RIETI Discussion Paper Series 06-E-022

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April 20, 2006

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JEL Classification: L51, L94, Q41, R41,

Keywords: regulatory reform, electric utilities, energy demand and supply, network congestion

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Abstract

A key intention of the regulatory reform of transmission charge schemes on Japan's electric power market was to promote inter-regional competition between power suppliers by lowering long-distance transmission charges with a postage-stamp charge scheme. This can lead to extensive use of inter-regional links and cause congestion. Congestion segments the market into several regional markets, making the reform less successful. We developed a nine-region spatial equilibrium model to simulate the reform at the peak-load hour. We found the reform would lead to significant increases of inter-regional transmission and congestion at the link between the 50-Hz area and the 60-Hz area.

JEL Classification: L94, L51, R12, C61

Keywords: electric power market, regulatory reform, spatial equilibrium model, network congestion

1. Introduction

1.1 Background on Regulatory Reforms

Japan's electric power sector has been regionally monopolized by nine (and ten from 1972) vertically integrated companies, called general electric utilities (GEU's). The electric power industry used to be considered a natural monopoly because of its subadditive cost structure. Regional demand was, in principle, supposed to be met with domestic power plants held by GEU's. In other words, the power system was developed for regional autarky. Recently, the situation has been reversed. We no longer expect sizeable benefits from scale economies in this sector but recognize such a regional autarky system to be less efficient than the systems used in the US and Europe due to a lack of competition among incumbents and entrants in and across regions. The differences in charges between these countries and Japan suggest the magnitude of the inefficiency of the electric power industry in Japan. Charges in Japan are higher then other countries by 20–30%.

To tackle the inefficiency of the domestic electric power industry, the regulatory authority has permitted entrants, called power producers and suppliers (PPS's), to generate electricity with their own plants or to retail power to large-scale users. In contrast, the authority did not propose deregulation in the transmission nor the distribution sector, in which natural monopolies still prevail because of network externalities. The deregulation in the power generation sector cannot work alone because transmission and distribution network is possessed and managed by the incumbents. Free access to the network has to be accompanied by reasonable charge schemes to ensure competition among GEU's and PPS's to abolish the inefficiency of this industry.

1.2 Transmission Charge Schemes

A huge amount of investment has been made for development of a nationwide transmission network system. Transmission charges are imposed to recover the costs sunk into this development. Various transmission charge schemes can be considered. Lump-sum charge schemes are the most efficient for recovering such investment, as a conventional theory tells us, but can exclude small-scale players from accessing the market. Thus, we have used some ad quantum schemes as well as such lump-sum charge schemes.

Japan used a zone-based transmission tariff scheme of pancake pricing till the end of March in 2005, which charged on the volume and distance of transmission in combination with lump-sum charges. Transmission charges were accumulated in accordance with the distance of transmission between producers and users (Table 1). This provided less incentive for long-distance transmission and discouraged inter-regional competition. The market tended to be segmented into several regional markets, which were dominated by GEU’s and had a few fringe players.

From a technological viewpoint, the distance does not necessarily matter in electric power transmission. A contract between a supplier and its customer does not necessarily require physical transmission between them. Instead, the power injected by the supplier can be extracted by other users (probably those nearby); the customer can extract power injected by other producers. This is a unique feature of electricity, compared with usual commodities, and provides no reason to charge for transmission according to its distance.

1.3 The Charge Scheme Reform and Related Concerns

To improve competition between all the power producers and suppliers on the network, the regulatory authority decided to replace the pancake pricing scheme with a postage-stamp one. The postage-stamp scheme charges only on transmission volume but not on distance. The charge scheme is more lump-sum fashion and is thus more efficient than the pancake pricing scheme.

This reform can lead to extensive use of inter-regional transmission links. Such use is a potential risk factor for Japan's electric power network because it is popularly recognized that the inter-regional transmission links have had low capacity (Figure 1). Particularly, the capacity of the link between Tokyo and Chubu is less than 5% of their market sizes. This is because this link is equipped with frequency converters (FC) to connect two areas with different frequencies: the 50-Hz area in eastern Japan and the 60-Hz area in western Japan. The GEU's were against this reform because they anticipated excessive use of these poor inter-regional transmission links, and such use can make the network system unmanageable.

However, their claim has not yet been found to be valid. Japan has historically developed electric power markets on the principle of regional autarky, where regional demand has been met mostly with its domestic supply sources. Inter-regional transmission has been regarded only as a supplementary source and has been carried out on a small scale. Moreover, even if inter-regional transmission is carried out extensively, congestion can be managed by various means, such as congestion charges, rationing, competitive bidding on transmission options, or a combination of these means.

Economists cast concern on the poorness of the inter-regional network from another viewpoint. If the inter-regional links have low capacity compared with potential transmission demand and congestion follows, the market will be segmented to reduce competitive pressure from players in other regions as it was before the transmission charge reform. Non-competitive behavior can reduce the efficiency of the market. These concerns motivate us to examine whether congestion can really take place under the postage-stamp pricing scheme and determine the locations of any bottlenecks.

