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Efficiency and Productivity Impacts of Restructuring the Korean Electricity Generation[*]

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This paper investigates the performance of various generation plants in the Korean electricity market. The objective is to compare performance before and after the 2001 separation by using data from 1995 to 2006. The efficiency and productivity of the generation units is estimated by using a stochastic frontier model as well as data envelopment analysis and Malmquist productivity index. The result suggests that generation is mainly affected by facility type, maintenance cost, real fuel cost, and other costs. The national generation plan is characterized by high efficiency of nuclear plants, base type facilities, and large size facilities. It is also found that efficiency enhancement from the separation effect is not clearly discernible when comparing periods before and after the separation. Suggestions are made for the better utilization of economies of scale to further raise the efficiency of generation companies and the electricity industry through enhancement of fuel purchasing power and reallocation of labour.

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1. INTRODUCTION AND BACKGROUND

Korea inevitably is dependent on imports of primary energy to meet its energy demands. The country has very limited supplies of indigenous energy resources. The energy situation can have a critical impact on the national economy with the continuous surge in power demand and consumption. Another related issue for the country that needs to be considered seriously is the fact that energy is imported from a small number of source countries, which could translate into a high level of uncertainty in the energy supply. Korea not only ranks fifth among oil importing countries, but also is a significant importer of liquefied natural gas (LNG). In such a situation it is even more important that the electricity market operate under optimal conditions in order to avoid a shortage situation. The most fundamental way to secure energy supply is to raise the efficiency and productivity of the electricity industry.

Many countries undergo restructuring to enhance the productivity of their electricity markets. Since the introduction of competition in the electricity industry in 1990 in the UK, competition reform has been introduced in many other markets worldwide. Over 76 countries worldwide are currently implementing or planning to implement a reorganization of their electricity industries. The vertical monopolized structure of the electricity industry, in which only one company takes charge of all the processes in the generation, transmission, distribution, and market sale, is now radically changing.

In order to examine the present status of overseas electricity industry reorganization, Horwath Choongjung Consulting and Seoul National University Engineering Lab (HCC-SNUEL, 2008) conducted a study analysing the market in the UK, Nord Pool (Norway, Sweden, Finland, and Denmark), the US, Spain, Australia, France, and Japan. Examination of the different markets reorganizations led to a number of conclusions: For example, it was found that the reorganization process be conducted with a concrete object as it progresses, that reorganization is not associated with price cuts, that facility investment needs are under long-term plan, that institutional support by the government is important, and that consideration of environmental problems and alternative energy is urgently needed.

The HCC-SNUEL (2008) study analysed performance of the generation part of the Korean electricity market as well. The objective was to compare performance before and after the separation by using data from 1995 until 2006. The study was divided into four parts: analysis of circumstances of the industry, model development for performance analysis, analysis of the result, and presentation of a plan to raise the efficiency in power generation. Three methods were used: process benchmarking methodology (PBM) to compare performance before and after reorganization, data envelopment analysis (DEA) to estimate efficiency, and Malmquist productivity index (MPI) was constructed to analyse efficiency change at each process. Suggestions and guidelines were presented to further raise the efficiency of generation companies.

In this study, by using the same database but with different set of variables, we employ different approaches for performance analysis. More specifically, we estimate efficiency of the generation parts by using parametric stochastic frontier analysis (SFA) as well as non-parametric DEA and MPI. A parametric approach is preferred as this allows us to model production while accounting for characteristics of producers and markets in addition to inputs and outputs. Our results suggest that the generation is mainly affected by facility type, maintenance cost, real fuel cost, and other costs. When we considered the heterogeneity in efficiency, we found that the national generation plan was characterized by the high efficiency of nuclear plants, base type facilities, and large size facilities. In addition, we found that the management efficiency was slightly lowered after the six GENCOs (Generation Companies) separation from KEPCO (Korea Electric Power Corporation). Furthermore, efficiency enhancement from the restructuring effect is not clearly discernible when comparing periods before and after restructuring.

The remainder of this study is organized as follows. Section 2 gives a review of the electricity market in Korea. Section 3 provides data description and section 4 describes the measurement methods on efficiency and productivity used in this study. Section 5 and 6 present the parametric and non-parametric results of our performance analysis, respectively. The results are provided by each methodology and classified by time-invariant firm characteristics. Finally, some concluding remarks can be found in section 7.

2. THE ELECTRICITY MARKET IN KOREA

Korea has very limited supplies of indigenous natural resources. Recognizing its high dependence on external sources of energy, Korea has successfully managed to diversify its energy use to reduce its risk and vulnerability. The energy sector has expanded greatly given its crucial role in supporting the country's economic development over the past 40 years. Korea has experienced a series of structural changes in the electricity market especially following the world oil crisis which led Korea to seek diversification in its energy sources. The main primary energy sources for generating electricity have been diversified into coal, oil, LNG, and nuclear. Recently there has been great public interest in developing renewable energy sources. The choice however has been constrained by the large-scale investment in power plants and equipment dictated by the long-term demand forecasts.

Also worth noting is that Korea has exerted itself to overcome monopoly issues associated with KEPCO by transforming the power generation sector into a competitive system. KEPCO was separated into six GENCOs, but still retains the national transmission and distribution grids, and continues to own all of the six GENCOs. At the same time, a power market, the state-owned Korea Power Exchange (KPX), was established. While liberalization remains a key policy goal of the government, it has not been able to establish a concrete schedule for liberalization.

Through maintaining a stable supply of energy, the Korean government has provided long-term energy policy directions and information on electricity supply and demand. Korea's overall energy policies seek to achieve sustainable development through energy security, energy efficiency, and environmental protection. The government has not only accelerated policies and measures for energy efficiency linked with a carbon abatement measure, but has also considered transforming the market. The desired change is from the current energy system, which centres on a concentrated supply-oriented system, toward a sustainable energy system that involves the elements of a demand-oriented system.

