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A Spatial Equilibrium Analysis of Regulatory Reform in Japan's Electric Power Industry

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Abstract

This paper examines the impact of the deregulation of the electricity industry, in which the entry of independent power producers (IPPs) into the power generation sector is expected. We employ a nine-region electricity spatial and temporal price and allocation (e-STPA) model, à la Takayama and Judge (1971). Our main findings are: (1) currently, IPP entry is so small-scale as to bring about only marginal welfare gains while reallocating the industry's surplus from producers to consumers; and (2) expected future IPP entry could deliver significant welfare gains in all regions with substantial inter-regional transmission.

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1. Introduction

1.1 Background to Regulatory Reforms

The domestic electricity sector has been regionally monopolized by nine (10 from 1972) vertically integrated companies, known as General Electric Utilities (GEUs) in Japan. The electric power industry used to be considered a natural monopoly because of its subadditive cost structure. Recently, the situation has been reversed. We no longer expect sizeable benefits from scale economies in this sector but expect it to be less efficient than those of the US and Europe because of a lack of competition between existing power companies and potential entrants. The differences in charges between these countries suggest the scale of the GEUs' inefficiency in Japan.

To tackle the inefficiency of the domestic electric power system, the regulatory authority intends to use two policy instruments in the reform. The authority has permitted the entry of independent power producers (IPPs)—or power producers and suppliers—as wholesale suppliers in power generation. Stimulated by this deregulation, many IPPs are expected to operate to increase competition and thereby lower the supply price of electricity. The results of actual bids for the wholesale supply by IPPs support this expectation. Second, the regulatory authority will permit IPPs to retail electricity directly to large-scale users. In contrast, the authority does not propose deregulating either the transmission or the distribution sector, in which natural monopoly still prevails, because of network externalities. Third, to ensure an improvement from competition, the authority will change the current zone-based transmission tariff system (i.e., pancake pricing). This system is thought to discourage long-distance transmission and reduce inter-regional competition. To overcome this problem, an alternative tariff system (known as the "postage stamp") is being designed to replace the zone-based system.

1.1.1 IPP Entry

Between 1996 and 1999, bidding took place for the wholesale supply to the GEUs by the IPPs for the period 2000–2007. The IPPs offered 7,413 MW in total at prices 10–40% lower than those of the GEUs. This bidding was carefully designed so that the IPPs would not disturb the domestic power flow. It was not only because of this carefulness, but also because of a revised demand outlook in the lingering recession that the GEUs quit bidding for this type of power supply in 2000 despite there being a substantial number of potential IPPs.

The "Survey of Potential Entry of IPPs" was conducted by Agency of Natural Resources and Energy (ANRE) (1998).[1] This survey found that potential supply capacity was 21,350–34,950 MW under the current bidding system and that an additional 8,850–16,000 MW would be available under a more preferable bidding system for IPPs. The potential capacity is more than 10% of the current GEUs' capacity. There is no consensus on the quantitative effect of IPP entry on this scale.

1.1.2 Zone-based Tariffs versus Postage-stamp Tariffs

The current transmission tariffs consist of an access charge and a wheeling charge. The former is charged for the use of the distribution grid; the latter is charged for the use of transmission networks via which inter-regional transmission is conducted (Figure 1.1). When power is transmitted to other regions via the third or other regions under this system, wheeling charges are accumulated. Not only long-distance transmission but also inter-regional competition can be strongly discouraged.

The postage-stamp tariff system can resolve this problem. Under this system, electricity can be transmitted over any distance once a uniform transmission charge has been paid (Figure 1.1). Typically, postal services employ this tariff system. On the one hand, this system can increase the number of potential outside competitors for regional monopolists, and correspondingly, reduce their monopolistic power. On the other hand, the postage-stamp system can increase transmission losses because of frequent long-distance transmission and cause congestion in potential bottlenecks.

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[1] Of the 818 companies surveyed, 436 responded, and these are summarized by region, fuel, load pattern, etc. They were owners of power plants, large-scale companies in manufacturing, mining, construction, warehousing, railway, trading, and gas sectors, and companies that had never bid for wholesale power supply, and so on.

1.1.3 Popular Concerns about the Reform

Concerns have arisen over the current reform measures. The first is over the degree of price reductions. If IPPs have only a small capacity and/or consumers have a low price elasticity of demand, consumer benefits from deregulation would not be as significant as expected.

Second, IPP entry could make the domestic power markets difficult to control. The Japanese transmission networks have small capacity for inter-regional transmission. Because IPPs are *independent* of the GEUs and, therefore, not directly controlled by the network operators of the GEUs, this concern has been repeatedly expressed by the GEUs. If the IPPs' entry causes excessive use of the transmission networks, this concern is possibly—but not necessarily—valid. This risk will increase with increased congestion in the transmission networks. Therefore, congestion must be carefully managed by, for example, congestion charges.

The third concern, which is related to the second, is that the reform of the transmission tariff system from a zone-based system to the postage-stamp system may encourage IPPs to locate at long distances from consumers and thereby increase long-distance transmission. The reform could also cause congestion in transmission networks. In Japan, the transmission networks are thought to be poor because they are "spit-shaped". That is, regions are connected to each other primarily by one backbone link. Once this backbone link becomes congested, the network cannot be fully used. In particular, there is a potential bottleneck in the middle of the backbone link between Tokyo and Chubu. To transmit power between Tokyo and Chubu, the frequency has to be converted between 50 Hz and 60 Hz because the power systems of eastern and western Japan differ. The converter is costly and has limited capacity. This is expected to be the most crucial bottleneck for the transmission networks when there is a large amount of (long-distance) transmission.

1.2 Necessity for Quantitative Analysis of the Reform Measures

Although the authority planned the regulatory reform primarily on the basis of qualitative analysis and reviews of similar reforms in the US and Europe, there has been little quantitative evaluation of the impact of the regulatory reform. For example, the ANRE (1998) carried out the survey mentioned above to evaluate the potential supply capacity of IPPs in each region but did not analyze its impact on either regional demand and supply, welfare, or inter-regional power flows. To design effective regulatory reforms, we need more concrete and detailed pictures of future electricity markets. The allocation of IPP capacity and the design of the transmission tariff system can crucially affect regional demand and supply prices, welfare, and inter-regional transmission patterns. Evaluation of the regulatory reforms requires models that are characterized by regional demand and supply functions.

Electricity demand functions were estimated in the context of Ramsey pricing by Matsukawa *et al.* (1993). Supply functions (or cost functions) were estimated by, for example, Shinjo (1994) to evaluate scale economies in this industry. Although providing empirical insights into demand and supply behavior, none of these studies analyzed the impact of regulatory reforms by considering IPP entry and reform of the transmission tariff system.

