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The Impact of Liberalization on the Production of Electricity in Japan

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Abstract

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The Impact of Liberalization on the Production of Electricity in Japan*

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ABSTRACT

This study aims to measure the impact of liberalization on the efficiency of electricity production in Japan, and to examine whether or not economies of scope exist between electricity generation and transmission. Since 1995, liberalization of the electricity market in Japan has been phased in and regulations on entry have been relaxed three times. One motivation for these regulatory changes has been to improve the efficiency of electricity production by introducing competition. Using a panel data set on the nine main power companies in Japan over the period 1970-2010, fixed-effects and stochastic frontier estimates of the cost function are obtained and compared. Estimates of the cost function show that liberalization has improved cost efficiency. Economies of scope are found to exist for all firms.

Keywords: cost function, liberalization, fixed-effects model, stochastic frontier analysis, vertical integration

JEL Classification Codes: H32, D22, L11

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1. Introduction

Recently inefficiencies in the Japanese electricity market have been the focus of some attention. In particular, even though the liberalization of the electricity market has been phased in and regulations on entry have been relaxed three times since the 1990s, the monopolistic nature of the Japanese electricity market has been the subject of much discussion. There has also been some discussion of the possible separation of electricity generation and transmission. Hence, this study aims to measure the impact of these liberalizations on the efficiency of electricity production in Japan, and to examine whether or not economies of scope exist between electricity generation and transmission. It is expected that the previous liberalizations have contributed to improving cost efficiencies step by step.

A great deal of literature has examined whether or not inefficiencies exist in the electricity industry. Papers in this literature which estimate either a production function or a cost function can be divided into two groups; those which use a parametric approach; and those which use non-parametric approach. Papers using a parametric approach tend to estimate the cost function rather than the production function because there are endogeneity problems associated with input choices when estimating a production function. Kuwabara and Ida (2000) estimate a translog cost function for the Japanese electric companies. This method to estimate the translog cost function is popular and is the same method used to estimate the cost functions of firms in other industries. For example, Kitasaka (2011a) and (2011b) estimates translog cost functions for Japanese public and private universities. Kuwabara and Ida (2000) aim to measure the extent of economies of scale and economies of scope in the electricity industry in Japan, but they do not examine the impact of the liberalization measures

that have been implemented). Goto and Inoue (2012) estimate a composite cost function for the Japanese electric companies, using a simultaneous estimation. One advantage of estimating a composite cost function is that 0 can be directly substituted for the quantities of outputs into the model when the economies of scope are calculated. Goto and Inoue (2012) measure the economies of scope, in electricity production under this assumption. Most of the existing studies using a parametric approach estimate whereby the cost function and cost share functions are estimated jointly. Harimaya (2003) estimates a translog cost function of Japanese banks using stochastic frontier analysis, and this enables him, to examine the change of inefficiencies and the significance of the inputs.

Papers using a non-parametric approach typically employ Data Envelopment Analysis (DEA). Tsutsui (2000) measures the inefficiencies of Japanese electric companies using Malmquist Index, and then compares the estimated inefficiencies of Japanese electric power companies with those of U.S. companies. In addition to measuring these inefficiencies, Tsutsui (2000) also examines whether there has been a shift in the production frontier. This is one advantage of Malmquist Index. Arocena (2008) measures the impact of the diversification and the vertical integration of Spanish electric companies via the DEA approach by comparing companies which have different degrees of diversification and vertical integration. One disadvantage of the DEA approach is that the significances of the input variables cannot be evaluated. Hence, the impact of the liberalization cannot be examined via DEA statistically.

As can be seen from this literature survey, the impact of the relaxation of entry restrictions on the inefficiency of Japanese electric companies has not examined. The first contribution of this study is to examine the impact of the liberalization in the

Japanese electricity market by estimating a translog cost function directly. The second contribution of this paper is to measure the economies of scope, using estimates of this translog cost function.

The rest of this paper is organized as follows. Section 2 provides an outline of the liberalizations of the electricity market that have been implemented in Japan. Section 3 discusses the empirical models used to examine the impact of these liberalizations and how this model can be used to check for existence of economies of scope between electricity generation and electricity transmission, while section 4 details the definitions of the variables used and the data sources. Estimation results are reported in section 5, and section 6 contains a conclusion.

2. Liberalization of the Electricity Market in Japan

In the 1990s, deregulation to reduce inefficiencies in the electricity market was popular all over the world. At that time, many European countries and the United States deregulated their electricity markets. Since 1995, liberalization of the electricity market in Japan has been phased in and the regulations on entry have been relaxed three times. This liberalization aimed to improve the structural efficiency of firms in the industry and to reduce electricity bills that were said to be higher than the average level paid by consumers in foreign countries (Yamaguchi (2007)).

Prior to 1995, Japan was divided into ten geographic regions, and within each region a monopoly on power generation and distribution was allocated to one general electric power utility. As a result, there are ten general electric power utilities in Japan (see, Yamaguchi (2007))¹. These ten companies each engaged in generation,

¹ The ten companies are *Hokkaido Electric Power Company* in Hokkaido, *Tohoku Electric*

transmission and distribution of electricity within their respective geographical regions. After the collapse of Japan's overheated stock and real estate markets in the early 1990s, higher electricity bills in Japan compared to those paid by consumers in foreign countries became an issue. The Japanese government aimed to improve the efficiency of electricity production by introducing competition into the electric power market.