Power consumption continues to steadily increase in Korea in tandem with its level of economic development. In spite of a decline in the economic growth rate since the early 1990s, the average power consumption per capita remains relatively high in comparison with other OECD member countries. The industry sector is the largest consumer, accounting for 53% of the total amount of generated power in 2007. In terms of the electricity price, electricity for the agriculture sector is the cheapest thanks to subsidization. The Korean electricity market uses a cost-based pool system. And, the price system differs depending on the type of generator and the inclusion or exclusion of unconstrained supply schedules.

Since the early stages, the electricity market has been made up of only seven main players, specifically KEPCO and the six GENCOs. Based on statistics produced in the late 2008, there were 302 members who were active in the market. Most of the generation companies, excluding those supplying energy to KEPCO under the power purchase agreement, participate directly in the power market. Nuclear, coal, and LNG have been the top three primary sources since 2001. However, the ranking changes frequently over time with changes in the different source prices.

In 2007 power generation from coal power plants was ranked first, and nuclear power plants second, while the third position was held by the combined cycle power plants. Coal power plants were mostly fuelled by bituminous coal. Although there are private companies operating combined cycle power plants, the share of GENCO's generation was much higher. Korea Hydro and Nuclear Power (KHNP) is currently in charge of 20 nuclear power plants commercially. Hydro power plants generate only about 1.0% of the total power supply. The portion of new and renewable energy sources remains very small, at 2.24% of the total power generation. The Korean government aimed to increase this proportion to 5.0% by 2011.

In relation with the regulations and regional agreements, several strategies are being put into action and the adequacy of a generation mix against environmental change is under consideration. In tandem, the government aims to contribute to the expansion of renewable energy sources. The optimization of resources utilization for demand side management is also considering the status of the electricity balance. All trends demonstrate that the Korean electricity industry is changing in its character. These dynamic situations require the generation companies to invest more effort in R&D and to cooperate in the development of cost efficient generation technologies. Interest readers are referred to previous analysis of the industry by Choi and Ang (2002), Lee and Ahn (2006), Park and Lesourd (2000) and Heshmati (2012).

3. THE DATA

The data consists of 171 generators observed for 1 to 12 years from 1995 to 2006. The total number of observations is 1,637. Apart from the generation data, financial-related and construction-related data were employed to improve the modelling and analysis. The data sets can be viewed in separate processes, namely, plant operation, plant maintenance, plant investment and plant construction.

In this study, we do not separate these processes for analysis. Rather we use net generation for output and facility capacity, maintenance cost, sales and management expenditure, real fuel cost, other costs, wages, number of generators, age of generator and facility type are treated as input and production characteristics. Summary statistics of the data are reported in table 1.

Table 1 Summary Statistics of the Electricity Generation Data, 1995-2006, N=1,637

Variable	Mean	Std Dev.
Dependent Variable:		
Facility Capacity (MW)	328	272
Independent Variables:		
Electricity Generation (MWh)	1,940,094	2,299,155
Maintenance Cost (Million Won)	1,676	2,061
Sales and Management Expenditure (Million Won)	1,128	1,279
O&M Cost (Million Won)	42,549	59,519
Real Fuel Cost (1000 USD)	38,839	39,217
Wages (Million Won)	2,915	3,163
Other Costs 1) (Million Won)	46,064	59,826
Number of Generators	1.40	1.07
Age	17	15

Note: 1) Other costs = (total cost) – (fuel cost) – (wage) – (sales and management expenditure).

As expected, the electricity generation had a strong correlation with facility capacity and maintenance cost. The real fuel cost and the generation are correlated weakly, because the different types of fuel source had different purchasing costs. The time trend variable is highly correlated with wages suggesting increased labour cost over time.

4. EFFICIENCY AND PRODUCTIVITY MEASUREMENT METHODS

The literature on performance is, in general, divided into efficiency and productivity analysis. Productivity is usually defined as the ratio of some function of output to some function of inputs. There are numerous methods to measure productivity. The most common methods are the single factor productivity index, the total factor productivity (TFP) growth, and MPI. On the other hand, efficiency is a comparative concept with respect to feasible production sets at a point in time. The literature on performance is sometimes divided into parametric and non-parametric methods. Data envelopment analysis is the most common non-parametric method. Among parametric methods, econometric estimation of stochastic frontier production or cost models is the most common method of measurement.

For empirical estimation, we can distinguish between cross-sectional, time series, and panel data. In panel data analysis, estimation by fixed or random effects models is common. In this chapter, we apply a parametric SFA method to panel data as well as non-parametric DEA and MPI methods. The data covers the period 1995-2006 and the data unit is at the generation level. Each of these methods is described below. There is a comprehensive literature on performance analysis that has been applied to the electricity industry. Kumbhakar and Lovell (2000), Heshmati (2003), Coelli *et al.* (2005), and Cooper *et al.* (2007) provide reviews of the literature.

Furthermore, there is a vast amount of literature that covers the reorganization of the electricity market. A major goal is to stimulate competition leading to electricity price reduction. The literature also discusses the basic steps for liberalizing or reorganizing the transformation based on experiences from the developed and developing countries. Day *et al.* (2002) and Kirschen (2003) discuss supply and demand side aspects of the market. Several studies investigate the restructuring effects of the industry (e.g., Al-Sunaidy and Green, 2006; Blumsack *et al.*, 2006; Goto, 2008; Hattori and Tsutsui, 2004; Kleit and Terrell, 2001; Lee and Ahn, 2006; Williams and Ghanadan, 2006; Woo *et al.*, 2003). In a number of studies, general performance of the industry is studied (see Abbot, 2005; Arocena and Price, 1999; Atkinson and Halvorsen, 1986; Cramton, 2003; Christensen and Greene, 1976; Filippini *et al.*, 2005; Forsund and Kittelsen, 1998; Giannakis *et al.*, 2005, Zhang and Bartels, 1998).1)

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1) Several studies of the electricity industry investigate the issues of competition (Apt, 2005),

