		-7038.19	

Note) Superscripts ** and * of *t* ratio indicates significance at the 1% and the 5% levels, respectively.

Table 4: Statistical test of productive efficiency

	DRST		**DRP**		**DRST=1: Reg.**		**DRST=0: Dereg.**	
	1: Reg.	**0: Dereg.**	**1: —1995**	**0: 1996_**	**1: —1995**	**0: 1996_**	**1: —1995**	**0: 1996_**
Avg.	**0.695**	**0.678**	**0.687**	**0.684**	**0.691**	**0.698**	**0.684**	**0.674**
Max.	**0.918**	**0.903**	**0.880**	**0.918**	**0.880**	**0.918**	**0.810**	**0.903**
Min.	**0.586**	**0.441**	**0.510**	**0.441**	**0.596**	**0.586**	**0.510**	**0.441**
S.D.	**0.041**	**0.050**	**0.042**	**0.050**	**0.037**	**0.044**	**0.045**	**0.052**
No. of Obs.	**659**	**899**	**623**	**935**	**263**	**395**	**359**	**539**
***t* statistics**	**7.34****		**1.05**		**-2.32***		**2.96****	

Note) The *t* test is conducted under an assumption of the different variance between two groups.

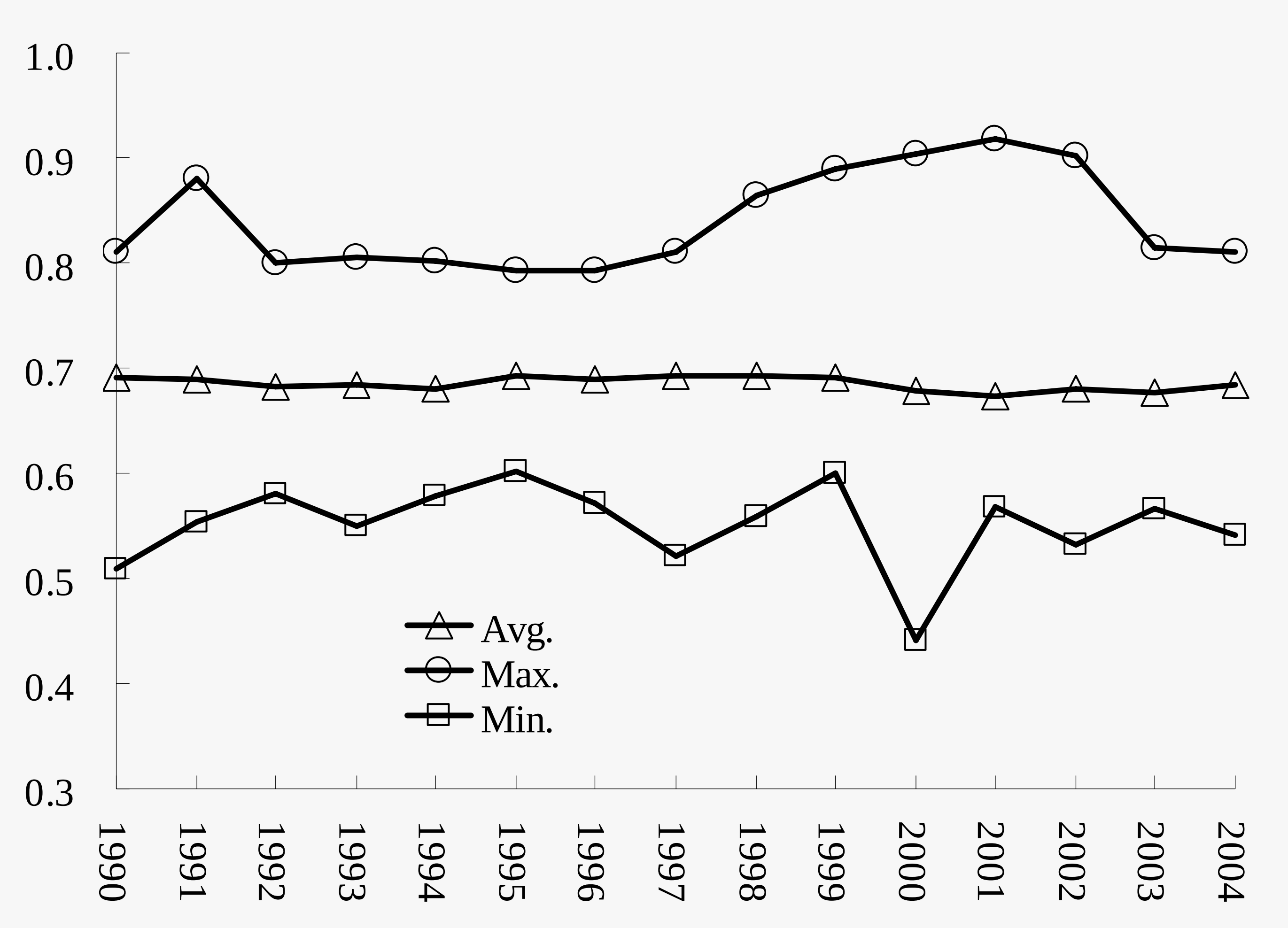

Figure 1: Central tendency of efficiency indexes