1.4 Literature Review

For Japan's power market, electricity demand functions were estimated in the context of Ramsey pricing by Matsukawa *et al.* (1993). Cost functions were estimated by, among others, Shinjo (1994) to evaluate scale economies in this industry. Although they provide empirical insights into demand and supply behavior, none of these studies analyzed the impact of regulatory reforms of the transmission tariff system.

To the best of our knowledge, no research has been made on the possibility of congestion of inter-regional links in connection with the transmission charge scheme reform in Japan. This lack of study is the reason that, even after the postage-stamp pricing scheme was implemented on April 1, 2005, the myth of "a poor inter-regional transmission network system in Japan" still seems common.

1.5 Outline

The need for an accurate understanding of the possibility of the transmission charge scheme reform causing congestion motivated us to carry out a numerical simulation analysis of this reform and its impacts on congestion at inter-regional links. We developed an electricity spatial and temporal price and allocation (e-STPA) model based on the work of Takayama and Judge (1971). Nine regions are distinguished in this model. Each region is represented by a node and is connected to others through inter-regional links. Users are located in each region and they extract power from their domestic node via distribution grids. Inter-regional links have their own transmission capacity. We can determine to what extent the links would be occupied and congested under different transmission charge schemes.

The reference point of our simulations is set at a typical hourly peak load in the summer of 2002. By simulating this peak-load situation, we can identify potential bottlenecks and draw policy implications. Our simulation yielded three important results regarding the transmission charge scheme reform toward a postage-stamp charge scheme: (1) it would markedly increase uses of inter-regional transmission links by 45.1% in comparison with the situation under the original pancake pricing scheme, (2) it would cause congestion at the FC-link, and (3) it would finally lead to total welfare gains by 1.3 million yen in the peak-load hour.

Next, Section 2 explains the details of our e-STPA model. Section 3 presents our simulation scenarios and results, followed by the concluding Section 4.

2. E-STPA model

2.1 Model Structure

Our e-STPA model distinguishes nine regions in Japan, each of which corresponds to the jurisdiction of an individual GEU (1: Hokkaido, 2: Tohoku, 3: Tokyo, 4: Chubu, 5: Hokuriku, 6: Kansai, 7: Chugoku, 8: Shikoku, and 9: Kyushu)[1]. The regions are connected with each other via nine inter-regional transmission links. In each region, users extract power via domestic distribution grids. Two logical links are defined on each physical inter-regional link to identify directions of power flow. The topology of the network is summarized in Figure 1[2].

Each region has a pair of inverse supply (1) and demand (2) functions, expressed as a nonlinear complementarity problem as follows:

* supply function

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[1] Another region, Okinawa, does exist but because it is isolated from the other nine regions on the Japanese mainland. We do not include it in our analysis.

[2] We omit another link between Hokuriku and Chubu partly because the link has a low capacity and partly because transmission can also be carried out between these regions via Kansai.

$$\left(-p_i^y + p_i^y(\cdot)\right)y_i = 0,$$
$$-p_i^y + p_i^y(\cdot) \geq 0, \quad (1)$$
$$y_i \geq 0$$

* demand function

$$\left(p_i^x - \left(A_i^x + B_i^x x_i\right)\right)x_i = 0,$$
$$p_i^x - \left(A_i^x + B_i^x x_i\right) \geq 0, \quad (2)$$
$$x_i \geq 0$$

The supply function $p_i^y(\cdot)$ describes the merit order of the power plants located in each region. Electric power generated in the *i*-th region y_i is distributed to its own and other regions $\sum_j z_{i,j}$, as Eq. (3) shows. In addition, losses accruing from outbound inter-regional transmission $\sum_{j\neq i} \Omega_{i,j} z_{i,j}^2$ are taken into account by applying a quadratic loss function. Eq. (4) shows that consumption in the *i*-th region x_i cannot exceed total inbound power shipped from all the regions $\sum_j z_{j,i}$ less the accompanying transmission losses $\omega_i \sum_j z_{j,i}$.

* Market-clearing conditions

$$\left(y_i - \sum_j z_{i,j} - \sum_{j\neq i} \Omega_{i,j} z_{i,j}^2\right)p_i^y = 0,$$
$$y_i - \sum_j z_{i,j} - \sum_{j\neq i} \Omega_{i,j} z_{i,j}^2 \geq 0, \quad (3)$$
$$p_i^y \geq 0$$

$$\left(-x_i + \sum_j z_{j,i} - \omega_i \sum_j z_{j,i}\right) p_i^x = 0,$$
$$-x_i + \sum_j z_{j,i} - \omega_i \sum_j z_{j,i} \geq 0, \tag{4}$$
$$p_i^x \geq 0$$

Exogenous transmission capacity $z_{i,j}^{up}$ is given by Eq. (5) for each inter-regional link. When there is no more room to transmit via this link, the shadow price of its capacity constraint $r_{i,j}$ arises. This can be interpreted as congestion charges. The network operator might not explicitly impose congestion charges in practice, instead using some other schemes, such as rationing, to manage congestion. In this case, corresponding quasi-rents arise with the same magnitude to take the role of congestion charges.