4.1. Stochastic Frontier Analysis

The stochastic frontier production function postulates the existence of technical inefficiency in production. Two different variants of the stochastic frontier are used here. These are the efficiency effects (EE) and the error components (EC) models. The EC model estimates a production function and efficiency level for each observation, while the EE model in addition explains the degree of inefficiency attributed to its determinants. The EE model suggested by Battese and Coelli (1995) can be written as:

$$Y_{it} = \exp(x_{it}\beta + V_{it} - U_{it}), \tag{1}$$

where Y_{it} denotes the output for the i-th firm (i =1, 2, ..., N) in time period t (t=1, 2, ..., T); x_{it} is a vector of inputs and other explanatory variables; β is a vector of unknown parameters to be estimated; the V_{it}'s are assumed to be i.i.d. $N(0, \sigma_v^2)$ random errors, independently distributed of the U_{it}'s; the U_{it}'s are non-negative random variables, associated with technical inefficiency of production, which are assumed to be independently distributed, such that U_{it} is obtained by truncation (at zero) of the normal distribution with mean, $z_{it}\delta$, and constant variance, σ^2; z_{it} is a vector of explanatory variables associated with technical inefficiency; and δ is a vector of unknown inefficiency effects. The technical inefficiency effect component, U_{it}, is specified as a function of its determinants written as:

$$U_{it} = z_{it}\delta + W_{it}, \tag{2}$$

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allocative efficiency (Atkinson and Halvorsen, 1990), ownerships (Bushnell and Wolfman, 2005; Hjalmarsson and Veiderpass, 1992; Koh *et al.*, 1996), vertical integration (Gilsdorf, 1994), quality of service (Growitsch *et al.*, 2009; Pollitt, 1995), determinants of performance (Hiebert, 2002; Olatubi and Dismukes, 2000; Kittelsen, 1993), economies of scale (Hisnanick and Kymn, 1999; Maloney, 2001; Nerlove, 1963), market structure (Kamerschen *et al.*, 2005), pricing of electricity (Kinnunen, 2005), multidivision efficiency evaluation (Tsutsui, 2006), assessment of reform (Al-Sunaidy and Green, 2006; Blumsack *et al.*, 2006; Peerbocus, 2007; Goto, 2008; Hattori and Tsutsui, 2004; Lee and Ahn, 2006); and benchmarking (Filippini *et al.*, 2005; Giannakis *et al.*, 2005).

where W_{it} is defined by the truncation of the normal distribution with zero mean and constant variance, σ^2. W_{it} is assumed to be a non-negative truncation of the $N(z_{it}\delta,\ \sigma_v^2)$ distribution. The technical efficiency is obtained from:

$$TE_{it} = \exp(-U_{it}) = \exp(-z_{it}\delta + W_{it}). \qquad (3)$$

The alternative EC approach, introduced previously by Battese and Coelli (1992), considered the time-varying model of inefficiency. The model can be written as:

$$Y_{it} = f(x_{it};\ \beta)\exp(V_{it} - U_{it}), \text{ and} \qquad (4)$$

$$U_{it} = \eta_{it}U_i = \{\exp[-\eta(t-T)]\}U_i,\ \ t \in \tau(i);\ \ i = 1,\ 2,\ \ldots,\ N, \qquad (5)$$

where Y_{it} represents output; $f(x_{it};\ \beta)$ is a suitable function of inputs; x_{it} and β are vectors of explanatory variable and their associated unknown parameters; the V_{it}'s are assumed to be i.i.d. $N(0,\ \sigma_v^2)$ random errors; the U_{it}'s are assumed to be i.i.d. $N^+(\mu,\ \sigma_v^2)$ truncated distribution; η is a scalar parameter determining time variance of inefficiency component; and $\tau(i)$ represents the set of T_i time periods. The rate of technical efficiency is obtained from:

$$TE_{it} = E[\exp(-\eta_t U_i)], \text{ where } \eta_t = \exp[-\eta(t-T)]. \qquad (6)$$

4.2. Data Envelopment Analysis

The DEA method identifies the best performance decision making unit (DMU) in the sample and evaluates all other units' performances as deviations from the frontier line. DEA can be linked to parametric approaches in identifying determinants of performance by employing a two-step procedure. There are in fact two DEA models: the CCR model

(Charnes, Cooper, and Rhodes, 1978), where constant return to scale (CRS) is assumed, and the BCC model (Banker, Charnes, and Cooper, 1984) in which variable return to scale (VRS) in production is assumed. For each firm, we obtain a measure of the ratio of all outputs over all inputs, where u_r and v_i are vectors of inputs and output weights. The optimal weights are obtained by solving the mathematical problem:

$$\max_{u,\,v}\ \theta = \frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{ij}} \ \text{ s.t. } \frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{ij}} \le 1 \ \ (j = 1,\ 2,\ \ldots,\ n),\ \ u_r v_i \ge \varepsilon, \tag{7}$$

where *i* indicates input type, *r* indicates output type, x_{ij} is input *i* of DMU *j*, and y_{ri} is output *r* of DMU *j*. This involves finding values for u and *v*, such that the efficiency measure for the *j*-th firm is maximized, subject to the constraints that all efficiency measures must be less than or equal to one. To avoid infinite number of solutions, we can impose the constraint $\sum_i v_i x_{ij} = 1$:

$$\begin{aligned} &\max_{u,\,v}\ \theta = \textstyle\sum_r u_r y_{rj} \ \text{ s.t. } \sum_i v_i x_{ij} = 1, \\ &\textstyle\sum_{ir} u_r y_{rj} - \sum_i v_i x_{ij} \le 0 \ (j = 1,\ 2,\ \ldots,\ n),\ u_r,\ v_i \ge 0. \end{aligned} \tag{8}$$

The CRS model is appropriate when all firms are operating at an optimal scale. However, imperfect competition, government regulations, and constraints on finances and skilled labour may cause a firm not to be operating at its optimal scale. That is, measures of technical efficiency (TE) may be confounded by scale efficiencies (SE). This limitation has led to development of an alternative less restrictive VRS approach which adds the convexity constraint, thereby providing:

$$\begin{aligned} &\max_{u,\,v}\ \theta = \textstyle\sum_r u_r y_{rj} - U_0 \ \text{ s.t. } \sum_i v_i x_{ij} = 1, \\ &\textstyle\sum_{ir} u_r y_{rj} - \sum_i v_i x_{ij} \le 0 \ (j = 1,\ 2,\ \ldots,\ n),\ u_r,\ v_i \ge 0. \end{aligned} \tag{9}$$