Takahashi and Asano (2000) simulated IPP entry by assuming two representative types of IPP and a hypothetical electric power company with and without entry-forestalling pricing behavior. Hosoe (2000) employed a 20-sector computable general equilibrium model to quantify the impact of IPP entry on the other (mainly energy) sectors, factor markets, and overall welfare in Japan. However, the models employed in these two studies were single-country models, and so could not analyze the impact of the reforms on, and through, inter-regional transmission networks from a spatial viewpoint.

To quantify the impact of IPP entry and reform of the transmission tariff system in Japan and to answer concerns related to these reforms, we employ an electricity spatial and temporal price and allocation (e-STPA) model, à la Takayama and Judge (1971). Our modeling technique is similar to that employed by Salerian *et al.* (2000). We econometrically estimate price elasticities of demand and supply in each region by using the generalized method of moments (GMM) estimator, whereas most other studies, including Salerian *et al.* (2000), made *ad hoc* assumptions about some elasticities or determined them from an engineering viewpoint.

Our simulation results suggest the following. (1) IPP entry would bring about significant price reductions and reallocation of the surplus from producers to consumers. (2) The introduction of the postage-stamp tariff system would bring welfare benefits to Tokyo, Chubu, and Kansai in the form of lower transmission costs, but would harm the other regions. (3) Depending on the capacity and the location of IPPs, various transmission patterns would arise. Current IPP entry of 7,413 MW in total would not cause congestion on any inter-regional transmission links. Although the link with frequency converters between Tokyo and Chubu is generally expected to be the most crucial bottleneck, IPP entry of 20,750 MW would not cause any congestion there. It is only when we assume IPP entry of 34,480 MW under the postage-stamp tariff system that the link with frequency converters would become a bottleneck. However, in this case, there would also be many other bottlenecks.

This paper proceeds as follows. Section 2 explains details of our e-STPA model. Section 3 presents our simulation scenarios. Simulation results are shown in Section 4. Section 5 concludes our paper by addressing the popular concerns.

2. The e-STPA Model

Our e-STPA model distinguishes nine regions in Japan, each of which corresponds to the jurisdiction of an individual GEU (1: Tokyo, 2: Chubu, 3: Kansai, 4: Chugoku, 5: Hokuriku, 6: Tohoku, 7: Shikoku, 8: Kyushu, and 9: Hokkaido).[2] Each region has a pair of supply and demand functions (2.1) and (2.2), which are expressed in linear complementarity form as follows:[3]

$$(2.1)\quad y_i \cdot \left(-p_i^y + A_i^y + B_i^y \cdot y_i\right) = 0,\ -p_i^y + \left(A_i^y + B_i^y \cdot y_i\right) \geq 0;\ y_i \geq 0\ \ \forall i,$$

$$(2.2)\quad x_i \cdot \left(p_i^x - A_i^x - B_i^x \cdot x_i\right) = 0,\ p_i^x - \left(A_i^x + B_i^x \cdot x_i\right) \geq 0;\ x_i \geq 0\ \ \forall i,$$

where i is the index of regions, p_i^y is the producer price in the i-th region, p_i^x is the consumer price in the i-th region, y_i is production in the i-th region, x_i is consumption in the i-th region, and $A_i^\bullet$ and $B_i^\bullet$ are the intercept and slope coefficients of the supply and demand functions in the i-th region.

Inter-regional transmission links connect regions and allow imports and exports to eliminate excess demand in one region by using excess supply in others (Figure 2.1). Producer and consumer prices, the gap between which represents transmission costs, are determined to clear these excess demands and supplies. With this extension, market-clearing conditions in the i-th region are:

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[2] There is another region of Okinawa, which is isolated from the other nine regions on the Japanese mainland. We do not include Okinawa in our analysis.

[3] When we consider IPP entry in the manner discussed in Section 3, the supply function should be:

$$y_i \cdot \left[-p_i^y + \min\left(\left(A_i^{y^0} + B_i^y \cdot y_i\right),\ \max\left(p_i^{IPP},\ \left(A_i^y + B_i^y \cdot y_i\right)\right)\right)\right] = 0,$$

$$-p_i^y + \min\left(\left(A_i^{y^0} + B_i^y \cdot y_i\right),\ \max\left(p_i^{IPP},\ \left(A_i^y + B_i^y \cdot y_i\right)\right)\right) \geq 0;\ y_i \geq 0\ \ \forall i,$$

where $A_i^{y^0}$ denotes the original intercept term without IPP entry, and p_i^{IPP} denotes the price offered by IPPs. A_i^y denotes the intercept term with IPP entry; thus $A_i^y \leq A_i^{y^0}$.

$$(2.3)\quad p_i^y \cdot \left(y_i - \sum_j z_{ij} \right) = 0\,,\ y_i - \sum_j z_{ij} \geq 0\,;\ p_i^y \geq 0\ \ \forall i\,,$$

$$(2.4)\quad p_i^x \cdot \left(-x_i + \sum_j z_{ji} \right) = 0\,,\ -x_i + \sum_j z_{ji} \geq 0\,;\ p_i^x \geq 0\ \ \forall i\,,$$

where z_{ij} is the amount of electricity transmission from the i-th region to the j-th region.

Equation (2.3) implies that the total supply from the i-th region to all the regions cannot exceed the domestic production of the i-th region. (Note that the transmission includes that from the i-th region to itself.) Equation (2.4) implies that the consumption in the i-th region cannot exceed the total supply from all the regions to the i-th region.

Equation (2.5) represents transmission capacity constraints on the total power flow at the s-th link.

$$(2.5)\quad r_s \cdot \left(\overline{Z}_s - \sum_i \sum_j \rho_{ijs} \cdot z_{ij} \right) = 0\,,\ \overline{Z}_s - \sum_i \sum_j \rho_{ijs} \cdot z_{ij} \geq 0\,;\ r_s \geq 0\ \ \forall s\,,$$

where ρ_{ijs} is a dummy variable used to specify links used for transmission from the i-th region to the j-th region, $\overline{Z}_s$ is the transmission capacity of the s-th link, and r_s is the congestion charge on the s-th link.