Table 1 shows the main points of the revisions of the Electricity Business Act (*Denkijigyouhou*). First, the Electricity Business Act was revised and a new act was enacted in December 1995. This first revision enabled independent power producers (IPP, *Dokuritsukei Hatsudenjigyousha*) to enter the wholesale markets for electricity supply. In this context, the wholesale market for electricity refers to the generation of electricity in Japan. The electricity generated by the new entrants was sold to the general power companies and then supplied to consumers through the transmission sectors owned and operated by the general electricity utilities. In March 2000, the Electricity Business Act was revised again so that power producer and suppliers (PPS, *Tokuteikibo Denkijigyousha*) could enter the retail markets for electricity, that is, PPS could sell electricity to consumers. This revision permitted new entry into the retail market for electricity where each consumer's electric power contract was for over 2,000 kW. The remaining part of the retail market was maintained as a monopoly of the relevant regional electric power company. That is why this second revision is called a partial liberalization. In 2003, the Electricity Business Act (*Denkijigyouhou*) was revised to allow entry into the retail market where each consumer's electric power

Power Company in the Tohoku region, *Tokyo Electric Power Company* in the Kanto region, *Hokuriku Electric Power Company* in the Hokuriku region, *Chubu Electric Power Company* in the Chubu region, *Kansai Electric Power Company* in the Kansai region, *Chugoku Electric Power* in the Chugoku region, *Shikoku Electric Power Company* in the Shikoku region, *Kyushu Electric Power Company* in the Kyushu, and *Okinawa Electric Power Company* in Okinawa.

contract was over 500 kW in April 2004, and then where each consumer's electric power contract was over 50 kW in April 2005. In short, this revision expanded the sections of the retail market where the PPSs could enter. That is why this is called an expansion of the partial liberalization. Moreover, the market rules for electricity transmission sector and the watchdog organization (*Souhaidengyoutou Gyomushienkikan*) have been established to realize fair deals.

Figure 1 shows how the retail market shares of various operators have changed after the electricity liberalization began. In Figure 1, the supply of electricity by IPPs is included in the Wholesale Electricity Utilities. The maximum of market share of the PPSs was 0.74 % after the PPS entered the retail market. The ten main electric power companies have been able to maintain a market share of 70 – 80 % even since the electricity liberalization. However, as a result of new entry, electricity prices have fallen. Figure 2 shows declines in the average electricity prices for households and industry around the liberalizations. Though competition between the new entrants and existing suppliers has occurred (Kinugasa (2011)), there would still appear to be ample room for increasing the market shares of new entrants by still more liberalization. The structural separation of the transmission sector of electricity from the generation of electric power, which has been discussed recently, is one example for the further liberalization. In the next section, the impacts of these three-step-liberalizations on the production of electricity are examined, using an econometric model.

[Table 1 around here]

[Figure 1 around here]

3. Model

3-1 Translog Cost Function with Inefficiency Term

Assume that in the generation, transmission and distribution of electricity there are three inputs, labor, capital and fuel, and two outputs, the generation of electricity, and the transmission and distribution of electricity, these inputs and outputs are assumed to be related by a translog cost function. The number of inputs and the number of outputs are defined following Goto and Inoue (2012). The outputs are measured as the total quantity electric power sold in fiscal year and the total length of transmission routes, respectively. This assumption makes the estimation of the economies of scope between the generation and transmission & distribution sectors easy. To measure the inefficiency due to technical factors, a stochastic frontier version of the translog cost function is employed. Once the symmetry of the second derivatives of the cost function with respective two different input prices is taken into account, the stochastic frontier translog cost function can be written as follows:

$$\begin{aligned} \ln TC_{it} = & \alpha_0 + \alpha_1 \ln y_{1it} + \alpha_2 \ln y_{2it} + \beta_1 \ln p_{1it} + \beta_2 \ln p_{2it} + \beta_3 \ln p_{3it} + \gamma_{11} \frac{1}{2} (\ln y_{1it})^2 + \\ & \gamma_{22} (\ln y_{2it})^2 + \gamma_{12} \ln y_{1it} \ln y_{2it} + \delta_{11} \frac{1}{2} (\ln p_{1it})^2 + \delta_{22} \frac{1}{2} (\ln p_{2it})^2 + \delta_{33} \frac{1}{2} (\ln p_{3it})^2 + \\ & \delta_{12} \ln p_{1it} \ln p_{2it} + \delta_{23} \ln p_{2it} \ln p_{3it} + \delta_{31} \ln p_{3it} \ln p_{1it} + \rho_{11} \ln y_{1it} \ln p_{1it} + \rho_{12} \ln y_{1it} \ln p_{2it} + \\ & \rho_{13} \ln y_{1it} \ln p_{3it} + \rho_{21} \ln y_{2it} \ln p_{1it} + \rho_{22} \ln y_{2it} \ln p_{2it} + \rho_{23} \ln y_{2it} \ln p_{3it} + \tau_1 D_{1t} + \tau_2 D_{2t} + \\ & \tau_3 D_{3t} + \ln t + \varphi_{thermal} thermal_{it} + \varphi_{nuclear} nuclear_{it} + \varphi_{new} new_{it} + u_{it} + v_{it}. \end{aligned} \quad (1a)$$

$$\ln TC_{it} = f(\cdot) + u_{it} + v_{it} \quad (1b)$$

where TC_{it} is the total cost of the i -th firm at time t , $y_{j\ it}$ is the quantity of the j -th output for the i -th firm at time t , $p_{k\ it}$ is the observed price of the k -th input for the i -th firm at time t , D_{st} is a 0-1 dummy variable taking the value of 1 if at time t the s -th change of the electricity liberalization has been implemented ($s=1,2,3$), t is a time trend, $thermal_{it}$ is the ratio of thermal power generation to hydroelectric generation for the i -th firm at time t , $nuclear_{it}$ is the ratio of nuclear power generation to hydroelectric generation for the i -th firm at time t , new_{it} is the ratio of new energy generation to hydroelectric generation for the i -th firm at time t , α_j , β_k , γ_{jl} , δ_{km} , ρ_{jk} , τ_s , $\varphi_{thermal}$, $\varphi_{nuclear}$, and φ_{new} are coefficients to be estimated, u_{it} is the inefficiency term for the i -th firm at time t , and v_{it} is a standard disturbance. In this model, it is assumed that all firms have the same production technology.