* Transmission capacity constraint

$$\left(z_{i,j}^{up} - z_{i,j}\right) r_{i,j} = 0,$$
$$z_{i,j}^{up} - z_{i,j} \geq 0, \tag{5}$$
$$r_{i,j} \geq 0$$

Let us interpret Eq. (6). When transmission from the i-th region to the j-th region takes place (i.e., $z_{i,j} > 0$), the consumer price of electricity in the j-th region p_j^x is equal to its producer price in the i-th region p_i^y with transmission charges $t_{i,j}$, congestion charges

$r_{i,j}$, shadow prices of marginal outbound transmission losses $2\Omega_{i,j} z_{i,j} p_i^y$, and shadow prices of marginal inbound transmission losses $\omega_j p_j^x$. When there is no transmission from the *i*-th region to the *j*-th region (i.e., $z_{i,j} = 0$), this inter-regional price linkage does not necessarily hold but allows the consumer price p_j^x to be lower than the producer price p_i^y plus transmission-related costs and losses. In the case of *intra*-regional transmission, neither outbound transmission losses nor congestion charges are considered.

* Price equilibrium condition

$$
\begin{aligned}
&\left(-p_j^x + p_i^y + t_{i,j} + r_{i,j} + 2\Omega_{i,j}\omega_j p_i^y x + \omega_j p_j^x\right) z_{i,j} = 0, \\
&-p_j^x + p_i^y + t_{i,j} + r_{i,j} + 2\Omega_{i,j} z_{i,j} p_i^y + \omega_j p_j^x \geq 0, \qquad \forall i \neq j \\
&z_{i,j} \geq 0 \\
&\left(-p_j^x + p_i^y + t_{i,j} + \omega_j p_j^x\right) z_{i,j} = 0, \\
&-p_j^x + p_i^y + t_{i,j} + \omega_j p_j^x \geq 0, \qquad \forall i = j \\
&z_{i,j} \geq 0
\end{aligned} \tag{6}
$$

Notations are:

* sets

i, j : regions

* endogenous variables

y_i : production in the *i*-th region

x_i : consumption in the *i*-th region

$z_{i,j}$: transmission from the *i*-th region to the *j*-th region

p_i^y : producer prices in the *i*-th region

p_i^x : consumer prices in the *i*-th region

$r_{i,j}$: congestion charges at the link from the *i*-th region to the *j*-th region

* exogenous variables/constants

A_i^x : constant terms of demand function in the *i*-th region

B_i^x : slope parameters of demand function in the *i*-th region

$t_{i,j}$: transmission charges from the *i*-th region to the *j*-th region

$\Omega_{i,j}$: marginal inter-regional outbound loss transmission parameters

ω_i : marginal inbound transmission loss parameters

$z_{i,j}^{up}$: transmission capacity of the link from the *i*-th region to the *j*-th region

The inter-regional relationships can be graphically confirmed in Figure 2. The gap between domestic production y_i and consumption x_i corresponds to the amount of exporting transmission to the other region of *j*, $z_{i,j}$. This must be equal to the importing transmission in the other region, which also corresponds to the gap between its production y_j and consumption x_j. The producer price p_i^y plus transportation charges $t_{i,j}$ are exactly equal to the consumer price in the other region p_j^x because inter-regional transmission takes place (i.e., $z_{i,j} > 0$) in this figure (omitting transmission losses and congestion). The consumer price p_j^x is also equal to its domestic producer price p_j^y plus its domestic transmission cost $t_{j,j}$. This inter-price linkage ensures that domestic producers can be as competitive as foreign producers.

2.2 Model Calibration

We developed supply functions (1) on the basis of merit-order curves considering all the thermal plants of the GEU's and large-scale wholesalers, while assuming nuclear plants and thermal plants of PPS's are low-cost must-run plants. We assume that the operation rate of non-pumping plants is 50% of their available capacity and that these plants are also must-run ones[3]. The capacity of the pumping plants and the remaining capacity of the non-pumping ones are supposed to generate reactive power to maintain the network, not to be consumed by any users. The reference load is set at the three-day average hourly peak

[3] The available capacity takes seasonality of river water and rain fall for plant operation into account.

load in each region.

Price elasticity in the demand function (2) is econometrically estimated for each region and converted into slope parameters at the annual mean load in each region. Intercept terms are calibrated to the peak load[4]. Outbound transmission loss parameters $\Omega_{i,j}$ are calibrated to an average occupation rate of transmission links (19%) and the loss rate (2%), assuming the quadratic transmission loss function (3). Inbound transmission loss rates ω_i are set at a constant rate of 2%.

3. Simulation

3.1 Simulation Scenarios and Base Run

The pancake pricing scheme shown in Table 1 was replaced with the postage-stamp scheme in 2005. Under the postage-stamp charge scheme, transmission tariffs are determined considering the place of demand, but not that of supply or transmission distance. The charge reform can bring more or less earnings than the pancake pricing scheme and could lead to revenue gaps for the network operator. We take the revenue gap into account only when considering welfare in a lump-sum manner.

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[4] The price elasticity is reported in Appendix I with results of its econometric diagnostics tests.