This approach envelope the data points more tightly than the CRS and provides *TE* scores that are greater than or equal to those obtained using the CRS model. Scale efficiencies can be obtained for each firm by conducting both the CRS and VRS procedures, and then decomposing the technical efficiency scores obtained from the CRS into scale and technical inefficiency components. Following Coelli *et al.* (2005) the relationships between the measures and components are written as:

$$TE_{CRS} = TE_{VRS} \times SE. \tag{10}$$

4.3. Malmquist Productivity Index

A DEA-like linear programming method is used here to compute the MPI index. The MPI approach is commonly used for output comparisons over time. MPI is defined as:

$$Q_0^t(y_s, y_t, x) = \frac{d_0^t(x, y_t)}{d_0^t(x, y_s)}. \tag{11}$$

We can obtain a measure of Q_0^t by solving the following linear programming problem:

$$D^t(x^t, y^t) = \inf[\theta : (x^t, y^t / \theta \in F^t)]. \tag{12}$$

So the final equation of the MPI is a geometric average of input utilization and production of output in two periods written as:

$$\begin{aligned} & MPI^t(x^{t+1}, y^{t+1}, x^t, y^t) \\ & = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \sqrt{\frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} \times \frac{D^t(x^t, y^t)}{D^{t+1}(x^{t+1}, y^{t+1})}}, \end{aligned} \tag{13}$$

where the first term is the technical efficiency change index (ECI), which reflects internal efficiency changes between the *t* and *t*+1 periods due to learning effect, market competition, cost structure, and improvement of the facility operation rate. The latter term, labelled as technical change index (TCI), measures change in the production frontier, which reflects technology innovation. The ECI is further divided into pure efficiency change index (PCI) and scale efficiency change index (SCI) components attributed to the difference between VRS and CRS measures.

5. THE PARAMETRIC ESTIMATION RESULTS

5.1. Specification and Estimation of the SFA Models

In the case of the EE model, a stochastic frontier production function is specified and estimated. The dependent and independent variables and determinants of inefficiency are presented in tables 1 and 2. More specifically, the stochastic frontier production function to be estimated is:

$$\begin{aligned}\log Gen_{it} &= \beta_0 + \beta_1 \log(faccap_{it}) + \beta_2 \log(mai\cos_{it}) + \beta_3 \log(sme_{it}) \\ &\quad + \beta_4 \log(fue\cos_{it}) + \beta_5 \log(oth\cos_{it}) + \beta_6 \log(wage_{it}) \\ &\quad + \beta_7 (Trend_{it}) + V_{it} - U_{it},\end{aligned} \tag{14}$$

where V_{it} is a random error term, and U_{it} is the inefficiency component modelled in the case of EE model in the following way:

$$\begin{aligned}U_{it} &= \delta_0 + \delta_1(numgen_{it}) + \delta_2(age_{it}) + \delta_3(Trend_{it}) + \delta_4(midfac_{it}) \\ &\quad + \delta_5(peakfac_{it}) + \delta_6(dfaccap_{it}) + \delta_7(dfue\cos_{it}) \\ &\quad + \delta_8(dwage_{it}) + W_{it}.\end{aligned} \tag{15}$$

The production frontier model is estimated by maximum likelihood estimation (MLE) using the statistical package FRONTIER due to Coelli

Table 2 Frontier Production Function Models
MLE Parameter Estimates, N=1,637

Technical Efficiency Effect (EE) Model			Error Component (EC) Model		
Parameter	Coefficient	Std. Error	Parameter	Coefficient	Std. Error
constant	8.9500***	0.0585	constant	12.9000***	0.1330
log(faccap)	0.9470***	0.0192	log(faccap)	0.8640***	0.0308
log(maicos)	0.0068	0.0116	log(maicos)	–0.031**	0.0153
log(sme)	0.6040***	0.0219	log(sme)	0.1950***	0.0196
log(fuecos)	0.0734***	0.0058	log(fuecos)	0.6270***	0.0216
log(othcos)	–0.1950***	0.0242	log(othcos)	–0.0132	0.0287
log(wage)	–0.3420***	0.0301	log(wage)	–0.0022	0.0335
Trend	0.0116***	0.0042	Trend	0.0036	0.0061
Determinants of Inefficiency U_{it}			numgen	0.2460***	0.0362
constant	–10.9000***	0.3610			
numgen	0.0610	0.0546	age	0.0090***	0.0023
age	–0.0220***	0.0071	midfac	0.0578	0.1010
Trend	0.1190***	0.0227	peakfac	–1.1200***	0.0855
midfac	7.2700***	0.3370	dfaccap	–4.2000***	0.1870
peakfac	8.6700***	0.3790	dfuecos	–6.2300***	0.2000
dfaccap	3.9000***	0.4350	dwage	–0.3340*	0.2430
dfuecos	7.0100***	0.3950	μ	–6.6900	0.5160
dwage	–8.7000***	0.3940	η	–0.1140	0.0071
σ^2	1.7400	0.0995	σ^2	11.4000	1.0500
γ	0.9590	0.0023	γ	0.9830	0.0019
Log L		–1,280.1	Log likelihood function		–1,280.0

Notes: 1) gen=electricity generation, faccap=facility capacity, maicos=maintenance cost, sme=sales and management expenditure, fuecos=real fuel cost, othcos=other cost, wage=wage, trend=time trend, numgen=number of generators, age=age of generator, midfac=middle type facility, peakfac= peak type facility, dfaccap=dummy for facility capacity, dfuecos=dummy for real fuel cost, dwage=dummy for wage. *** indicate significance at the 1% level; ** 5% level; and * 10% levels.

(1996). The estimation results for the EE and EC models are shown in table 2.

The signs of the coefficients are as expected. When the company invests in maintenance, the generator will stay in good condition enabling more power generation. Sales and management expenditure tend to support electricity generation indirectly. The negative signs of the coefficients of real fuel cost and other costs are as expected.