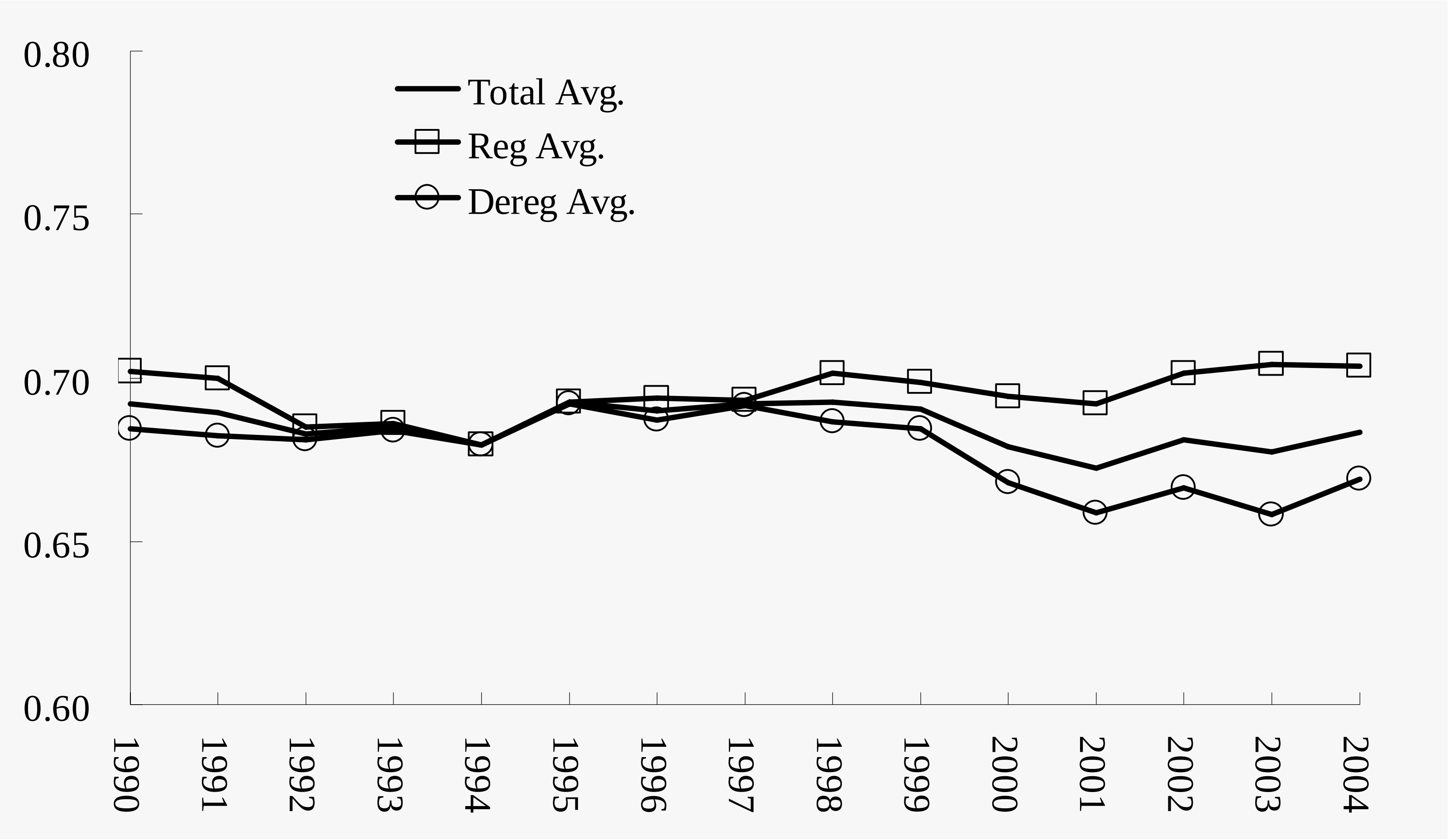

Figure 2: Central tendency of efficiency indexes for total sample, regulated states and deregulated states

Appendix 1: Construction of Capital Stock Data

This study constructs the capital stock data employing a perpetual inventory method as follows. The data period of this study is from 1990 to 2004.

$$CS_t = CS_{t-1} + \frac{NI_t}{PI_t}, \quad t = 1990,...,2004,$$

where CS_t is a capital stock in period *t*, NI_t is a net investment in period *t*, and PI_t is a price index for the capital stock investment in period *t*. The capital stock for a base-year period, which is set in 1990 in this study, is constructed applying a "triangularized" weighted average procedure proposed by Cowing *et al*. (1981) to the data as follows:

$$CS_b = \frac{BK_b}{\sum_{r=1}^{20} \left\{ \left(r \Big/ \sum_{r=1}^{20} r \right) PI_r \right\}},$$

where BK_b is a book value of the capital in base-year period, and PI_1 to PI_{20} corresponds to PI_{1971} to PI_{1990} for each.