3-2 Method for Estimating Economies of Scope²

Baumol, Panzar and Willing (1982) define costs as being complementary if

$$\frac{\partial^2 TC}{\partial y_1 \partial y_2} < 0. \quad (2)$$

One interpretation of equation (2) is that for costs to be complementary the marginal cost of each output decline when the amount of the other output increases. The second derivative on the left hand side of equation (2) can be computed using (1) as:

$$\frac{\partial^2 TC}{\partial y_1 \partial y_2}$$

² For the convenience, the i and t subscripts denoting the firm number and time are omitted.

$$\begin{aligned}
&= \left(\frac{TC}{y_1 y_2} \right) \left[\frac{\partial \ln TC}{\partial \ln y_1 \partial \ln y_2} + \frac{\partial \ln TC}{\partial \ln y_1} \cdot \frac{\partial \ln TC}{\partial \ln y_2} \right] \\
&= \left(\frac{TC}{y_1 y_2} \right) [\gamma_{12} + (\alpha_1 + \gamma_{11} \ln y_1 + \gamma_{12} \ln y_2 + \rho_{11} \ln p_1 + \rho_{12} \ln p_2 + \rho_{13} \ln p_3)(\alpha_2 + \\
&\gamma_{22} \ln y_2 + \gamma_{12} \ln y_1 + \rho_{21} \ln p_1 + \rho_{22} \ln p_2 + \rho_{23} \ln p_3)]. \tag{3}
\end{aligned}$$

In equation (3), $\left(\frac{TC}{y_1 y_2} \right)$ is always positive because TC, y_1 , and y_2 are all positive.

Therefore, to see if (3) is satisfied, it is only necessary to examine the sign of the following expression:

$$\begin{aligned}
SCP_{12} &= \gamma_{12} + (\alpha_1 + \gamma_{11} \ln y_1 + \gamma_{12} \ln y_2 + \rho_{11} \ln p_1 + \rho_{12} \ln p_2 + \rho_{13} \ln p_3)(\alpha_2 + \\
&\gamma_{22} \ln y_2 + \gamma_{12} \ln y_1 + \rho_{21} \ln p_1 + \rho_{22} \ln p_2 + \rho_{23} \ln p_3). \tag{4}
\end{aligned}$$

Since this is a function of unknown parameters and the values of the explanatory variables, it needs to be evaluated using estimates of the parameters and the sample values of the explanatory variables.

3-3 Estimated Model

In equation (1) with $u_{it}=0$ we get a pooling model.

Since the data being used to estimate the cost function are panel data, it is natural to estimate equation (1) allowing for individual firm effects that are either fixed and random effects. In this case, u_{it} is a time-invariant random variable that is (not) correlated with the explanatory variables for the fixed (random) effects model. In addition to these standard panel models, some stochastic frontier models are estimated in this study to consider the possibility of the existence of the stochastic inefficiencies. To try and capture any cost inefficiency, four models are assumed: the pooling Stochastic Frontier (SF) model; the random-effects SF model; the fixed-effects SF

model; and the Battese and Coelli (1992) Time Varying Stochastic Frontier (TV-SF) model. The estimated models are as follows:

Pooling Stochastic Frontier Model

$$\ln TC_{it} = f(\cdot) + u + v_{it}, \quad u \sim HN(0, \sigma_u^2), \quad v_{it} \sim N(0, \sigma_v^2) \quad (5)$$

Random-Effects SF Model

$$\ln TC_{it} = f(\cdot) + u_i + v_{it}, \quad u_i \sim HN(0, \sigma_u^2), \quad v_{it} \sim N(0, \sigma_v^2) \quad (6)$$

Fixed-Effects SF Model

$$\ln TC_{it} = f(\cdot) + \zeta_i + u_i + v_{it}, \quad u_i \sim HN(0, \sigma_u^2), \quad v_{it} \sim N(0, \sigma_v^2) \quad (7)$$

Battese and Coelli Time Varying SF Model

$$\begin{aligned} \ln TC_{it} = f(\cdot) + u_{it} + v_{it}, \quad u_{it} = \exp\{-\eta(t - T_i)\}u_i \\ u_i \sim HN(0, \sigma_u^2), \quad v_{it} \sim N(0, \sigma_v^2), \end{aligned} \quad (8)$$

where u , u_i , and u_{it} is a measure of technical inefficiency, v_{it} is standard disturbance, ζ_i is the individual fixed effect, T_i is the number of periods in their balanced panel data, N denotes a normal distribution that generates a non-negative random variable, and HN denotes a half-normal distribution that generates a non-negative random variable. The difference between models (5), (6), (7) and (8) is the specification of the inefficiency term is. Models (5), (7), and (8) take no account of the panel nature of the data, while model (6) does. It should be noted that models (5) and (6) and non-nested models, while equation (6) can be obtained as a special case of equation (7) by imposing

the restriction $\zeta_i = 0$ for all i , and as a special case of equation (8) by imposing the restriction $\eta = 0$. The pooling model can be obtained as a special case of equations (5) and (6) by imposing the restriction $\sigma_\mu^2 = 0$.