A negative coefficient of a characteristic variable in the efficiency effect model suggests that an increase in the factor will reduce the level of inefficiency (Knittel, 2002). More specifically, from the estimates of the EE model above, we can state that the degree of inefficiency decreases as the number of generators, year, middle load type facility, peak load type facility, facility capacity, and real fuel cost increase. The variable with the largest positive impact is peak load type facility. Hence, in order to increase the efficiency of a generator facility, more peak load type facility is desirable. The variable with the largest absolute negative value is wage which indicates that, as the wage gets smaller, the efficiency of the facility increases.

The negative sign of age of generator coefficient is not expected. Generally, new generators with better technology should exhibit improved performance, but arguably it may take some time before a generator is in operation effectively. We estimated that the large coefficient of middle load type and peak load type facilities are determined by the national generation plan and energy supply and security considerations. The base load type facilities are operating continuously, but middle and peak load types operate when electricity supply by base load type facilities is insufficient to cover the national power demand.

In the case of the error component model, the estimated stochastic frontier production function is formulated as:

$$\begin{aligned}\log Gen_{it} &= \beta_0 + \beta_1 \log(faccap_{it}) + \beta_2 \log(mai\cos_{it}) + \beta_3 \log(sme_{it}) \\ &\quad + \beta_4 \log(fue\cos_{it}) + \beta_5 \log(oth\cos_{it}) + \beta_6 \log(wage_{it}) \\ &\quad + \beta_7 (Trend_{it}) + \beta_8 (numgen_{it}) + \beta_9 (age_{it}) \\ &\quad + \beta_{10} (midfac_{it}) + \beta_{11} (peakfac_{it}) + \beta_{12} (dfaccap_{it}) \\ &\quad + \beta_{13} (dfue\cos_{it}) + \beta_{14} (dwage_{it}) + V_{it} - U_{it}.\end{aligned} \tag{16}$$

It should be noted that the factors considered as determinants of inefficiency in the EE model are in the EC model considered as characteristics of production, and their effects are estimated together with the production inputs parameters. The different treatment of the production characteristics as determinants of inefficiency or alternatively as determinants of the production in itself remains controversial.

5.2. Efficiency Results and Its Dynamics

The mean efficiency by different generator characteristics and its development over time is shown in Appendix table A1. The mean efficiency in the EE model is 0.623, suggesting that the sample generators currently produce only 62.3% of their potential output. The efficiency level is the relative efficiency compared to the most efficient facility of the corresponding year. The list of most efficient firms changes a great deal in the earlier period. The frequency distribution of facilities shows that a large proportion of the facilities have efficiency levels between 0.80 and 0.90. This suggests that quite a lot of the base load facilities are operating at their efficiency levels close to the frontier firms.

We can see a decreasing trend of the level of efficiency, however. For the EE model there is no change in the trend, but the efficiency level continues to decrease. For the EC model, however, there is some fluctuation in the level of efficiency mainly during the period in the aftermath of the Asian financial crisis. In 2001, the year when the separation of generating firms occurred, efficiency tended to decrease. The levels of efficiency before and after the separation of the generation companies differ. From the results of both models reported in table 3, we observe that the efficiency has decreased since the separation process. We observe however that the separation process had a negative impact on the efficiency of firms, at least in the immediate period following the separation process. A *t*-test of the equality of means indicates a statistically significant difference between the two periods. Moreover, the difference in the EC model case is much larger.

Table 3 Average Efficiency before and after 2001 Separation Process

Period	Before Separation	After Separation	Difference (Before-After)	*t* value	Pr > |*t*|
EE Model	0.641	0.607	0.034	2.42	0.016
EC Model	0.695	0.539	0.156	13.91	0.001

5.3. Performance Heterogeneity

The efficiency results, which vary both by generator and over time, are reported by grouping the observations by different time invariant characteristics of generators. These characteristics are: facility size, facility type (base, middle, and peak loads), ages of generators, company, fuel sources, and plant types. Each of these is discussed below and further illustrated in Appendix table A1.

The size is defined by the generation capacity in disproportionate intervals, ranging from 0-15 to 750-1,000 megawatts. The largest efficiency levels occur for the facilities of the largest size. The value of the efficiency is over 0.78 for both of the EE and EC models. However, there is no clear relationship between efficiency and the size of plants. The relationship seems to be U-shaped, but this cannot be statistically confirmed.

The facility type is divided into base, middle, and peak load types. We note that there is a decreasing trend in the EE model, as the facility type changes from base load type to peak load type, but there is no such trend in the EC model. The most efficient facility type is the base load type for both models, as these facilities use their capacity more efficiently in production.

Age cohort is defined in years of operation intervals of five-years ranging from 0-5 years to 45-50 years, and more than 50 years. Generators over 50 years exhibit the largest efficiency when compared with plants in other age cohorts. This seems sensible considering the fact that only the most efficient facilities will remain in operation. Inefficient facilities would cease operating when they are inefficient and not profitable. The average efficiency differs across age cohorts, but no concrete trend appears in the models. The average efficiency from the two models for each age cohort is highly correlated.

We note that the company with the highest efficiency is KHNP. This is true in both models. The second highest ranked company is Korea South East Power Company (KOSEP) for the EE model and Korea Western Power Company (WP) for the EC model. The other four companies have efficiency levels which are lower and range between 0.50 and 0.60.

As expected, the nuclear-sourced facility has the highest level of average efficiency in both model specifications. The coal-based plants' efficiency is also quite high.

The criterion for classification of plants by type is almost the same as that used to classify plants by fuel source. The only difference is that the hydro type here is divided into normal hydro and pumping hydro. The normal hydro plant has a higher efficiency level compared to that of the pumping hydro in the EE model. However, the reverse is true in the case of the EC model.

6. THE NON-PARAMETRIC DEA AND MPI RESULTS

6.1. Data Envelopment Analysis Results

In order to analyse the efficiency of generation plants by DEA, we used facility capacity, maintenance cost, sales and management expenditure, other costs, real fuel cost, and wage as input factors and electricity generation as an output. The TE results based on VRS and CRS assumptions and SE is described below by common characteristics of generation plants.