The base run solution is shown in Figure 3. In western Japan, which is a 60-Hz frequency area consisting of Chubu, Kansai, Hokuriku, Shikoku, Chugoku, and Kyushu, the link from Shikoku to Kansai experiences a high occupation rate (93.6%). In eastern Japan, which is a 50-Hz frequency area consisting of Hokkaido, Tohoku, and Tokyo, heavy transmission from Tohoku to Tokyo appears to cause congestion. Other links generally show low occupancy.

Due to the frequency converter between Tokyo and Chubu, high transmission charges are imposed (Table 1). This leads to the amount of transmission between the western and eastern areas being quite small (only 8.7% of transmission capacity) even though the producer price in Chubu is significantly lower than that in Tokyo by 2.13 yen/kWh.

The total inter-regional transmission amounts to 13,490 MW, which is only 7.8% of the total power generation. No congestion is caused by this inter-regional transmission except at the Tohoku-Tokyo link, which is true to the prediction based on the regional autarky system. As a whole, the base run generally shows results consistent with our common knowledge about inter-regional transmission patterns. Our counter-factual simulation was carried out on the basis of this base run solution.

3.2 Reform for Postage-stamp Pricing Scheme

In the counter-factual run, the pancake style transmission charges shown in Table 1 (1.19–7.39 yen/kWh) were replaced with postage-stamp charges. Charges for long-distance transmission were lowered to stimulate inter-regional transmission (Figure 4). The total amount of inter-regional transmission would amount to 19,574 MW, which is 45.1% more than that in the base run.

In the western area, Kansai would intensify its imports from other regions, particularly from Kyushu and Shikoku. Kansai would consume half of this imported power and re-export the other half to Chubu. Chubu would again re-export 40% of its imports to Tokyo via the FC-link. Notably, inter-regional transmission would not hit transmission capacity ceilings in the western area but would do so at the FC-link. The congestion would cause a price gap of 1.61 yen/kWh between Tokyo and Chubu. This price gap consists of congestion charges (0.28 yen/kWh) as well as imputed charges of transmission losses (1.33 yen/kWh). However, the gap would be smaller than that in the base run.

In the eastern area, inter-regional transmission would increase marginally because the Tohoku-Tokyo link was already congested in the base run and thus had no room to transmit power to Tokyo. Finally, transmission patterns in the east would not differ significantly.

Generally, imports and exports let domestic consumers and producers access lower consumer and higher producer prices to increase their surpluses. Consumers in Tohoku, Tokyo, Chubu, and Kansai would gain along with the gains of producers in Hokkaido, Chugoku, Shikoku, and Kyushu. The overall welfare in Japan would increase by 1.3 million yen in the peak-load hour we considered.

4. Concluding Remarks

By simulating transmission patterns under two different transmission charge schemes, we found that no serious congestion would take place under the postage-stamp pricing scheme at any links in western Japan. Its abundant transmission capacity could allow further deregulation, which presupposes inter-regional competition. However, the FC-link and the Tohoku-Tokyo link would experience congestion at the peak-load hour. Congestion at these two links to Tokyo could provide an opportunity for its domestic power companies to exercise monopolistic power in the peak-load hour. We therefore need to keep a special watch on their possible non-competitive behavior.

Our simulation was for a typical peak load. The regional load is much lighter at other times, but patterns of inter-regional power flow are uncertain. Between regions, regional power companies are equipped with technologically similar natural gas- and oil-fired thermal plants for their peak-load times. As far as we focus on peak-load times, their marginal costs are thus similar. In contrast, capacity of cheap plants such as nuclear and coal-fired thermal ones considerably vary by region. Depending on domestic load size, marginal plants and costs vary widely between regions. Accordingly, inter-regional transmission patterns are dynamically different. Our simulations have to be extended to cover the off-peak times, during both the day and the night. After covering all of the situations and summing up the welfare changes in all of them for a year, we will finally be able to evaluate the overall costs and benefits of the regulatory reform in transmission charge schemes.

Our simulations do not consider any uncertainty or the impacts of uncertainty on inter-regional transmission patterns. As network operators worry, unscheduled shutdown of large-scale nuclear plants —— which actually took place in 2004 —— can be critical for power markets. Under the regional autarky regime, each GEU used to be responsible for meeting demand in its domain. This responsibility can now be shared by all the power producers integrated with inter-regional transmission. By simulating sudden shocks to demand and supply, we can evaluate the robustness of the network under such uncertainty.

Acknowledgements

We thank the members of research workshops on regulatory reforms in the electric power industry at the Research Institute of Economy, Trade and Industry, the National Graduate Institute for Policy Studies, and other conferences/seminars for valuable comments and suggestions. Grants-in-aid for Young Scientists (B) No. 16730149 for Shu-ichi Akiyama and No. 17730145 for Nobuhiro Hosoe provided by the Ministry of Education, Culture, Sports, Science and Technology are also gratefully acknowledged. Any remaining errors should be attributed solely to the authors.

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Appendix I: Estimation of Demand Price Elasticity

We estimate the following demand function for regions of i:

$$Q_i = \alpha_i + \beta_i \cdot \log(GDP)_i + \gamma_i \cdot \log(Poil) + \delta_i \cdot \log(DAY_i) + \varepsilon_i \cdot \log(p_i),$$

where Q_i is the index of power demand excluding lighting service, GDP_i is real gross regional product, $Poil$ is the wholesale price index of heavy oil, which is common across regions, DAY_i is sum of the summer days and the winter days, and p_i is the index of regional power price. Price elasticity ε_i is estimated for each region i and used to calibrate the demand function (2).