If $\sigma_\mu^2 = 0$ in all these models, then the pooling model is chosen. The standard fixed models is a nested within equation (7) by imposing $\sigma_\mu^2 = 0$. The standard random effects model and any one of the stochastic frontier models are non-nested models. In this case, this study revert to standard panel analysis by estimating a pooling model, a random-effects model, and a fixed-effects model.

4. Data

Data on the corporate accounts of the ten general electricity utilities are drawn from the “Electricity Statistics Information (*Denryoku Toukeijouhou*)” published by the Federation of Electric Power Companies of Japan. Though ten general electricity utilities have existed in Japan since 1970, *Okinawa Electric Power Company* is excluded from the analysis in this study. The reason for this is that electricity production by *Okinawa Electric* has some important characteristics that differ from other companies. For example, the scale of electricity production at *Okinawa Electric* *P* is much smaller than at the other companies. In addition, *Okinawa Electric* is the only general electricity utility not using nuclear energy for electric power generation. Finally, the prefecture of *Okinawa* is made up of a number of small islands where *Okinawa Electric* is obliged to generate and supply electricity. As a result, it is thought that *Okinawa Electric Power Company* has a unique production function and a unique cost function. Hence, a balanced panel data set consisting of annual data on the other nine general electricity utilities from 1970 to 2010 is used.

TC is total costs and is measured in million yen. The output in the electricity generation sector, y_1 , is defined as the total quantity of electric power sold to consumers in the lighting and power sections (MWh). The output in the transmission sector, y_2 , is defined as the length in kilometers of the transmission route including both overhead and underground routes. The unit fuel cost, p_1 (million yen), is defined as

$$p_1 = (\text{total fuel expenses})/(\text{total quantity of fuel inputs}). \quad (8)$$

Two definitions for the cost of capital, p_2 (million yen), are employed in this study. The first uses the gross fixed capital (including nuclear fuel). It is defined as

$$p_{2t} = (DE_t/GFC_{t-1}) + LPR_t, \quad (9)$$

$$GFC_{t-1} = EUFA_{t-1} + FAP_{t-1} + NF_{t-1} + IA_{t-1}, \quad (10)$$

where p_{2t} is the cost of capital in year t , DE_t is the depreciation expenses, GFC_{t-1} is the gross fixed capital in year $t-1$, LPR_t is the long-term prime rate for loans made by the main Japanese banks in year t , $EUFA_{t-1}$ is the electric utility's fixed assets in year $t-1$, FAP_{t-1} is the fixed assets in process in year $t-1$, NF_{t-1} is the nuclear fuel in year $t-1$, and IA_{t-1} is investment and other assets in year $t-1$. Data on the long-term prime rate for loans made by the main Japanese banks are drawn from the "Bank of Japan Statistics" published by Bank of Japan. The second definition of the cost of capital also uses the gross fixed capital except that nuclear fuel is not treated as an asset. That is, NF_{t-1} is excluded from the right hand side of equation (9). Table 2

reports descriptive statistics for the two cases, when the price of capital is estimated using the gross fixed capital including nuclear fuel as an asset, p_{2_1} , and when the price of capital is estimated using the gross fixed capital excluding the nuclear fuel, p_{2_2} . The personal expenses per worker per year, p_3 (million yen), is defined as

$$p_3 = (\text{personal expenses}) / (\text{the number of workers}). \quad (11)$$

D_1 is a 0 - 1 dummy variable taking the value of 1 in 1995 – 2010, D_2 is a 0 - 1 dummy variable taking the value of 1 in 2001 – 2010, and D_3 is a 0 - 1 dummy variable taking the value of 1 in 2004 – 2010. These three dummy variables correspond to the three entry related liberalizations discussed in section 2.

Table 2 provides descriptive statistics on all the relevant variables. The variables LNC, LNY1, LNY2, LNP1, LNP2, and LNP3 in Table 2 refer to the natural logs of TC, y_1 , y_2 , p_1 , p_2 , p_3 , respectively.

[Table 2 around here]

5. Result and Discussion

LIMDEP 9.0 is used for this estimation (see Greene). Tables 3 shows the estimated results³. For models A – E show the estimated results when in calculating the price of capital nuclear fuel is treated as an asset, while for models F – J show the estimated results when in calculating the price of capital nuclear fuel is not treated as an asset.

³ Sensible estimates for the Random-effects Stochastic Frontier model and Battese and Coelli Time Varying Stochastic Frontier model could not be obtained correctly because estimated variance matrix of estimates is singular.

In all models (Models A - J), the coefficients of three dummy variables associated with the electricity liberalization are negative and significant. This suggests that the three entry liberalizations have had some impact in cutting costs. The coefficients of the ratio of thermal power, nuclear power, and new energy to hydroelectric power differ between the non-frontier models and the frontier models. In both non-frontier models and frontier models, the coefficients of thermal power are positive and significant in models A, D, E, F, I, and J, but insignificant models B, C, G, H. The reason why the costs of thermal power generation have been increased is thought that the oil price has been increased in the sample period. Before the coefficients of nuclear power and new energy are discussed, the models are specified.

In choosing between the usual panel models and frontier models, frontier models (Models D, E, I, J) are supported because the estimates of λ are positive and significant in all cases; every model suggests that there is a statistically significant inefficiency. In all the frontier models (Models D, E, I, J), the coefficients of nuclear power are positive but insignificant. This means that increasing of the ratio of nuclear power generation has not reduced the electricity generation costs. The coefficients of new energy are positive but insignificant in pooling SF models (Models D and I), while they are negative but insignificant in fixed-effects SF models (Models E and J). The cost efficiency of new energy is not clear.

The estimated coefficients associated with the time trend are positive and significant in all models. While technical innovation might be expected to lead to reductions in the cost of generation over time, stricter environmental and safety standards can be expected to have increased production costs over time.