Each link can be used for transmission from/to the i-th region to/from the j-th region. Thus, although there are nine physical links considered in Figure 2.2, 18 logical links are identified in our e-STPA model.[4] ρ_{ijs} is a dummy variable used to specify routes of transmission. If transmission from the i-th region to the j-th region is possible using the s-th link, ρ_{ijs} is unity, otherwise it is zero. If the second condition of (2.5) holds with strict equality, the shadow price r_s (i.e., the congestion charges) is positive. Otherwise, the shadow price is zero. The capacity of inter-regional

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[4] Two-way transmission on the same physical link never takes place. This is ensured by (2.6), discussed later, which implies a reasonable assumption about transmission costs.

transmission links is shown in Figure 2.2.[5], [6]

Equation (2.6) describes the condition for price equalization between the supply price in the *i*-th region and the demand price in the *j*-th region, with gaps being due to transmission costs.

$$(2.6)\quad z_{ij}\cdot\left(-p_j^x+p_i^y+t_{ij}+tl_{ij}+\sum_s \rho_{ijs}\left(r_s+r_s^{ini}\right)\right)=0,$$

$$-p_j^x+p_i^y+t_{ij}+tl_{ij}+\sum_s \rho_{ijs}\left(r_s+r_s^{ini}\right)\geq 0\;;\; z_{ij}\geq 0\ \ \forall i,j,$$

where t_{ij} are *ad quantum* unit transmission costs, which consist of an access charge and wheeling charges from the *i*-th region to the *j*-th region, tl_{ij} are *ad quantum* physical losses in transmission from the *i*-th region to the *j*-th region, and r_s^{ini} is the initial transmission rent.[7]

The congestion charges are endogenously determined as the shadow price of (2.5); the initial transmission rent is exogenous. In (2.6), congestion charges (and initial transmission rents) are summed with respect to all the links that are on the route from departure region *i* to destination region *j*. When transmission from the *i*-th region to the *j*-th region is not possible using a link, say the *s*-th link, its congestion charge $r_{s'}$—even if it is strictly positive—does not affect the price gap between these regions. This is because the dummy variable, $\rho_{ijs'}$, is set to zero for such off-route links. Equation (2.6) implies that the supply price in the *i*-th region plus unit transmission costs cannot be lower than the demand price in the *j*-th region. If transmission from the *i*-th region to the *j*-th region is strictly positive/zero, the second condition in (2.6) holds with equality/inequality.

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[5] In Figures 2.2 and 4.1 to 4.3, the link between Hokuriku and Chubu is drawn with a broken line. This indicates that we do not consider it in our simulations, although it does exist. The rationale for this simplification is discussed in detail in Appendix I.

[6] Figure 2.2 shows that Shikoku has two direct links with Kansai. To simplify our model and simulations, we assume that transmission between these two regions always uses one of them and that transmission between Shikoku and Chugoku always uses the other. The rationale is discussed in Appendix I.

[7] See Appendix II for discussion of the initial transmission rent.

3. Simulation Scenarios

To evaluate the impact of the regulatory reforms, we perform quantitative simulations with six scenarios, which are formed by combining two cases of the transmission tariff system (Cases Z and P) and three cases of IPP capacity (Cases A to C). In all six (two by three) cases, constraints on inter-regional transmission capacity are imposed (Figure 2.2). These are reported by the Central Electric Power Council (CEPC) (2002), setting aside the currently occupied capacity for inter-GEU transmission, which is determined by their long-term contracts (Table 3.1). With this transmission given, our simulation scenarios are arranged as follows.

3.1 Transmission Tariff Systems

Case Z assumes that the zone-based transmission tariff system is retained. A unit transmission charge consists of the transmission charge, which is the sum of an access charge and wheeling charges (Table 3.2), the transmission losses (Table 3.3), the initial transmission rent, and total congestion charges, as shown in (2.6).[8]

As the amounts and patterns of transmission are changed by IPP entry, total transmission-related revenue also changes. We chose not to employ a scenario that keeps the total revenues unchanged (compared with the Base Run) by adjusting the (unit) transmission charges because our objective was to shed light on the impact of IPP entry, not on the effects of changes to (unit) transmission charges.

Case P assumes that the postage-stamp transmission tariff system is introduced. The access charge imposed in Case Z is abolished and the wheeling charge is made uniform irrespective of points of departure and destination. In addition to this wheeling charge, transmission losses (exogenous), initial transmission rents (exogenous), and total congestion charges (endogenous) are

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[8] Although neither the initial transmission rent nor the congestion charge is explicitly employed under the current transmission tariff system, in practice, a rationing mechanism is instead supposed to play the same role to manage congestion and prohibit inter-regional transmission.

imposed as in Case Z.

When we simulate the introduction of a new tariff system, the assumed level of the postage-stamp price is crucial. To clarify the impact of reform of the transmission tariff system, we use Case Z as a reference for calculating the amount of transmission-related revenues (i.e., access and wheeling charges, the initial transmission rents, and congestion charges) and calculate postage-stamp prices for Case P that equalize the amounts of transmission-related revenues for Cases Z and P under the same scale of IPP entry.[9]

3.2 The Scale of IPP Entry

Case A assumes that entry of IPPs as wholesale suppliers occurs on the basis of actual bids, which were made between 1996 and 1999 for the wholesale supply to the GEUs for the period 2000–2007. We have IPPs in eight of the nine regions, and a total capacity of 7,413 MW (in the first column of Table 3.4).[10]

Case B simulates the hypothetical entry of IPPs that are actually planning to operate according to the ANRE (1998). This case assumes that IPPs will operate in all nine regions and have a total capacity of 20,750 MW (in the second column of Table 3.4).

Case C simulates the hypothetical entry of IPPs that intend to operate under a more favorable bidding system and conditions than the current ones, also following the ANRE (1998). This implies

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[9] Given the transmission tariffs, IPP entry would increase transmission and associated revenues for the network proprietor. If costs to maintain transmission networks are constant irrespective of the amount of transmission—as we often expect for network industries—the increased transmission revenues can be regarded as the network proprietor's surplus. The surplus constitutes social welfare in our simulation results (shown later).

[10] We convert the capacity of power plants (W) into the amount of the electricity generated (Wh) by multiplying 365 (days) by 24 (hours) by 0.50 (the operation rate). Note that the operation rate of 50% is our guess. However, we set the operation rate to 100% in the unit conversion for the transmission capacity.

an IPP entry with the largest capacity (34,480 MW) of the three scenarios (and is reported in the third column of Table 3.4).

For these cases, we assume that the IPPs in each region offer prices shown in the last column of Table 3.4. Most of these IPP supply prices are estimated by using weighted averages of actual bids in each region. The IPP supply prices in Hokuriku and Tohoku, however, come from an arithmetic average of these prices in eight regions. The reason for this special treatment of Hokuriku is that there has been no bidding for IPPs' wholesale supply to the GEUs in this region. For Tohoku, because there has been no bidding for base-load supply but only for peak- and middle-load supply, a simple weighted average of actual bids would be biased upwards. The access and wheeling charges, except for congestion charges, are exogenous and common under the zone-based tariff system.