Durbin-Watson statistics indicate a serial correlation in residuals in plain ordinary panel estimates. To correct a serial correlation in the error term, we use the generalized method of moments (GMM). A test of overidentifying restrictions (Hansen (1982)) cannot be rejected at conventional significance level. All of our estimates of price elasticity and the others are statistically significant and theoretically reasonable (Table A).

Table A: Estimation Results (Dependent Variable: Q_i)

Regions	Constant	GDP_i	$Poil_i$	DAY_i	p_i	Adjusted R^2
Hokkaido	-2.5379 [.000]	0.6144 [.000]	0.3165 [.000]	0.0461 [.192]	-0.4547 [.000]	0.990
Tohoku	-4.4147 [.000]	0.6945 [.000]	0.2879 [.000]	0.1074 [.001]	-0.4034 [.000]	0.990
Tokyo	-6.0157 [.000]	0.7109 [.000]	0.1988 [.000]	0.1070 [.001]	-0.2370 [.000]	0.995
Chubu	-3.6418 [.000]	0.6261 [.000]	0.1556 [.000]	0.0771 [.034]	-0.2722 [.000]	0.993
Hokuriku	-0.0728 [.788]	0.4532 [.000]	0.1062 [.000]	0.0572 [.059]	-0.3111 [.000]	0.978
Kansai	-3.6826 [.000]	0.5617 [.000]	0.1409 [.000]	0.1436 [.002]	-0.1595 [.006]	0.990
Chugoku	-1.5248 [.014]	0.5042 [.000]	0.2639 [.000]	0.0915 [.272]	-0.4176 [.000]	0.950
Shikoku	-0.6365 [.076]	0.4603 [.000]	0.2846 [.000]	0.1145 [.016]	-0.4575 [.000]	0.972
Kyushu	-5.2881 [.000]	0.7455 [.000]	0.2634 [.000]	0.1302 [.030]	-0.3606 [.000]	0.990

Note: P-values are in brackets.

Data Sources

(1) Electric power quantity, capacity, revenues, and costs

Agency of Natural Resources and Energy (ANRE), *Denryoku-Jyukyu-no-Gaiyou* [Abstract of the Electric Power Demand and Supply].

The Federation of Electric Power Companies, *Denki-Jigyou-Binran* [Handbook of the Electric Power Industry].

(2) Prefectural economic data

Asahi Newspaper, *Minryoku* [National Power].

Bank of Japan, *Bukka-Shisu-Geppo* [Price Indexes Monthly], Research and Statistics Department.

Economic and Social Research Institute, *Annual Report on Prefectural Accounts*, Cabinet Office.

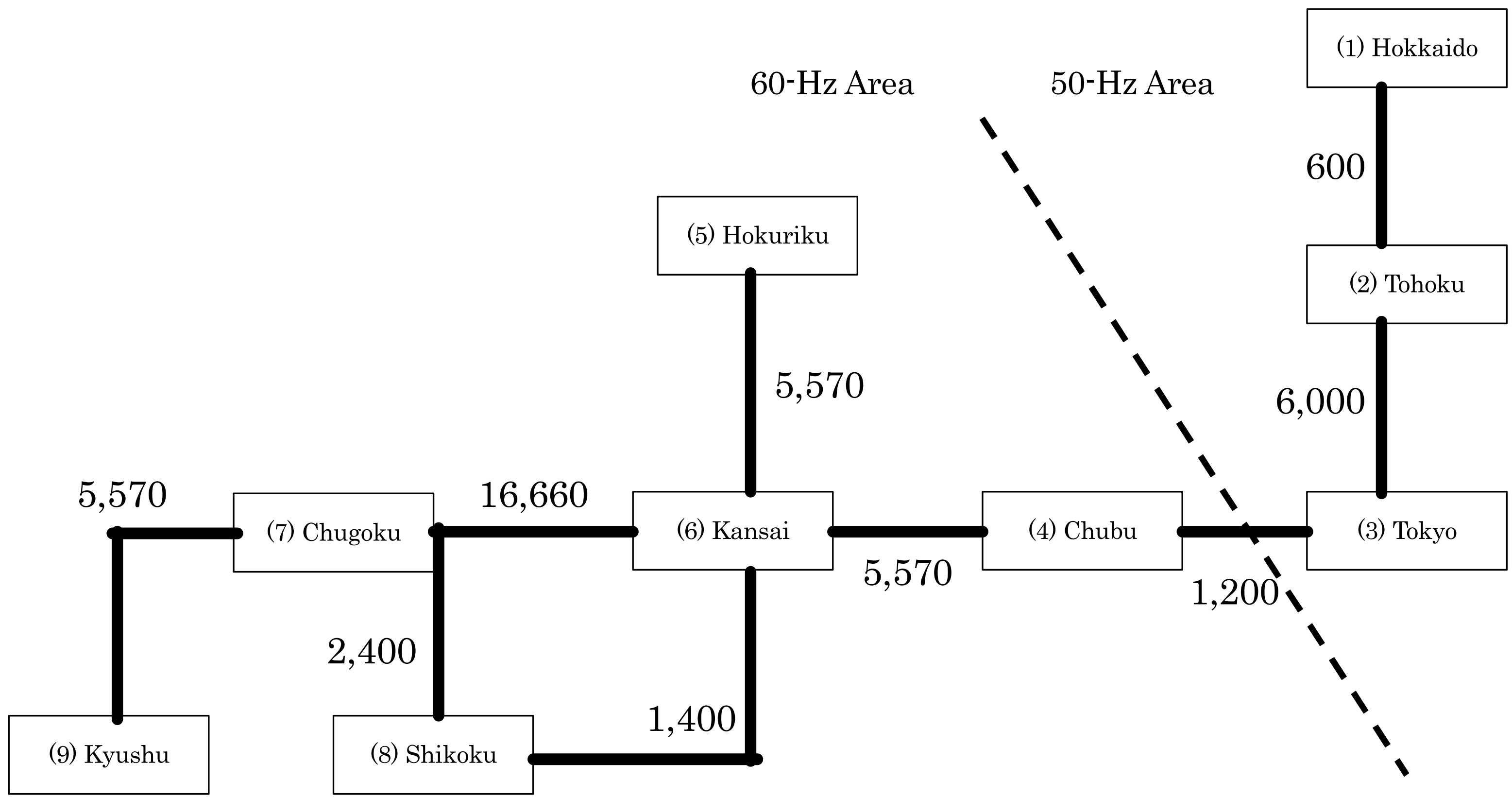
National Astronomical Observatory, *Rika-Nempyo* [Chronological Scientific Tables], Maruzen.