When the results for the pooling SF models (Model D and I) and the fixed-effects SF models (Models E and J) are compared, the fixed-effects SF model (Models E and J) appears to be the more acceptable model because the fixed-effects models have considerations of panel.

To determine whether economies of scope exist, estimates from the fixed-effects models (Models E and J) are used. In both fixed-effects models, the assumption that the cost functions are increasing function on y_1, y_2, p_1, p_2 , and p_3 are satisfied in most of observation points. Table 4 reports some descriptive statistics for estimates of SCP_{12} for each power utility. The upper table shows the results when the nuclear fuel is treated as an asset, while the lower table show the results when the nuclear fuel is not treated as an asset. Since the minimum and maximum values of the estimates of SCP_{12} for each power utility are positive, economies of scope exist between the generation sector and transmission sector.

[Table 3 around here]

[Table 4 around here]

6. Concluding Remarks

This study measures the impact of liberalization on the efficiency of electricity production in Japan, and examines whether or not economies of scope exist between electricity generation and transmission. The estimation results suggest that production costs have fallen significantly following each of the three entry-related liberalizations and the existence of economies of scope. One notable result is that the existence of the inefficient factors which have been reduced the cost efficiency. One possible reason for this is that the the manegement cost of the nuclear power plants

have been increasing year by year. Though the actual cost nuclear power generation may be lower than other generation options, the management costs associated with nuclear power plants also should be considered. In this Stochastic Frontier Analysis (SFA), the form of cost function are assumed. Future research will check the robustness of the estimated results via SFA by using Data Envelopment Analysis (DEA).

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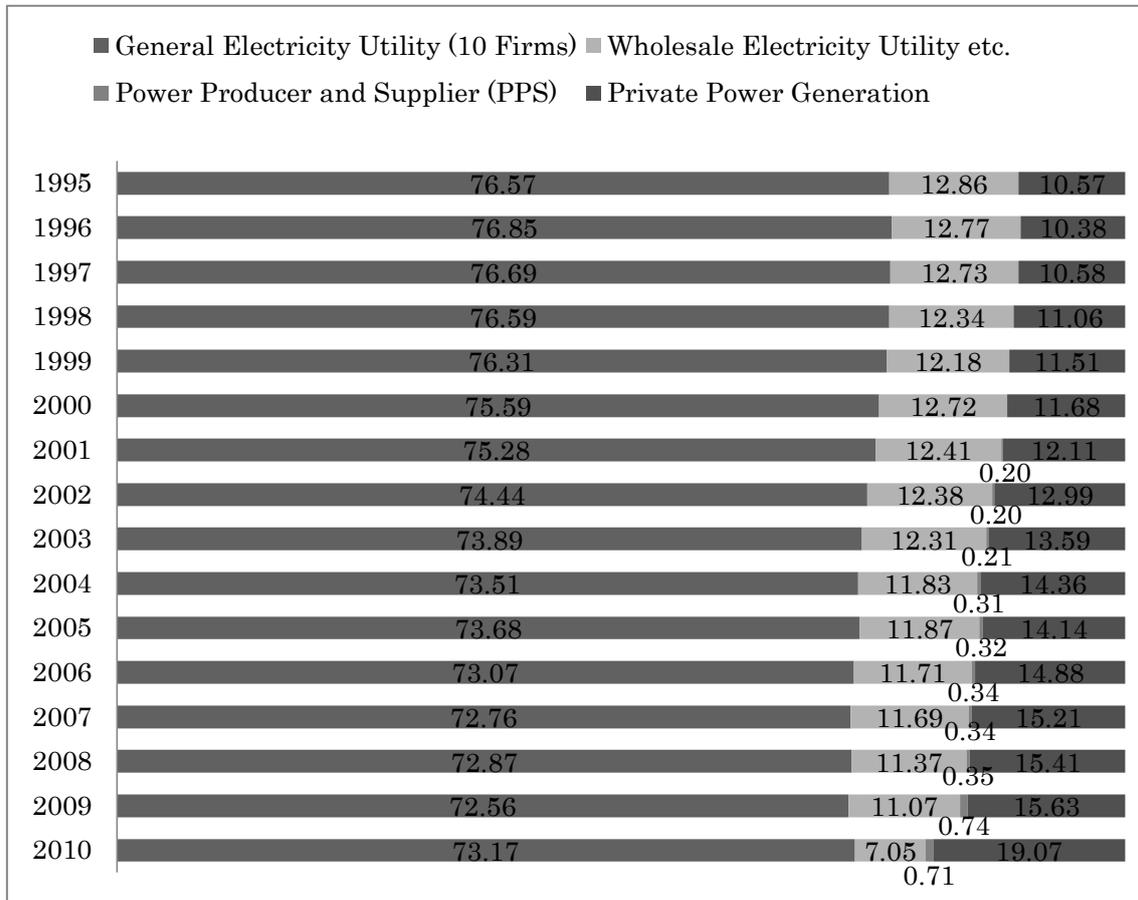
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(Website)