IPP entry causes a shift in a supply function according to IPP capacity (y_i^{IPP}) as shown in Figure 3.1. (To simplify the figures, we do not consider inter-regional transmission, congestion, or transmission losses.) If the prices offered by IPPs (p_i^{IPP}) are low and/or their capacity is small, the demand curve tends to cross the new supply curve at a point where its slope is positive (Figure 3.2). If IPP prices are high and/or their capacity is large, the demand curve tends to cross the flat part of the supply curve (Figure 3.3). In this case, the IPPs are the marginal supplier and their capacity is not fully used. Note also that, if IPP prices are too high and/or demand is too small, the part of the supply curve that shifts does not intersect the demand curve. That is, IPP entry in the region does not affect the market.

Figure 3.4 illustrates how IPP entry in one region affects another in the two-region case. Suppose that the initial equilibrium is represented by the white dots. This case generates no inter-regional transmission because the supply price in the *i*-th region p_i^y plus transmission costs T_{ij} exceeds region *j*'s demand price p_j^x, which is equal to its supply price p_j^y plus the intra-regional transmission costs T_{jj}. When IPPs enter the market in the *i*-th region with a sufficiently large capacity and at a low bidding price, the supply price in the *i*-th region would fall as shown by the black dots. Now, the supply price plus inter-regional transmission costs can be competitive with the price in the other region. The inter-regional transmission from the ith region to the jth region takes place and reduces production in the jth region.

4. Simulation Results

4.1 Impact of Actual IPP Entry as Wholesale Suppliers

4.1.1 Scenario AZ: Under the Zone-based Tariff System

The GEUs in the eight regions decided to accept wholesale supply by IPPs with a total capacity of up to 7,413 MW, which takes effect in 2000–2007 as assumed in Case A. The simulation results show that IPP entry would cut demand prices by 10.1–14.5% and supply prices by 12.2–17.2% to redistribute the surplus from producers to consumers (Table 4.1). Because the price fall would lead to increases in total regional demand, the decline in GEU production would be less than the scale of IPP entry. Although there would be a decline in the producers' surplus in all regions, this does not imply that IPPs would incur losses but does imply that the GEUs' profits would fall. In the case of Tokyo, the IPPs' surplus would amount to 64,900 million yen and the GEUs' loss would amount to 690,000 million yen as shown in Table 4.1. IPP entry would affect not only the domestic market but also other markets via inter-regional transmission.

With large-scale IPP entry and a significant price fall in Tokyo, inter-regional transmission from Tokyo to Tohoku would occur to lower production in Tohoku by 1.4% (Table 4.2). This is illustrated in Figure 3.4. Similarly, the supply declines in Chugoku and Hokuriku can be explained by the large IPP capacity in Kansai and transmission from Kansai.

Actual IPP entry would lead to strictly positive welfare gains in all regions, as measured by the sum of producer and consumer surpluses. For example, the largest gains of 80,100 million yen would be in Tokyo, followed by Kansai, Chubu, and Kyushu. The welfare gains would depend primarily on the assumed scale of IPP entry (Table 3.4). Even without IPP entry, Hokuriku would gain slightly because of transmission from Kansai. With increases of intra- and inter-regional transmission and transmission tariffs unchanged, the network proprietor would obtain a surplus of 39,000 million yen.

As shown in Table 4.2, IPP entry would stimulate exports mainly from Tokyo to Tohoku and from Kansai to Chubu, Chugoku, and Hokuriku, and also generate inter-regional power flow as shown in Figure 4.1. It should be noted that these flows would not cause congestion on any transmission links.

4.1.2 Scenario AP: Under the Postage-stamp Tariff System

When we change the transmission tariff system from being zone-based to a postage-stamp system and keep constant the assumed scale of IPP entry and the total transmission-related revenues, it is mainly the welfare indicators and the amount of inter-regional transmission that would be affected (Table 4.3). The former can be explained by the changes in intra-regional transmission charges; the latter by changes in inter-regional transmission charges. Most domestically generated electricity is transmitted to its own market. A postage-stamp price of 2.54 yen/kWh would generate the same total transmission-related revenue as that by the zone-based transmission tariff system. Given this postage-stamp price, all regions except for Tokyo, Chubu, and Kansai would experience increased domestic transmission charges, which were originally 1.70–2.19 yen/kWh under the zone-based tariff system (Table 3.1). Therefore, reform of the transmission tariff system would reduce welfare in these six regions. On the other hand, Tokyo and Chubu would double their welfare gains. Kansai would achieve smaller gains because there would be only small gains from the decline of its domestic transmission charges and losses from the increased transmission charges on its exports to the two other regions. In terms of social welfare, the postage-stamp tariff system would deliver gains of 600 million yen more than would those of Scenario AZ.

It is often argued that the postage-stamp tariff system promotes long-distance transmissions by reducing inter-regional transmission charges. Our results, however, suggest that increases in inter-regional transmissions would occur only between nearby (i.e., short-distance) regions (Table 4.4). The power flow would not be large enough for any transmission capacity constraints to be binding (Figure 4.2). That is, even though the transmission networks are thought to be poor in Japan, this lack of quality would not matter given this scale of IPP entry.

4.2 Impact of Hypothetical IPP Entry (1)

4.2.1 Scenario BZ: Under the Zone-based Tariff System

Case B assumes entry of IPPs that are planning to operate as wholesale suppliers under the *current* bidding system and conditions, following the survey by the ANRE (1998). The scale of IPP entry is assumed to be sufficiently large to induce demand price falls ranging from 21.6% in Hokuriku to 45.2% in Kyushu (Table 4.5). All regions would obtain positive benefits in terms of welfare. Tokyo would again obtain the largest benefit of 117,700 million yen, followed by Kyushu.

Because of the entry of the IPPs' substantial capacity, Chugoku and Kyushu would become new exporters (Table 4.6). Power flows would occur in opposite directions between Kansai, Chugoku, Shikoku, and Kyushu compared with those in Scenario AZ (Figure 4.3). In this case, the transmission capacity constraints on the link from Kansai to Hokuriku would be binding to yield quite high congestion charges of 1.67 yen/kWh.

Chugoku, in which IPP entry is assumed to be high, would carry out long-distance transmission to Hokuriku via the third region of Kansai. This is simply due to abundant capacity arising from large-scale IPP entry (and transmission from Kyushu), and is not due to the reform of the transmission tariff system.