Table 1: Transmission Charges under Pancake Pricing Scheme (yen/kWh)

From/To	Hokkaido	Tohoku	Tokyo	Chubu	Hokuriku	Kansai	Chugoku	Shikoku	Kyushu
Hokkaido	1.50	3.36	3.90	5.91	6.09	5.94	6.16	6.88	6.57
Tohoku	3.55	1.41	1.95	3.96	4.14	3.99	4.21	4.93	4.62
Tokyo	3.84	1.70	1.53	3.54	3.72	3.57	3.79	4.51	4.20
Chubu	5.85	3.71	3.54	1.59	1.77	1.62	1.84	2.56	2.25
Hokuriku	6.37	4.23	4.06	2.11	1.23	1.60	1.82	2.54	2.23
Kansai	6.15	4.01	3.84	1.89	1.53	1.38	1.60	2.32	2.01
Chugoku	6.53	4.39	4.22	2.27	1.91	1.76	1.30	2.41	1.71
Shikoku	7.39	5.25	5.08	3.13	2.77	2.62	2.47	1.19	2.88
Kyushu	6.84	4.70	4.53	2.58	2.22	2.07	1.61	2.72	1.33

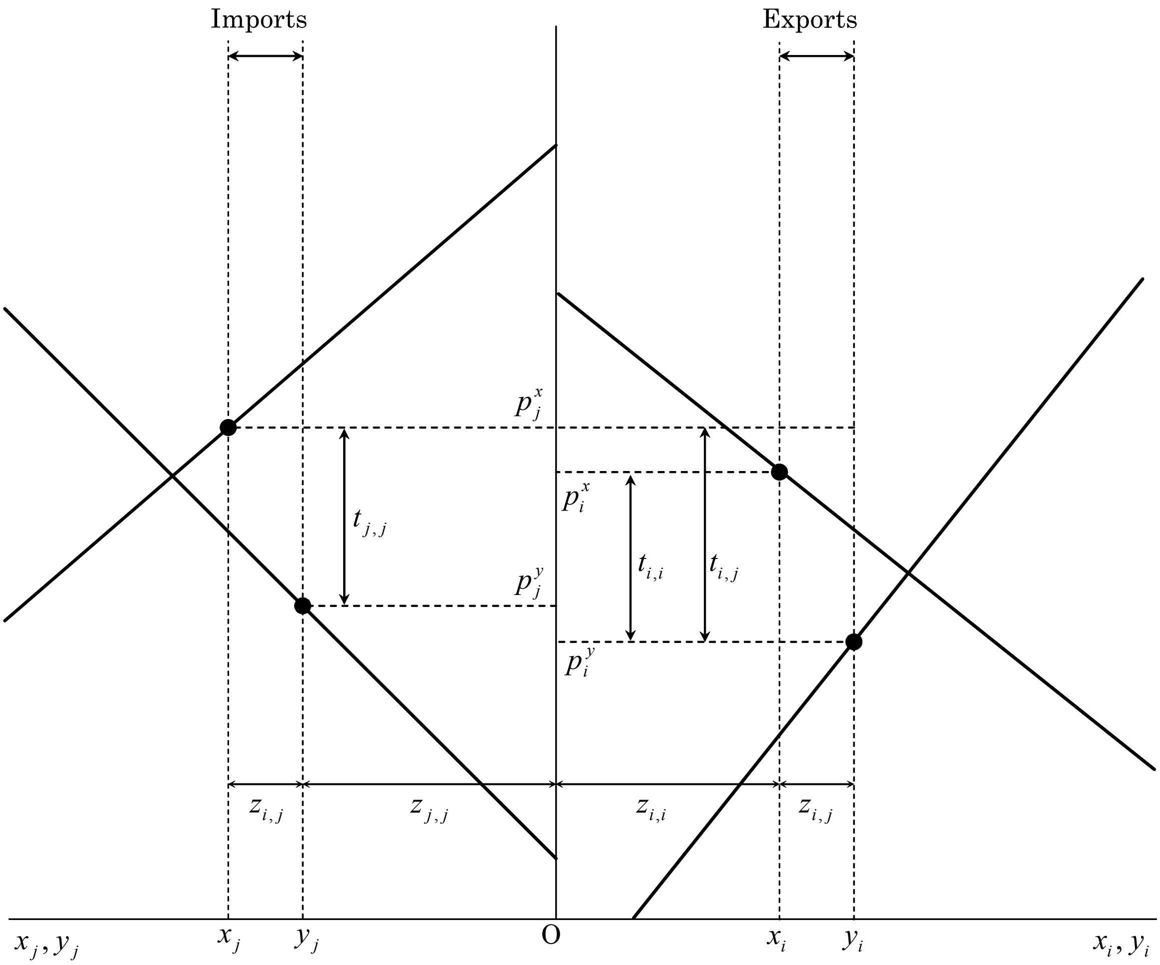
Source: Wheeling and access charges as of April 2004 compiled by the authors.