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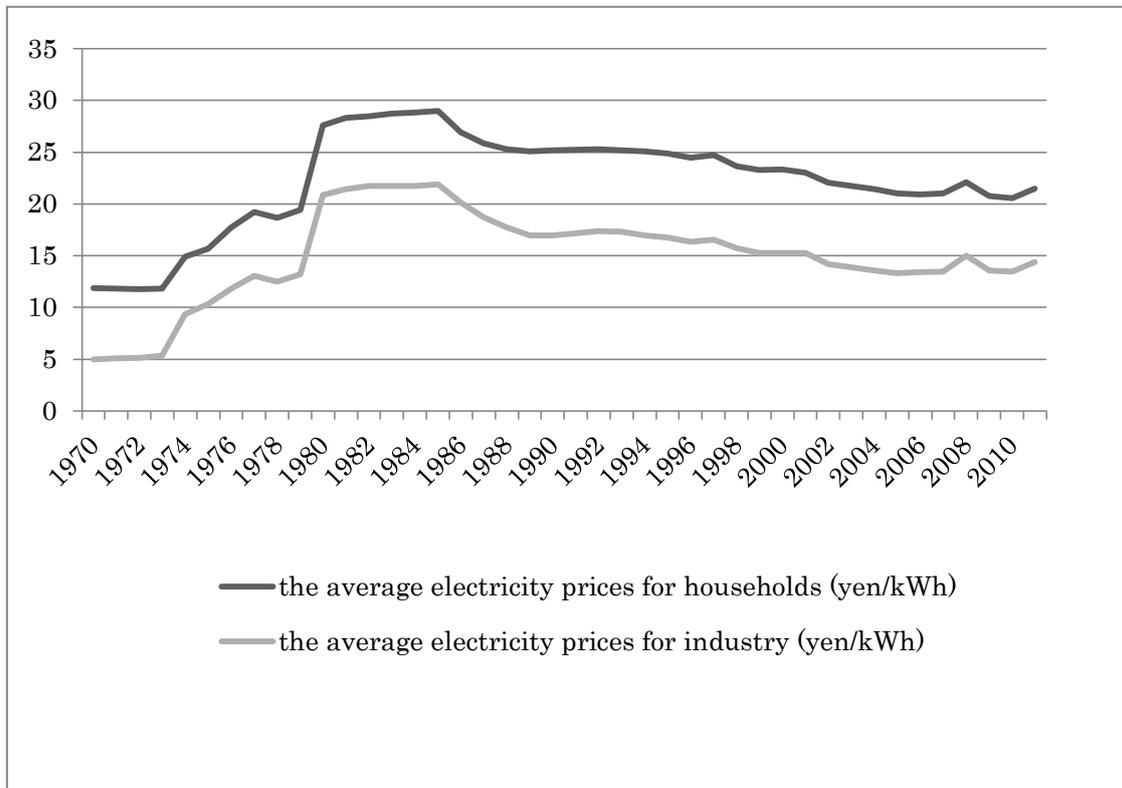
Tokyo Electric Power Company (<http://www.tepco.co.jp>)

Figure 1: Changes in Market Shares



Source: Minister of Economy, Trade and Industry (2011). “Material 3: Discussion Points of the Calculations for Electricity Charges” (*Shiryō 3: Denkiryoukin Santeijou no Kaku Ronten nitsuite*), constructed by *Heisei 23 nen 12 gatsu Denkiryoukinseido Unyou no Minaoshi nikakaru Yushikisyakaigi Jimukyoku*.

Figure 2: The Changes of the Average Electricity Prices in Japan



Source: Constructed by Author using the “Electricity Statistics Information (*Denryoku Toukeijouhou*)” published by the Federation of Electric Power Companies of Japan.

Notes:

The average electricity price for households is defined as
 (profit from electricity for lighting)/(total electricity consumed in lighting sector).

The average electricity price for industry is defined as
 (profit from electricity for power)/{(total electricity sales) – (total electricity consumed in power sector)}

Table 1: The Main Points of Revisions of the Electricity Business Act

Year	Entrants in the electric power generation	the liberalized retail market
- March, 1995	<u>Suppliers</u> <ul style="list-style-type: none"> · General Electricity Utility · Wholesale Electricity Utility · Private Power Generation 	/
April, 1995 - February, 1999	<u>Existing Suppliers</u> <ul style="list-style-type: none"> · General Electricity Utility · Wholesale Electricity Utility · Private Power Generation <u>New Entrants</u> <ul style="list-style-type: none"> · Wholesale Supplier (IPP etc.) · Specified Electricity Utility 	
March, 2000 - March, 2003	<u>Existing Suppliers</u> <ul style="list-style-type: none"> · General Electricity Utility 	Over 2,000 kW
April, 2004 - March, 2005	<ul style="list-style-type: none"> · Wholesale Electricity Utility · Private Power Generation 	Over 500 kW
April, 2005	<ul style="list-style-type: none"> · Wholesale Supplier (IPP etc.) · Specified Electricity Utility <u>New Entrant</u> <ul style="list-style-type: none"> · PPS 	Over 50 kW

Source: Constructed by Author referring the website constructed by Tokyo Electric Power Company

Table 2: Descriptive Statistics

Variable	Mean	Std.Dev.	Minimum	Maximum
LNC	13.588	0.992	10.874	15.682
LN1	17.684	0.847	15.817	19.511
LN2	8.977	0.594	7.829	9.957
LNP1	-3.734	0.546	-5.256	-2.685
LNP2_1	1.542	0.632	0.470	2.299
LNP2_2	1.543	0.631	0.472	2.299
LNP3	2.041	0.505	0.676	2.751
D1	0.390	0.488	0	1
D2	0.244	0.430	0	1
D3	0.171	0.377	0	1
LNT	7.596	0.006	7.586	7.606
THERMAL	5.699	3.159	0.537	17.145
NUCLEAR	2.639	2.791	0.000	12.955
NEW	0.026	0.083	0.000	0.462

Notes:

The total sample size is 369. The data is for the period from the 1970 fiscal to the 2010 fiscal year. *Okinawa Electric* is excluded from the analysis.