4.2.2 Scenario BP: Under the Postage-stamp Tariff System

In this simulation, we find a qualitatively similar impact of the introduction of postage-stamp tariffs to that in Scenario BZ. That is, the introduction of postage-stamp tariffs of 2.54 yen/kWh would benefit Tokyo, Chubu, and Kansai in the form of reduced transmission tariffs, whereas it would harm the other regions (Table 4.7).

This scenario generates transmission from Tokyo to Chubu (Figure 4.4). The link between these two regions requires a special facility to convert the frequency and is prone to being the main bottleneck in the transmission network. However, this simulation result implies that there would be no congestion with this scale of IPP entry. Rather than the capacity constraints on this link being binding, the constraints on links from Kansai to Hokuriku and from Tohoku to Hokkaido would be binding. Hokuriku, the biggest loser, is located behind this link under a capacity constraint.

Except for transmission via the Tokyo to Chubu link mentioned above, there would be no change in transmission patterns in western Japan. In combination, the four simulation results imply that inter-regional transmission patterns would depend strongly on the location of new plants rather than on the transmission tariff system.

4.3 Impact of Hypothetical IPP Entry (2)

4.3.1 Scenario CZ: Under the Zone-based Tariff System

The survey by the ANRE (1998) also expects *additional* entry of IPPs that can operate under more favorable entry conditions. This simulation result implies that further expansion of IPP entry would provide additional benefits to consumers in all regions while providing much stronger competition between producers, thereby reducing producer surpluses in all regions (Table 4.9).

We found that competition would increase not only between IPPs and the GEUs but also between IPPs. Supply prices would fall drastically (to almost half) relative to the assumed IPP supply prices. Then, the IPPs would become the marginal producers and hence determine the market-clearing supply prices in these six of the nine regions, as Figure 3.3 illustrates. In these six regions, IPPs operate at less than 100% capacity.[11] This implies that our assumed IPP supply prices might be lowered by severe competition. This cutthroat competition could be compared to that between new common carriers in the telecommunications industry, which experienced regulatory reforms a few decades ago.

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[11] As a result, IPPs' surplus in these regions would be zero because their demand curves would intersect the horizontal part of their supply curves as Figure 3.3 shows.

Chugoku is assumed to have IPP entry with the second largest capacity—following Tokyo—which markedly increases its production by 25.2% and brings about significant changes in transmission patterns in western Japan. This is why Chugoku would be the main exporter to the nearby regions of Kansai, Hokuriku, Shikoku, and Kyushu (Table 4.10). With increased IPP capacity relative to that assumed in Scenario BZ, power flows between Chugoku and Kyushu would be reversed (Figure 4.5). In addition, because the transmission from Chugoku to Kansai would increase by up to its full capacity, detour power flows from Shikoku to Kansai would also arise.

With IPP capacity in Hokuriku trebled relative to that assumed in Scenario BZ, Hokuriku would have less need to import power from Kansai. Thus, the congestion charge on the link from Kansai to Hokuriku would be reduced.

4.3.2 Scenario CP: Under the Postage-stamp Tariff System

In this case, the postage-stamp price is 2.53 yen/kWh, which is very similar to the price in the other simulations under the postage-stamp tariff system. Hence, the simulation results are also very similar (Table 4.11). The tariff system reform would raise the domestic transmission tariff rates and lead to welfare losses in all regions except Tokyo, Chubu, and Kansai. In terms of social welfare, increased IPP entry would bring about strictly positive gains. Furthermore, the introduction of the postage-stamp tariff system would increase the efficiency of the transmission networks and yield additional gains.

The inter-regional transmission charge would be reduced to promote inter-regional transmission between Hokkaido, Tohoku, Tokyo, Chubu, and Kansai (Table 4.12 and Figure 4.6). The amount transmitted between Kansai, Hokuriku, Chugoku, and Kyushu would be the same as that in Scenario CZ. This is because transmission between these regions is already at full capacity. The introduction of the postage-stamp tariff system would extensively promote inter-regional transmission and the use of all the links. Congestion would occur on six of the nine links.

5. Concluding Remarks

We have analyzed the impact of the regulatory reforms involving independent power producer (IPP) entry and the introduction of the postage-stamp transmission tariff system by employing the electricity spatial and temporal price and allocation (e-STPA) model with nine regions for Japan. As the regulatory reforms have not yet been finalized, our simulation scenarios partly reflect actual IPP entry according to the results of competitive bidding for wholesale supply and partly assume hypothetical IPP entry according to the estimates provided in the survey by the ANRE (1998). With these scenarios of the regional electricity markets in the near future, we have obtained several useful simulation results. The main findings are as follows.

IPP entry would cause sharp falls in supply prices and reallocate the surplus from producers to consumers to lead to welfare gains in all regions. The size of regional welfare gains would differ by region and depend on IPP capacity and the transmission tariff system. Generally, regions with large IPP capacity and/or high initial transmission charges would gain more. Even without (large-scale) IPP entry in a region, inter-regional transmission from other regions can benefit its consumers.

The larger the capacity of entrants, the more inter-regional transmission would take place. On the one hand, transmission links in western Japan would tend to have more congestion than those in eastern Japan. This implies that increasing the capacity of transmission links in western Japan should have a higher priority. On the other hand, the link between Tokyo and Chubu, which requires a frequency converter, does not seem to be the main bottleneck in the sense that before the transmission capacity constraint on this link becomes binding, those on other links would.

The postage-stamp tariff system would not necessarily cause congestion, but IPP entry with a large capacity would. Cases B and C demonstrate this with long-distance transmission from Shikoku and Chugoku to Hokuriku via the third region of Kansai. This long-distance transmission would occur, even without the introduction of the postage-stamp tariff system. As a result of introducing the postage-stamp tariff system, social welfare would increase by 600–3,400 million yen.

The postage-stamp price would be in the very narrow range of 2.53–2.54 yen/kWh in our simulation results. The postage-stamp price is roughly equal to the total transmission tariff revenues divided by the total amount of intra- and inter-regional transmission. The total amount of inter-regional transmission is very small compared with the total amount of intra-regional transmission. For this reason, IPP entry cannot affect the postage-stamp price, which consists of total (i.e. inter- and intra-regional) transmission costs divided by transmission quantity. Thus, the postage-stamp price would not differ much between cases.