Figure 1: Capacity of Inter-regional Transmission Links (MW)



Source: CEPC (2002)

Figure 2: The e-STPA Model —— A Two-region Case ——



Note: Transmission losses and capacity constraints are omitted for simplicity of the figure.

Figure 3: Base Run under Pancake Pricing Scheme

Total			
Production	(MW)	172,133	-
Consumption	(MW)	167,807	-
Transmission Losses	(MW)	4,325	-
Inter-reg. Transmission	(MW)	13,490	-
Welfare	(100 mil. yen)	37.04	-
Producer Surplus	(100 mil. yen)	7.30	-
Consumer Surplus	(100 mil. yen)	29.74	-
Network. Op. Surplus	(100 mil. yen)	0.00	-
Tran. Charge Rev.	(100 mil. yen)	2.62	-
Netwk. Fixed Cost	(100 mil. yen)	2.62	

Hokkaido		
Production	4,274	-
Consumption	3,933	-
Prod. Price	3.67	-
Cons. Price	5.28	-
Welfare	0.35	-
Prod. Surp.	0.14	-
Cons. Surp.	0.21	-

Transmission	949
Occup. Rate	(17.0)
Loss Rate	(3.6)
Cong. Charg.	0.00

Hokuriku		
Production	6,228	-
Consumption	5,157	-
Prod. Price	5.45	-
Cons. Price	6.81	-
Welfare	0.60	-
Prod. Surp.	0.26	-
Cons. Surp.	0.34	-

Transmission	250
Occup. Rate	(41.7)
Loss Rate	(8.8)
Cong. Charg.	0.00

Transmission	1,953
Occup. Rate	(11.7)
Loss Rate	(2.5)
Cong. Charg.	0.00

Kansai		
Production	29,227	-
Consumption	31,218	-
Prod. Price	5.86	-
Cons. Price	7.39	-
Welfare	10.89	-
Prod. Surp.	1.03	-
Cons. Surp.	9.86	-

Transmission	1,540
Occup. Rate	(27.6)
Loss Rate	(5.8)
Cong. Charg.	0.00

Tohoku		
Production	18,893	-
Consumption	12,261	-
Prod. Price	5.94	-
Cons. Price	7.50	-
Welfare	1.35	-
Prod. Surp.	0.72	-
Cons. Surp.	0.63	-

Transmission	444
Occup. Rate	(8.0)
Loss Rate	(1.7)
Cong. Charg.	0.00

Chugoku		
Production	11,942	-
Consumption	11,121	-
Prod. Price	5.35	-
Cons. Price	6.78	-
Welfare	1.54	-
Prod. Surp.	0.39	-
Cons. Surp.	1.15	-

Transmission	1,310
Occup. Rate	(93.6)
Loss Rate	(19.7)
Cong. Charg.	0.00

Chubu		
Production	25,323	-
Consumption	26,222	-
Prod. Price	6.50	-
Cons. Price	8.26	-
Welfare	5.66	-
Prod. Surp.	0.89	-
Cons. Surp.	4.78	-

Transmission	6,000
Occup. Rate	(100.0)
Loss Rate	(21.1)
Cong. Charg.	1.02

Kyushu		
Production	16,364	-
Consumption	15,598	-
Prod. Price	4.96	-
Cons. Price	6.41	-
Welfare	1.58	-
Prod. Surp.	0.55	-
Cons. Surp.	1.03	-

Transmission	940
Occup. Rate	(39.2)
Loss Rate	(8.2)
Cong. Charg.	0.00

Shikoku		
Production	7,306	-
Consumption	4,791	-
Prod. Price	3.86	-
Cons. Price	5.15	-
Welfare	0.41	-
Prod. Surp.	0.21	-
Cons. Surp.	0.20	-

Transmission	104
Occup. Rate	(8.7)
Loss Rate	(1.8)
Cong. Charg.	0.00

Tokyo		
Production	52,577	-
Consumption	57,507	-
Prod. Price	8.63	-
Cons. Price	10.37	-
Welfare	14.66	-
Prod. Surp.	3.11	-
Cons. Surp.	11.55	-

Unit: Price and congestion charges are in yen/kWh. Numbers in parentheses are percentages.