Table 3: Estimated Results

[1] p2 = P2_1

Model	Model A	Model B	Model C	Model D	Model E
	Pooling	Random-effects	Fixed-effects	Pooling SF	Fixed-effects SF
Variable					
Constant	-211.548 (45.921)***	-189.145 (44.130)***		-186.626 (42.011)***	
LNY1	1.828 (0.598)***	0.732 (0.973)	0.619 (1.507)	1.517 (0.549)***	1.879 (0.428)***
LNY2	-4.486 (0.998)***	-1.397 (1.261)	-0.001 (1.989)	-3.920 (0.952)***	-4.795 (0.772)***
LNP1	0.877 (0.553)	0.787 (0.508)	1.112 (0.519)**	1.006 (0.513)**	1.060 (0.336)***
LNP2	0.241 (0.580)	0.578 (0.548)	0.547 (0.595)	0.262 (0.515)	0.116 (0.294)
LNP3	1.894 (0.752)**	1.992 (0.777)***	0.733 (0.954)	2.442 (0.712)***	2.417 (0.484)***
LNY1_2	-0.359 (0.093)***	-0.146 (0.118)	-0.030 (0.166)	-0.316 (0.088)***	-0.375 (0.069)***
LNY2_2	-0.620 (0.190)***	-0.397 (0.235)*	-0.006 (0.349)	-0.600 (0.183)***	-0.655 (0.140)***
LNY1LNY2	0.592 (0.142)***	0.304 (0.160)*	0.022 (0.209)	0.548 (0.137)***	0.623 (0.107)***
LNP1_2	0.237 (0.059)***	0.244 (0.054)***	0.241 (0.055)***	0.251 (0.054)***	0.252 (0.040)***
LNP2_2	0.032 (0.075)	0.001 (0.070)	0.042 (0.072)	0.019 (0.067)	0.024 (0.042)
LNP3_2	-0.314 (0.150)**	-0.295 (0.139)**	-0.286 (0.144)**	-0.378 (0.138)***	-0.401 (0.090)***
LNP1LNP2	0.146 (0.055)***	0.181 (0.051)***	0.217 (0.053)***	0.129 (0.051)**	0.110 (0.033)***
LNP2LNP3	0.264 (0.092)***	0.281 (0.086)***	0.391 (0.091)***	0.218 (0.086)**	0.201 (0.060)***
LNP1LNP3	0.053	0.069	0.062	0.067	0.061

	(0.064)	(0.059)	(0.060)	(0.060)	(0.039)
LNY1LNP1	-0.015	-0.029	-0.067	-0.026	-0.020
	(0.030)	(0.027)	(0.029)**	(0.028)	(0.018)
LNY1LNP2	-0.098	-0.078	-0.036	-0.100	-0.108
	(0.036)***	(0.036)**	(0.043)	(0.031)***	(0.020)***
LNY1LNP3	0.018	-0.008	0.025	-0.006	-0.001
	(0.048)	(0.052)	(0.066)	(0.043)	(0.028)
LNY2LNP1	0.017	0.048	0.079	0.030	0.019
	(0.037)	(0.034)	(0.035)**	(0.035)	(0.022)
LNY2LNP2	0.165	0.104	0.005	0.172	0.199
	(0.052)***	(0.050)**	(0.059)	(0.047)***	(0.034)***
LNY2LNP3	-0.162	-0.119	-0.063	-0.142	-0.147
	(0.065)**	(0.063)**	(0.072)	(0.060)**	(0.041)***
D1	-0.070	-0.066	-0.059	-0.072	-0.077
	(0.026)***	(0.024)***	(0.024)**	(0.027)***	(0.019)***
D2	-0.153	-0.141	-0.151	-0.150	-0.154
	(0.025)***	(0.023)***	(0.023)***	(0.023)***	(0.016)***
D3	-0.157	-0.127	-0.120	-0.154	-0.176
	(0.028)***	(0.026)***	(0.027)***	(0.028)***	(0.018)***
LNT	29.085	25.480	41.679	25.765	28.295
	(5.926)***	(5.691)***	(6.851)***	(5.435)***	(0.396)***
THERMAL	0.007	0.002	0.004	0.007	0.008
	(0.002)***	(0.003)	(0.003)	(0.002)***	(0.002)***
NUCLEAR	-0.002	-0.010	-0.008	0.000	0.002
	(0.003)	(0.004)***	(0.004)**	(0.003)	(0.002)
NEW	0.056	0.212	0.366	0.009	-0.051
	(0.082)	(0.084)**	(0.091)***	(0.077)	(0.052)
σ_u				0.103	0.114
σ_v^2				0.002	0.003
σ_u^2				0.011	0.013
$\sigma = \sqrt{\sigma_v^2/\sigma_u^2}$				0.114	0.125
$\lambda = \sigma_u/\sigma_v$				2.132	2.268
				(0.274)***	(0.194)***

Log likelihood	416.968		456.427	421.333	420.345
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[2] p2 = P2_2