Considering the sizeable reallocation of the surplus between producers and consumers and between IPPs and the GEUs, we can expect the GEUs to be reluctant to let IPPs freely use their transmission networks. A similar problem has accompanied regulatory reform in the telecommunications sector. Regulatory reform in the form of IPP entry for freer electricity markets must be accompanied by appropriate policy measures to ensure fair competition under open-access to the transmission networks.

Our assumptions about the scale of IPP entry might seem overly optimistic, particularly considering the current economic situation and the suspension of the bidding for wholesale supply. However, these may not be appropriate criticisms of our assumptions. In the long run, economic recovery is expected. Indeed, the GEUs no longer accept wholesale suppliers, and retailing activities by private plants have begun. The potential supply capacity will support these retailing activities. Although we use the term "IPPs" to refer to new entrants or power plants with lower supply costs, new power plants owned by the GEUs, which replace their own old plants, have the same effect of lowering market prices. In this sense, we can expect intense competition not only between IPPs but also between GEUs.

Our work could be extended in a number of directions. Our simulation results suggest that IPP entry would generate a large surplus (390–1,278 million yen) to the network proprietor. Experiments to simulate tariff cuts might be needed. Concerning the model structure, we could assume that GEUs and IPPs engage in Stackelberg competition because they differ greatly in size. In addition, we could analyze whether or not the additional transmission-related revenues from expanded transmission capacity cover the investment costs incurred by the network proprietor. This would have important implications for the degree to which proprietors have an incentive to maintain networks in the context of future unbundling.

Appendix I: Model Simplification and its Rationale

There are special treatments for two links in the network assumed in our model. Hokuriku has a link (the *Minami-Fukumitsu* BTB) to Chubu and another (*Echizen-Reinan*) to Kansai. The former is omitted in our model for simplicity. This is because its transmission capacity from Hokuriku to Chubu is zero and that from Chubu to Hokuriku is not specified separately but as the sum of its capacity and the capacity of the *Echizen-Reinan* link between Kansai and Hokuriku. With this simplification, we cannot define a case in which the link from Chubu to Hokuriku is in use, which occurs *only when* the route from Chubu to Kansai is congested and a detour via the *Minami-Fukumitsu* BTB link is required. (Note that the *Minami-Fukumitsu* BTB link is not used first because of its high transmission charges under the zone-based tariff system.) However, no such case arose in practice in any of our simulation results.

Shikoku has two direct links to Kansai (*Honshi* and *Anan-Kihoku*). We assume the *Honshi* link is used only for transmission between Shikoku and Chugoku and between Shikoku and Kyushu. Similarly, the *Anan-Kihoku* link is only used for transmission between Shikoku and the other regions. This simplification can (but does not necessarily) cause a bias to our simulation results, but *only when all* of the following conditions hold. (1) The *Anan-Kihoku* link from Shikoku to Kansai is congested. (2) The *Honshi* link can transmit power from Shikoku to Chugoku. (3) The link can transmit from Chugoku to Kansai. (Or, if all of these conditions hold for transmission in the opposite direction). That is, our simplification excludes the possibility of a detour in transmission from Shikoku to Kansai (or the other eastern regions) via Chugoku. This case, however, did not arise in our simulations.

Appendix II: Model Calibration

Our e-STPA model consists of nine regions, each of which has a pair of regional supply and demand functions. As stated in Section 2, we assume that they are linear functions, i.e., (2.1) for supply and (2.2) for demand. We obtain their slope parameters (B_i^y and B_i^x) by taking weighted averages of the above elasticity estimates. For example, in the case of Tokyo's supply, shares of hydroelectric, thermal, nuclear, and purchased power generations for 1998 are 4.7%, 39.7%, 43.4%, and 12.2% respectively. The weighted average of their price elasticities is 0.143; the calculated slope parameter is 3.100 following the definition of the elasticity. The intercept terms (A_i^y and A_i^x) are calibrated to be consistent with the actual price and quantity for supply and demand in the benchmark year of 1998. (The supply price is calculated in the manner discussed later.) The intercepts are –90,837 for the supply function and 156,362 for the demand function in Tokyo.

Transmission costs (t_{ij}), reported in Table 3.2, are equal to the sum of wheeling charges from the *i*-th region to the *j*-th region and the access charge in the *j*-th region (recall Figure 1.1). Their data sources are wheeling and access charge articles (*Furikae-Kyokyu-Yakkan and Setsuzoku-Kyokyu-Yakkan*) issued by the GEUs. Data for transmission losses (tl_{ij}) are from Table 3.3 of "the Minutes of the Electric Utility Subcommittee, Natural Resources and Energy Committee (the *Denki-Jigyo-Bunkakai-Sougou-Shigen-Enerugi-Chousakai*)" from the Agency for Natural Resources and Energy. The losses are originally shown in physical terms, which we have converted into value terms. Given the observed demand price (p_i^x), domestic transmission charges (t_{ii}), and domestic transmission losses (tl_{ii}), the supply prices (p_i^y) are derived from the following expression:[12]

$$p_i^y = p_i^x - t_{ii} - tl_{ii}.$$

Theoretically, when a supply price plus transmission costs (i.e., charges and losses) in a region is

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[12] Note that congestion charges do not arise and neither do the initial transmission rents (discussed later).

less than the demand price(s) in other region(s), transmission must take place between these regions (see Equation (2.6)). However, this is not necessarily recorded in the actual data when we compare demand and supply prices region by region. To overcome this inconsistency between theory and data, we assume that there should be some quantitative restriction to yield a rent in the initial benchmark equilibrium. This rent (r_s^{ini}) on the s-th link, which directly connects the i-th region to the j-th region, is derived by using the data in the benchmark equilibrium as follows:

$$r_s^{ini} = \max\left(0\,,\, p_j^x - p_i^y - t_{ij} - tl_{ij}\right).$$

Note that there is no congestion charge in the benchmark equilibrium. The r_s^{ini} is an exogenous variable in our model.

In calibrating the intercept terms, we set the initial amount of inter-regional transmission equal to zero to simplify the model and the simulations. We obtained the transmission capacity ($\overline{Z}_{ij}$) from the *Chuou-Denryoku-Kyougikai* (the Central Electric Power Council) in 2002.