Consequently, the net investment value is constructed as follows:

$$NI_t = GI_t - CS_{t-1} \times EDR,$$

where NI_t is a net investment in period *t*, GI_t is a gross investment that is calculated by the summation of gross additions to utility capital assets described in the cash flow statement. EDR is an economic depreciation rate that is published by Bureau of Economic Analysis of U.S. Department of Commerce (http://bea.gov/bea/an/0597niw/tableA.htm). We use the rate of 0.0211 that is applied for the category of "private nonresidential structure - electric light and power".

Appendix 2: Results of Estimation with Alternative Control Variables

		Model 1A		Model 2A		Model 3A		Model 4A	
Variables	Parameters	Mean	*t*-ratio	Mean	*t*-ratio	Mean	*t*-ratio	Mean	*t*-ratio
				Production Technology					
Constant	β_0	0.3766	4.61 **	0.3599	4.48 **	0.4424	4.35 **	0.3416	7.18 **
$\ln x_v$	β_v	0.6902	54.39 **	0.6874	53.83 **	0.6884	55.07 **	0.6897	56.67 **
$\ln x_f$	β_f	0.3255	28.53 **	0.3258	28.65 **	0.3268	29.05 **	0.3260	29.96 **
$1/2(\ln x_v)^2$	β_{vv}	0.1350	10.83 **	0.1370	11.40 **	0.1353	11.31 **	0.1343	11.15 **
$1/2(\ln x_f)^2$	β_{ff}	0.1416	15.08 **	0.1422	15.59 **	0.1423	15.63 **	0.1413	15.78 **
$\ln x_v \ln x_f$	β_{vf}	-0.1345	-12.97 **	-0.1361	-13.53 **	-0.1352	-13.55 **	-0.1341	-13.40 **
t	β_t	-0.0039	-2.05 *	-0.0054	-2.20 *	-0.0054	-2.25 *	-0.0054	-2.18 *
$1/2t^2$	β_{tt}	-0.0012	-5.21 **	-0.0010	-4.21 **	-0.0011	-4.41 **	-0.0011	-4.41 **
$\ln x_v t$	β_{vt}	0.0036	3.28 **	0.0038	3.48 **	0.0037	3.36 **	0.0036	3.40 **
$\ln x_f t$	β_{ft}	-0.0051	-5.50 **	-0.0052	-5.61 **	-0.0052	-5.60 **	-0.0051	-5.65 **
				Control Variables					
RCR	β_{h1}	0.0020	7.80 **	0.0020	8.42 **	0.0020	7.97 **	0.002	8.12 **
EPR	β_{h2}	0.0025	8.28 **	0.0025	8.30 **	0.0025	8.41 **	0.002	8.41 **
FUEL	β_{h3}	0.0003	0.17	0.0000	0.02	0.0003	0.16	0.000	0.15
Rcomp	β_{h4}	-0.0100	-1.50	-0.0171	-2.70 **	-0.0104	-1.53	-0.010	-1.48
				Deregulation/Organizational Variables					
Constant	γ_0	0.3455	4.45 **	0.3140	3.89 **	0.4025	4.08 **	0.2783	5.58 **
ER	γ_1	0.0019	0.85	0.0030	1.45	0.0027	1.29	0.0018	0.87
PPR	γ_2	0.0099	7.94 **	0.0104	8.52 **	0.0099	7.94 **	0.0099	7.97 **
WSR	γ_3	0.0042	2.08 *	0.0049	2.40 *	0.0042	2.13 *	0.0042	2.13 *
DRST	γ_4	-0.1738	-2.89 **			-0.1685	-2.80 **	-0.1754	-2.82 **
DRP	γ_5			-0.1049	-0.99	-0.1081	-1.02	-0.1031	-0.93
DRST*DRP	γ_6							0.4223	1.39
				Variances					
σ_u^2		0.0047	24.17 **	0.0047	24.60 **	0.0047	23.69 **	0.0046	24.67 **
σ_v^2		0.0002	3.02 **	0.0002	2.98 **	0.0002	3.04 **	0.0002	2.77 **
DIC		-7028.61		-7145.25		-7065.01		-7044.86	

Note) Superscripts ** and * of *t* ratio indicates significance at the 1% and the 5% levels, respectively.