Model	Model F	Model G	Model H	Model I	Model J
	Pooling	Random-effects	Fixed-effects	Pooling SF	Fixed-effects SF
Variable					
Constant	-211.725 (45.918)***	-189.280 (44.125)***		-186.749 (42.010)***	
LNY1	1.828 (0.598)***	0.730 (0.972)	0.618 (1.507)	1.516 (0.549)***	1.878 (0.428)***
LNY2	-4.482 (0.998)***	-1.398 (1.260)	0.002 (1.989)	-3.916 (0.952)***	-4.791 (0.772)***
LNP1	0.875 (0.553)	0.786 (0.509)	1.111 (0.519)**	1.005 (0.513)**	1.058 (0.336)***
LNP2	0.245 (0.580)	0.580 (0.549)	0.549 (0.596)	0.265 (0.516)	0.118 (0.294)
LNP3	1.896 (0.753)**	1.996 (0.777)*	0.734 (0.954)	2.444 (0.713)***	2.420 (0.484)***
LNY1_2	-0.358 (0.093)***	-0.146 (0.118)	-0.030 (0.166)	-0.316 (0.088)***	-0.375 (0.069)***
LNY2_2	-0.619 (0.190)***	-0.397 (0.235)*	-0.006 (0.349)	-0.599 (0.183)***	-0.654 (0.140)***
LNY1LNY2	0.592 (0.142)***	0.304 (0.160)*	0.021 (0.209)	0.547 (0.137)***	0.622 (0.107)***
LNP1_2	0.236 (0.059)***	0.243 (0.054)***	0.241 (0.055)***	0.251 (0.054)***	0.252 (0.040)***
LNP2_2	0.032 (0.075)	0.000 (0.070)	0.041 (0.072)	0.019 (0.067)	0.023 (0.042)
LNP3_2	-0.315 (0.150)**	-0.295 (0.139)**	-0.287 (0.144)**	-0.378 (0.138)***	-0.401 (0.090)***
LNP1LNP2	0.146 (0.055)***	0.181 (0.051)***	0.218 (0.053)***	0.129 (0.052)**	0.111 (0.033)***
LNP2LNP3	0.264 (0.092)***	0.281 (0.087)***	0.391 (0.092)***	0.218 (0.086)**	0.201 (0.060)***
LNP1LNP3	0.054	0.069	0.062	0.067	0.061

	(0.064)	(0.059)	(0.060)	(0.060)	(0.039)
LNY1LNP1	-0.015	-0.029	-0.067	-0.026	-0.020
	(0.030)	(0.027)	(0.029)**	(0.028)	(0.018)
LNY1LNP2	-0.098	-0.078	-0.036	-0.100	-0.108
	(0.036)***	(0.036)**	(0.043)	(0.031)***	(0.020)***
LNY1LNP3	0.018	-0.008	0.025	-0.006	-0.001
	(0.048)	(0.052)	(0.066)	(0.043)	(0.028)
LNY2LNP1	0.017	0.048	0.079	0.030	0.019
	(0.037)	(0.034)	(0.035)**	(0.035)	(0.022)
LNY2LNP2	0.165	0.104	0.004	0.172	0.199
	(0.052)***	(0.050)**	(0.059)	(0.047)***	(0.034)***
LNY2LNP3	-0.162	-0.119	-0.063	-0.142	-0.147
	(0.065)**	(0.063)**	(0.072)	(0.060)**	(0.041)***
D1	-0.070	-0.066	-0.058	-0.072	-0.077
	(0.026)***	(0.024)***	(0.024)**	(0.027)***	(0.019)***
D2	-0.153	-0.141	-0.151	-0.150	-0.154
	(0.025)***	(0.023)***	(0.023)***	(0.023)***	(0.016)***
D3	-0.157	-0.127	-0.120	-0.154	-0.176
	(0.028)***	(0.026)***	(0.027)***	(0.028)***	(0.018)***
LNT	29.105	25.499	41.691	25.778	28.311
	(5.925)***	(5.690)***	(6.851)***	(5.435)***	(0.396)***
THERMAL	0.007	0.002	0.004	0.007	0.008
	(0.002)***	(0.003)	(0.003)	(0.002)***	(0.002)***
NUCLEAR	-0.002	-0.010	-0.008	0.000	0.002
	(0.003)	(0.004)***	(0.004)*	(0.003)	(0.002)
NEW	0.055	0.212	0.366	0.009	-0.052
	(0.082)	(0.084)**	(0.091)***	(0.077)	(0.052)
σ_u				0.103	0.114
σ_v^2				0.002	0.003
σ_u^2				0.011	0.013
$\sigma = \sqrt{\sigma_v^2/\sigma_u^2}$				0.114	0.125
$\lambda = \sigma_u/\sigma_v$				2.132	2.268
				(0.274)***	(0.194)***

Log likelihood	416.951		456.417	421.313	420.321
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Notes:

- (1) For each explanatory variable and λ , the first line reports the estimated coefficient, and the second line is the standard error.
- (2) *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively.

Table 4: Estimated Economies of Scope

[1] p2 = P2_1

Firm	Mean	Std.Dev.	Minimum	Maximum	Cases
Hokkaido	0.369	0.081	0.200	0.505	41
Tohoku	0.586	0.052	0.468	0.696	41
Tokyo	1.057	0.029	0.999	1.098	41
Chubu	0.931	0.039	0.830	0.990	41
Hokuriku	0.793	0.033	0.721	0.857	41
Kansai	0.965	0.051	0.808	1.019	41
Chugoku	0.817	0.062	0.689	0.906	41
Shikoku	0.781	0.025	0.722	0.815	41
Kyushu	0.812	0.046	0.696	0.893	41
All	0.790	0.201	0.200	1.098	369

[2] p2 = P2_2

Firm	Mean	Std.Dev.	Minimum	Maximum	Cases
Hokkaido	0.369	0.081	0.200	0.505	41
Tohoku	0.585	0.052	0.468	0.695	41
Tokyo	1.057	0.029	0.999	1.097	41
Chubu	0.931	0.039	0.829	0.989	41
Hokuriku	0.792	0.033	0.720	0.856	41
Kansai	0.964	0.051	0.807	1.018	41
Chugoku	0.816	0.062	0.688	0.905	41
Shikoku	0.780	0.025	0.722	0.814	41
Kyushu	0.812	0.046	0.696	0.892	41
All	0.789	0.201	0.200	1.097	369