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Figure 1.1: Comparison of the Two Transmission Tariff Systems

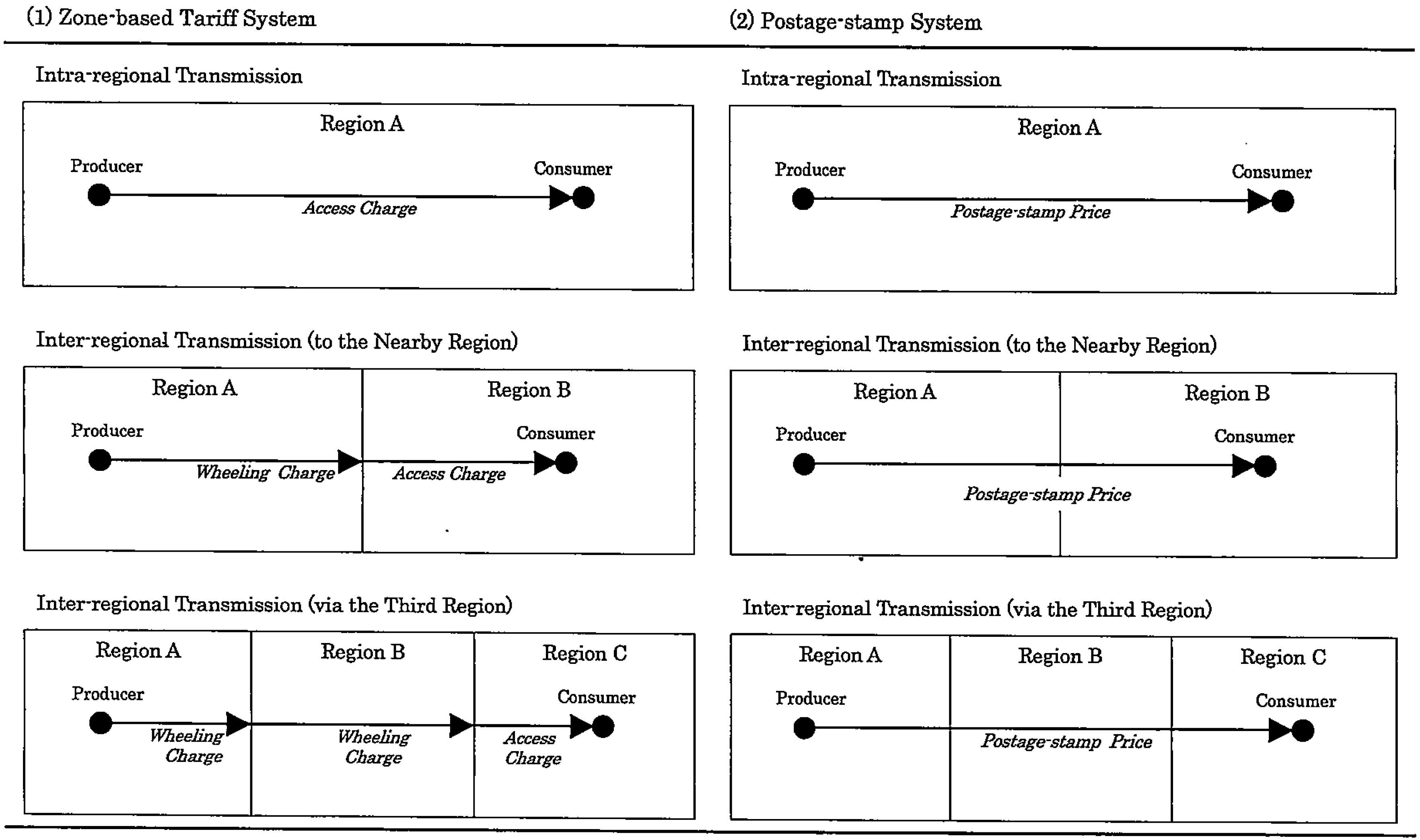
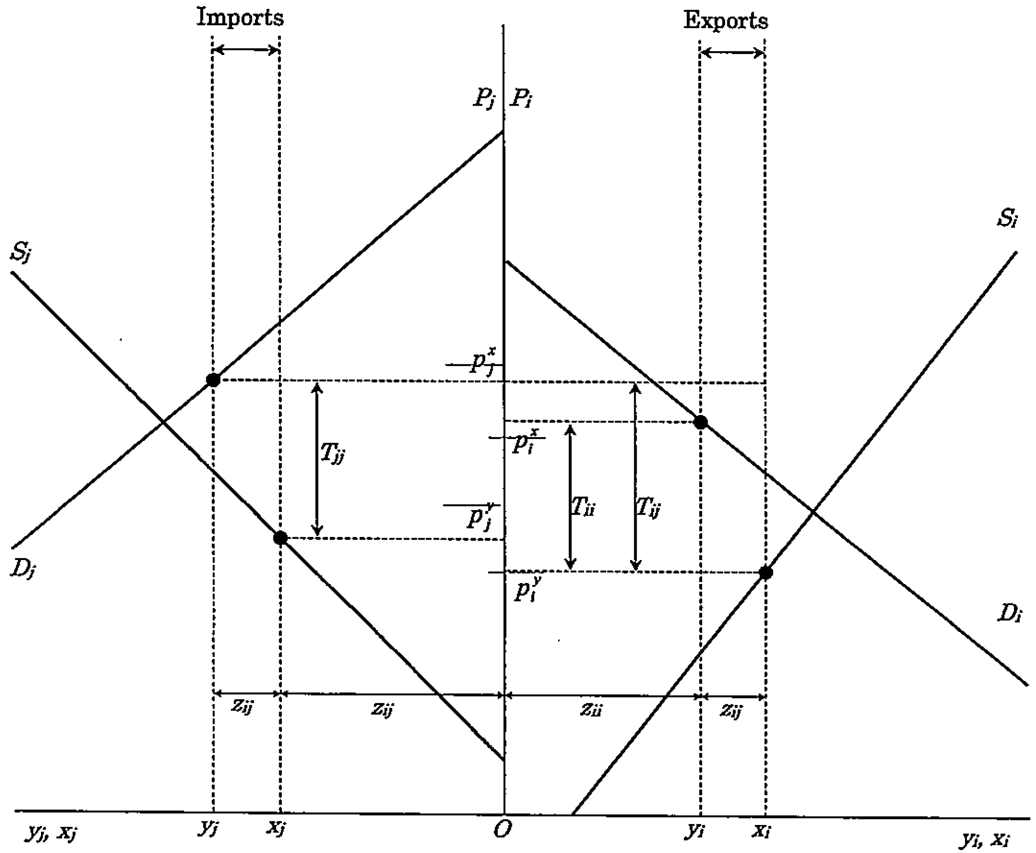
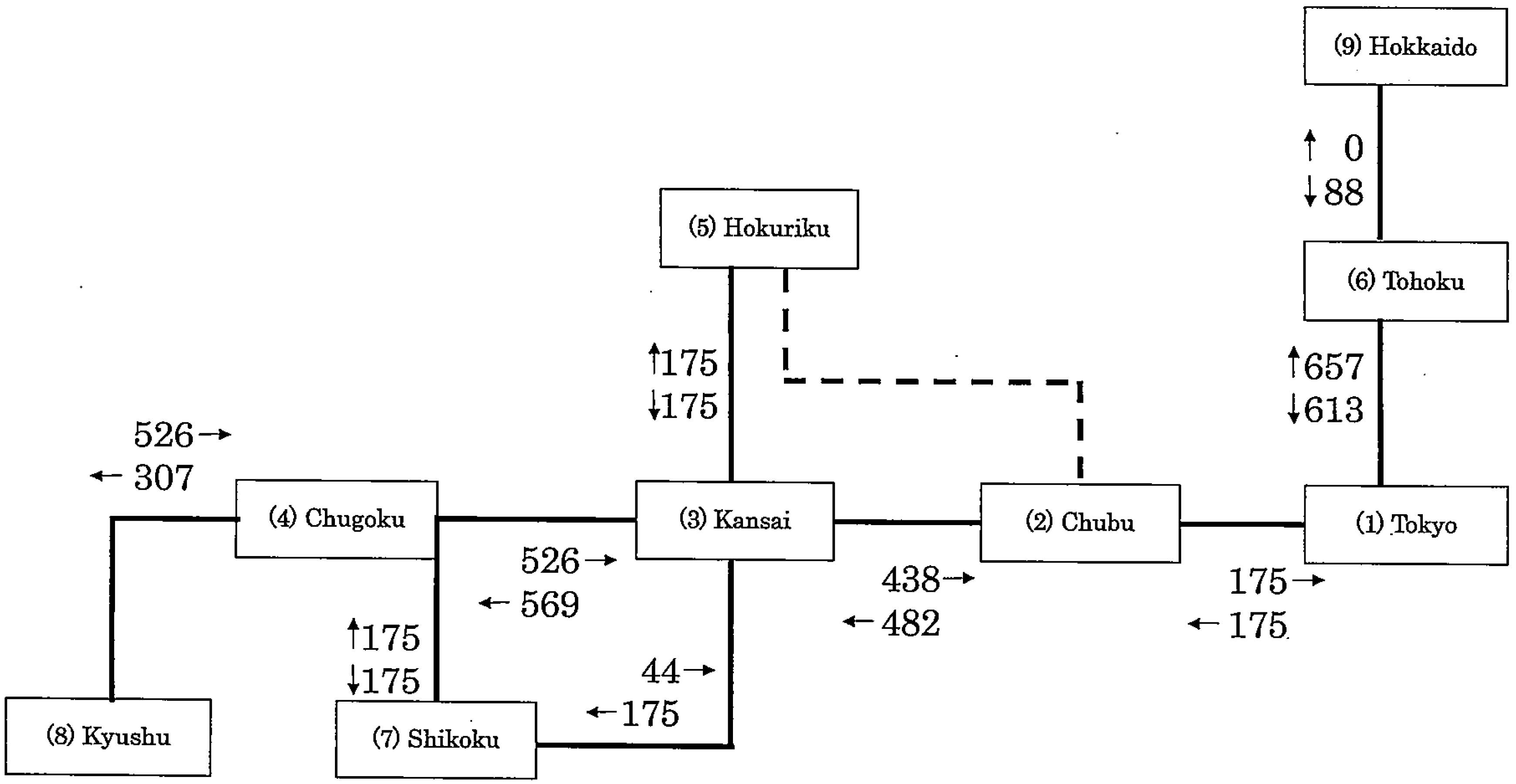