In looking at the DEA efficiency results by companies, KHNP had the highest efficiency under CRS and VRS. All values of KHNP's plants are above 90% of efficiency. There were no changes in facility capacity during the period of study. The first highest cost component in relation to total cost in the nuclear plant is other cost (about 72%), the second is fuel cost (about 12%), and the third is maintenance cost (about 9%). The companies WP and

KOSEP exhibit highest efficiency among the GENCOs, excluding KHNP. The company KOMIPO has the lowest efficiency.

A disaggregation of average technical and scale efficiency by plants measured under CRS and VRS for different fuel sources is reported. The efficiency of nuclear plants is the highest among the different alternatives. Under CRS, the order for efficiency is bituminous, oil, anthracite, LNG, and pumping hydro. The rankings between LNG and pumping hydro have changed under the VRS model. All efficiency values of bituminous, excluding one plant under VRS, are higher than 0.90. The high level of efficiency of nuclear and bituminous plants is related to facility type. They are designated as base load type generators, which generate power continuously.

The mean efficiency by facility type shows that the efficiency of base load type plants is the highest and that of peak load power plants is the lowest. There are three fuel types in the base load type plants, which are nuclear, bituminous, and anthracite coals. The efficiency of the bituminous type plant is lower than that of the others. The efficiency of medium load type plant is the same as the oil type plant. The peak load type plants consist of LNG and pumping hydro plants.

We also compute the mean efficiency by facility size and age and also investigate average efficiency over time. According to the efficiency by age of plant, the generators from plants aged 15 to 20 have the highest efficiency values. In 1995 the mean efficiency was the highest and was the lowest in 2000.

In the case of facility size, the efficiency of generators whose size is from 750 to 1000 MW is the highest. Accordingly, the relevant plants are nuclear generators. The second best size class is from 500 to 750 MW generation capacity which include seven plants which have high efficiency scores.

The *t*-test result for the equality of mean efficiency based on DEA method before and after the separation is also presented in table 4. A deterioration in efficiency following the separation, but improved scale efficiency, is confirmed.

Table 4 *T*-test for Equality of Mean Efficiency

	Before Separation	After Separation	Difference (Before-After)	*t* value	Pr > |*t*|
CRS DEA	0.760	0.727	0.033	2.10	0.036
VRS DEA	0.884	0.790	0.094	7.08	0.001
VRS DEA SE	0.861	0.908	–0.047	–4.32	0.001

Note: CRT=constant return to scale, VRS=variable return to scale, SE=scale effect.

Table 5 Mean (M) and Standard Deviation (SD) of Various Efficiency Measures Over Timer, N= Number of Generators, N=1,637

Year	N	EE Model		EC Model		DEA CRS		DEA VRS		DEA SE	
		M	SD	M	SD	M	SD	M	SD	M	SD
1995	111	0.692	0.227	0.754	0.195	0.851	0.171	0.944	0.094	0.903	0.159
1996	119	0.682	0.225	0.729	0.198	0.831	0.170	0.924	0.108	0.898	0.139
1997	126	0.688	0.233	0.704	0.204	0.803	0.198	0.888	0.163	0.905	0.142
1998	131	0.588	0.304	0.686	0.211	0.707	0.262	0.919	0.129	0.776	0.270
1999	131	0.596	0.301	0.671	0.207	0.715	0.285	0.904	0.175	0.790	0.266
2000	137	0.615	0.286	0.643	0.213	0.704	0.299	0.766	0.261	0.912	0.194
2001	142	0.634	0.297	0.618	0.220	0.738	0.300	0.783	0.268	0.921	0.162
2002	141	0.624	0.299	0.586	0.229	0.726	0.289	0.794	0.268	0.904	0.152
2003	145	0.637	0.293	0.556	0.236	0.747	0.273	0.810	0.246	0.915	0.156
2004	145	0.609	0.273	0.527	0.240	0.730	0.289	0.790	0.258	0.912	0.173
2005	150	0.591	0.272	0.498	0.243	0.715	0.273	0.787	0.235	0.898	0.185
2006	159	0.557	0.291	0.462	0.245	0.711	0.293	0.781	0.267	0.902	0.174

Table 5 summarizes the distribution of the five different efficiency outcomes based on the SFA and DEA methods in the form of CRS, VRS, and SE components. Here we utilize the information concerning the distribution of TE in terms of their means and standard deviations of all models. A full summary of heterogeneity in efficiency estimated by DEA and SFA methods across different generation characteristics is presented in Appendix table A1.

6.2. Malmquist Productivity Index Results

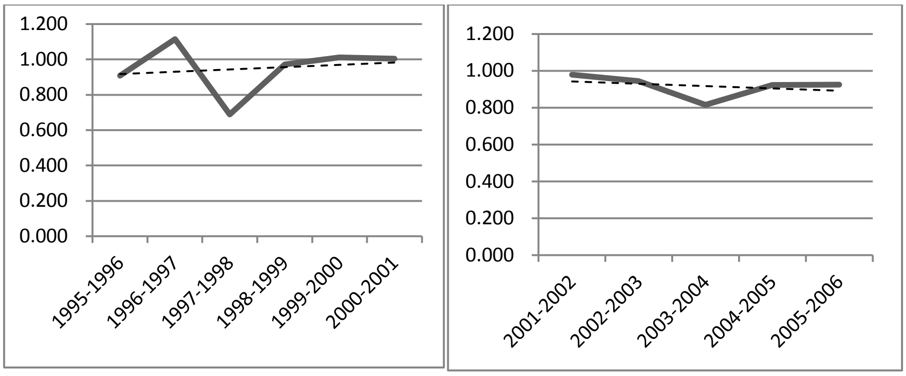
Table 6 shows the annual mean, overall mean and dispersion of the MPI measure for a balanced panel data of 63 generators observed consecutively between 1995 and 2006. ECI and TCI components are similar in this period. The average MPI is 0.928, which suggests a decreasing trend in average efficiency over time (see figure 1). The dotted line is the fitted linear regression of the MPI values, which exhibits a gradually decreasing trend over the sample period. In the early period, the values are largely fluctuating