Figure 4: Counter-factual Run under Postage-stamp Pricing Scheme

Total			
Production	(MW)	173,068	(0.5)
Consumption	(MW)	168,294	(0.3)
Transmission Losses	(MW)	4,774	(10.4)
Inter-reg. Transmission	(MW)	19,574	(45.1)
Welfare	(100 mil. yen)	37.06	0.013
Producer Surplus	(100 mil. yen)	6.90	-0.396
Consumer Surplus	(100 mil. yen)	30.21	0.469
Network. Op. Surplus	(100 mil. yen)	-0.06	-0.061
Tran. Charge Rev.	(100 mil. yen)	2.56	-0.061
Netwk. Fixed Cost	(100 mil. yen)	2.62	

Hokkaido		
Production	4,275	(0.0)
Consumption	3,548	(-9.8)
Prod. Price	4.69	(27.8)
Cons. Price	6.32	(19.7)
Welfare	0.35	0.005
Prod. Surp.	0.18	0.044
Cons. Surp.	0.17	-0.039

Hokuriku		
Production	6,228	(0.0)
Consumption	5,146	(-0.2)
Prod. Price	5.47	(0.5)
Cons. Price	6.84	(0.4)
Welfare	0.60	0.000
Prod. Surp.	0.26	0.002
Cons. Surp.	0.34	-0.001

Transmission	959
Occup. Rate	(17.2)
Loss Rate	(3.6)
Cong. Charg.	0.00

Transmission	593
Occup. Rate	(98.8)
Loss Rate	(20.8)
Cong. Charg.	0.00

Kansai		
Production	29,227	(-0.0)
Consumption	31,314	(0.3)
Prod. Price	5.67	(-3.3)
Cons. Price	7.19	(-2.6)
Welfare	10.90	0.005
Prod. Surp.	0.98	-0.056
Cons. Surp.	9.92	0.061

Transmission	3,614
Occup. Rate	(21.7)
Loss Rate	(4.6)
Cong. Charg.	0.00

Transmission	2,916
Occup. Rate	(52.4)
Loss Rate	(11.0)
Cong. Charg.	0.00

Tohoku		
Production	18,893	(-0.0)
Consumption	12,597	(2.7)
Prod. Price	5.67	(-4.7)
Cons. Price	7.22	(-3.8)
Welfare	1.34	-0.017
Prod. Surp.	0.67	-0.052
Cons. Surp.	0.67	0.035

Chugoku		
Production	11,942	(0.0)
Consumption	11,080	(-0.4)
Prod. Price	5.42	(1.4)
Cons. Price	6.86	(1.1)
Welfare	1.54	0.000
Prod. Surp.	0.40	0.009
Cons. Surp.	1.14	-0.008

Chubu		
Production	25,322	(-0.0)
Consumption	26,374	(0.6)
Prod. Price	6.29	(-3.2)
Cons. Price	8.05	(-2.6)
Welfare	5.67	0.003
Prod. Surp.	0.83	-0.052
Cons. Surp.	4.83	0.056

Transmission	1,544
Occup. Rate	(27.7)
Loss Rate	(5.8)
Cong. Charg.	0.00

Transmission	1,229
Occup. Rate	(87.8)
Loss Rate	(18.5)
Cong. Charg.	0.00

Transmission	6,000
Occup. Rate	(100.0)
Loss Rate	(21.1)
Cong. Charg.	1.04

Kyushu		
Production	17,299	(5.7)
Consumption	15,395	(-1.3)
Prod. Price	5.12	(3.4)
Cons. Price	6.58	(2.7)
Welfare	1.58	0.003
Prod. Surp.	0.58	0.030
Cons. Surp.	1.00	-0.026

Transmission	1,517
Occup. Rate	(63.2)
Loss Rate	(13.3)
Cong. Charg.	0.00

Shikoku		
Production	7,307	(0.0)
Consumption	4,259	(-11.1)
Prod. Price	4.79	(24.0)
Cons. Price	6.10	(18.3)
Welfare	0.44	0.025
Prod. Surp.	0.28	0.068
Cons. Surp.	0.16	-0.043

Transmission	1,200
Occup. Rate	(100.0)
Loss Rate	(21.1)
Cong. Charg.	0.28

Tokyo		
Production	52,576	(-0.0)
Consumption	58,580	(1.9)
Prod. Price	7.90	(-8.5)
Cons. Price	9.62	(-7.2)
Welfare	14.71	0.049
Prod. Surp.	2.72	-0.386
Cons. Surp.	11.99	0.435

Unit: Price and congestion charges are in yen/kWh. Numbers in parentheses are percentages. Second columns show changes from the Base Run.