Table 6 Development of Malmquist Productivity Index Over Time, 63x12=756 Observation

Year	ECI			TCI	MPI
		PCI	SCI		
1995-1996	0.992	0.997	0.995	0.915	0.908
1996-1997	0.998	0.996	1.002	1.117	1.115
1997-1998	0.841	0.971	0.866	0.819	0.689
1998-1999	0.988	1.004	0.984	0.983	0.971
1999-2000	0.958	0.975	0.982	1.055	1.011
2000-2001	0.990	0.985	1.005	1.012	1.003
2001-2002	1.003	1.001	1.002	0.975	0.978
2002-2003	1.033	0.986	1.048	0.914	0.944
2003-2004	0.910	0.959	0.949	0.895	0.815
2004-2005	0.924	1.070	0.864	0.999	0.923
2005-2006	0.987	0.860	1.148	0.935	0.924
Sample Mean	0.964	0.981	0.983	0.962	0.928
Sample Std dev	0.062	0.040	0.036	0.023	0.061
Average 1995-2000	0.953	0.989	0.964	0.972	0.927
Average 2001-2006	0.970	0.973	0.998	0.943	0.915
Difference	0.017	–0.016	0.033	–0.029	–0.012

Note: TCI=technical change index, ECI=Technical efficiency change index, PCI=Pure technical efficiency change, SCE=scale efficiency change, MPI=Malmquist productivity index.

Figure 1 MPI Trend before and after the 2001 Restructuring Process



due to the Asian financial crisis. At the beginning of the restructuring period, the efficiency level was high. However, as time elapses, efficiency deteriorates.

Figure 1 shows the different trends before and after the 2001 restructuring process. By comparing the fitted line of the two graphs, we see the slowly increasing pattern before 2001 and gradually decreasing trend after 2001. Thus efficiency during the period before restructuring period was generally higher than that of the period after restructuring. In sum, we cannot find any evidence of efficiency enhancement as a result of the restructuring process.

The efficiency factors of productivity change by separating the two key periods, before and after the restructuring process, suggest the following. During the before-restructuring period, inefficiency comes from TE factors, especially the SE component, while in the after-restructuring period, SE efficiency is increasing. On the other hand, the TCI declines considerably. The PCI also lowered. As a result, the total MPI decreases after the restructuring, due to the decreasing technical change effect.

In sum, comparing the two periods shows that: (i) while PCI was a main factor in the 1995-2001 period, SE is the source of positive impact in the post-2001 period with increasing facility capacity and utilization; (ii) the decrease of PCI and TCI means that there are not enough management efficiency enhancements and technological improvements in the electricity generation industry, and finally; (iii) the productivity index of both periods is less than unity, suggesting that the industry exhibited technically inefficient status on average. Despite productivity was declining over time, but we cannot conclude whether the decreasing productivity in recent years derives from the 2001 restructuring or from the 2004 holding restructuring process.

6.3. Lessons Learned

The parametric approaches provide some interesting result on effectiveness attributable to various characteristic of generators which cannot be acquired from a non-parametric approach. By analysing the effects of such factors, we identify the key factors that affect production efficiency. The stochastic frontier method has the added advantage in that it can be applied to unbalanced data resulting from the exit of old and the entry of new generators into the market. The methods employed are together complementary in analysing performance of power plants. In addition, MPI analysis provides important information about the changing trend of efficiency over time.

We have generated results based on a comprehensive model formulation, estimation and sensitivity analysis as well as examined characteristic-related features in efficiency and efficiency-trend over time. From the EE model and the VRS-DEA model, we identified the key factors in power generation. The significant factors that affect output are facility type, maintenance cost, real fuel cost, and other costs factors. As expected, nuclear plants, base load facilities, and large sized facilities are among those characteristics of power plants that show high levels of efficiency in power generation. Their organization and structure of production is mostly adapted to the long term national power generation plan and policy.

In analysing efficiency by characteristics, nuclear-sourced facilities and the largest size facilities show the highest efficiency values compared to their respective counterparts. The ranking of efficiency levels among fuel type sources is nuclear, bituminous, oil, anthracite, LNG, and pumping hydro in

CRS-DEA. The ranking of LNG and pumping hydro changed under the VRS condition. The mean efficiency values of nuclear and bituminous are higher than 90%. The high efficiency of these plants can be attributed to facility type. In this case base load, which has to be used with priority, exhibits the highest efficiency. There are major differences in efficiency between the CRS and VRS cases, except for the nuclear and coal fired plants. The efficiency of base load plants is the highest and that of peak load plants is the lowest. The generators with 15 to 20 years of operation show the highest efficiency levels among the different age cohorts.

We find a decreasing trend in the efficiencies generated from all the models. While the EE model shows a continually decreasing trend, the EC model shows some fluctuations over time. After separation in 2001 the technical efficiency lowered slightly compared with the period before the separation, due to a lower scale efficiency change. The DEA efficiency results also provide the same conclusion. In other words, the efficiency of GENCOs did not improve, as was expected, after the separation process. However, the amount of scale effect increased after the separation.

The MPI results suggest declining efficiency. The mean of MPI is 0.928, which suggests efficiency decreased over the period. By separating the period into before and after the separation, we can discern a slowly increasing pattern before 2001 and a gradually decreasing trend after 2001. Inefficiency comes from scale efficiency in the before-restructuring period, while in the after-restructuring time, technical change seems to be the cause of the decline. In total, productivity declines over time. As such, we cannot relate any efficiency enhancement effect to the restructuring of the industry.

There are two ways to improve the efficiency of the electricity industry. First, is through a continued restructuring process and the strengthening of competition among GENCOs. Second, is through GENCOs' reintegration into KEPCO, which allows for a better utilization of the economies of scale through centralized fuel purchasing, reallocation of labour and research and development which are important production factors and production cost components.

7. SUMMARY AND CONCLUSION

In this research we analysed the efficiency of power generation units in Korea with the use of different performance methodologies including estimations of stochastic frontier production models and computations using DEA and the MPI. The diversity of methods allows for comprehensive analysis and sensitivity of the efficiency and productivity variables based on the same dataset. The results indicated that net generation is affected mainly by facility type, maintenance cost, real fuel cost, and other production costs.

More specifically, from the analysis using SFA methodology, we noticed that the variable with the largest impact on the level of efficiency is the facility type. Facility efficiency was estimated to lie between 0.80 and 0.90 suggesting that many facilities are currently operating at their highest efficiency levels. The results also show that companies do differ in their level of efficiency and this has shown a decreasing trend over time. The restructuring was found to have had a short-run negative effect on the level of efficiency. The facility size on the other hand did not have much effect on efficiency levels, while the base load type was found to exhibit larger efficiency than the middle and peak load types. There was no concrete effect of age on the level of efficiency observed. Regarding the fuel source and plant type, the nuclear type was the most efficient plant type in the industry.

From the analysis using DEA methodology, as with the SFA methodology, we found that the same company KHNP was the most efficient among the GENCOs. Regarding the fuel source, facilities using nuclear are again the most efficient facilities. Facilities using hydro power had the lowest level of efficiency. We also noticed that the base load type facility is more efficient than the middle and peak load type facilities. Other factors such as facility size, age, and restructuring period also had effects on the efficiency level. Facility size and efficiency level had a positive relationship, whereas age and efficiency were negatively correlated. The restructuring process seemed to have had a negative effect on efficiency.

From the analysis using the MPI, we noticed a decreasing trend in productivity during the period of the study. We also noticed that in the beginning of the restructuring process efficiency was high, but as time elapsed, efficiency started to decrease. We conducted an analysis based on a separation of the before-restructuring and the after-restructuring periods. From the analysis, we found that in the before-restructuring period, inefficiency arose from TE factors, whereas in the after-restructuring period, SE went up. We therefore conclude that the decreasing TCI induced the productivity decline. Arguably, the national energy generation plan and security have been related to the high level of efficiency of nuclear power plants, base load type plants, and large size generation facilities. *T*-test for equality of means in efficiency suggests that the management efficiency was slightly lower after the six GENCOs separated from KEPCO in 2001.

Finally we wish to note some limitation of this study. First, for the SFA methodology, only a production function was used, putting aside the estimation of a cost function. This was due to the unavailability of price information. Further research may explore better models for the stochastic frontiers. In sum, we are in favour of parametric models where one can specify a model of behaviour based on theory and use advanced econometrics methods that take into account the exit and entry of generators and non-production and the unobservable characteristics of the producers and the market, as well as identify and estimate the effects of various determinants of inefficiency.

APPENDIX

Table A1 Summary of Heterogeneity in Efficiency by Different Plant and Generator Characteristics, N=1,637

	Company						Plant Type						
	KOSEPCO	KOMIPO	WP	KOSPO	EWP	KHNP	Nuclear	Hydro	Oil	Anthracite	Bituminous	Pumping Hydro	LNG
EE Model	0.640	0.527	0.559	0.591	0.556	0.740	0.881	0.653	0.559	0.822	0.832	0.170	0.388
EC Model	0.521	0.487	0.629	0.595	0.459	0.766	0.834	0.723	0.427	0.577	0.584	0.753	0.528
CRS	0.725	0.624	0.726	0.704	0.719	0.974	0.974	.	0.697	0.665	0.954	0.397	0.556
VRS	0.779	0.754	0.833	0.845	0.802	0.979	0.979	.	0.822	0.715	0.962	0.710	0.691
VRS-SE	0.927	0.831	0.875	0.826	0.894	0.995	0.995	.	0.851	0.941	0.992	0.603	0.824

	Year											
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
EE Model	0.692	0.682	0.688	0.588	0.596	0.615	0.634	0.624	0.637	0.609	0.591	0.557
EC Model	0.754	0.729	0.704	0.686	0.671	0.643	0.618	0.586	0.556	0.527	0.498	0.462
CRS	0.851	0.831	0.803	0.707	0.715	0.704	0.738	0.726	0.747	0.730	0.715	0.711
VRS	0.944	0.924	0.888	0.919	0.904	0.766	0.783	0.794	0.810	0.790	0.787	0.781
VRS-SE	0.903	0.898	0.905	0.776	0.790	0.912	0.921	0.904	0.915	0.912	0.898	0.902

	Facility Size (MW)						Facility Type		
	0-15	15-100	100-250	250-500	500-750	750-1000	Base	Middle	Peak
EE Model	0.474	0.792	0.516	0.562	0.797	0.866	0.846	0.559	0.470
EC Model	0.709	0.718	0.584	0.500	0.645	0.789	0.664	0.427	0.634
CRS	0.497	0.731	0.582	0.753	0.894	0.983	0.923	0.697	0.524
VRS	1.000	0.856	0.748	0.816	0.907	0.987	0.936	0.822	0.695
VRS-SE	0.497	0.855	0.799	0.911	0.983	0.995	0.986	0.851	0.779

	Age (Years)										
	00-05	05-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-99
EE Model	0.633	0.624	0.675	0.631	0.525	0.558	0.663	0.682	0.498	0.452	0.706
EC Model	0.643	0.582	0.649	0.580	0.503	0.564	0.624	0.715	0.660	0.547	0.762
CRS	0.783	0.760	0.807	0.817	0.651	0.545	0.449	0.210	.	.	.
VRS	0.885	0.817	0.855	0.898	0.793	0.677	0.562	0.229	.	.	.
VRS-SE	0.880	0.922	0.940	0.904	0.826	0.825	0.827	0.881	.	.	.

Notes: EE=Technical Efficiency Effect, EC=Error Component, CRS=Constant Return to Scale, VRS=Variable Return to Scale, SE=Scale Effect, Korea South-East Power Company (KOSEP), Korea Midland Power Company (KOMIPO), Korea Western Power Company (WP), Korea Southern Power Company (KOSPO), Korea East-West Power Company (EWEP) and Korea Hydro and Nuclear Power Company (KHNP).

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