Figure 2.1: The e-STPA Model (A Two-region Diagram with Transmission Costs)



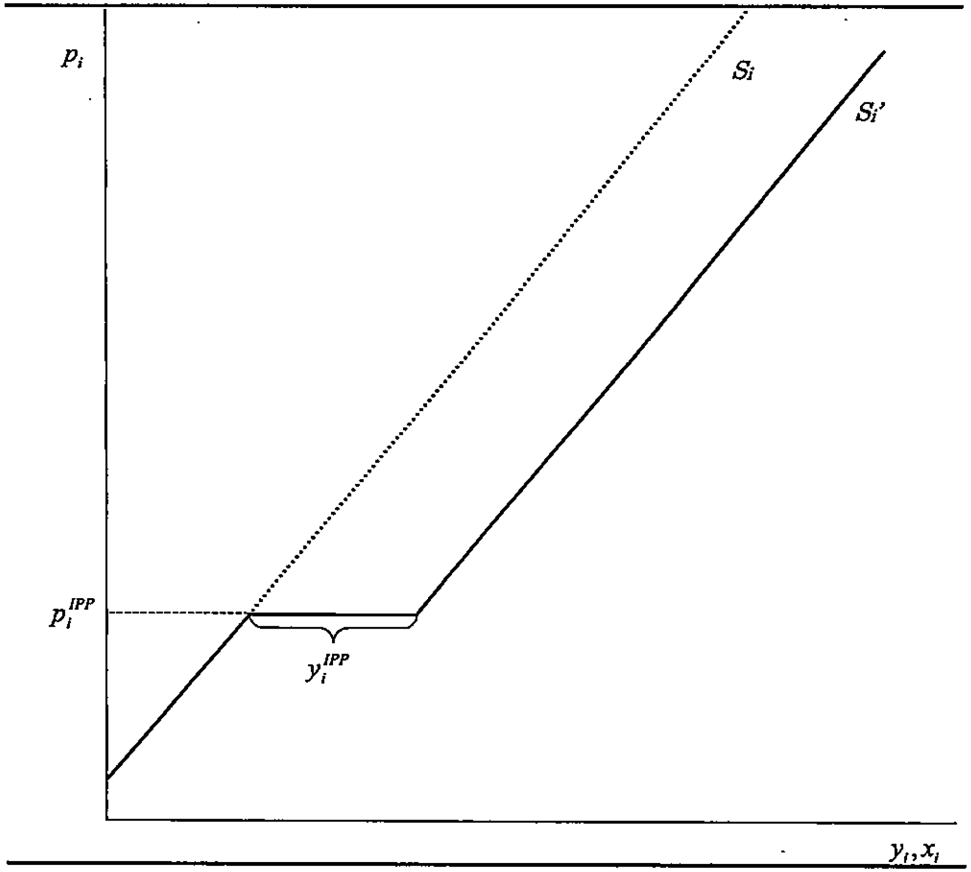
Note: $T_{ij} \equiv t_{ij} + tl_{ij}$.

Figure 2.2: Capacity of Inter-regional Transmission Links (10,000 MWh)



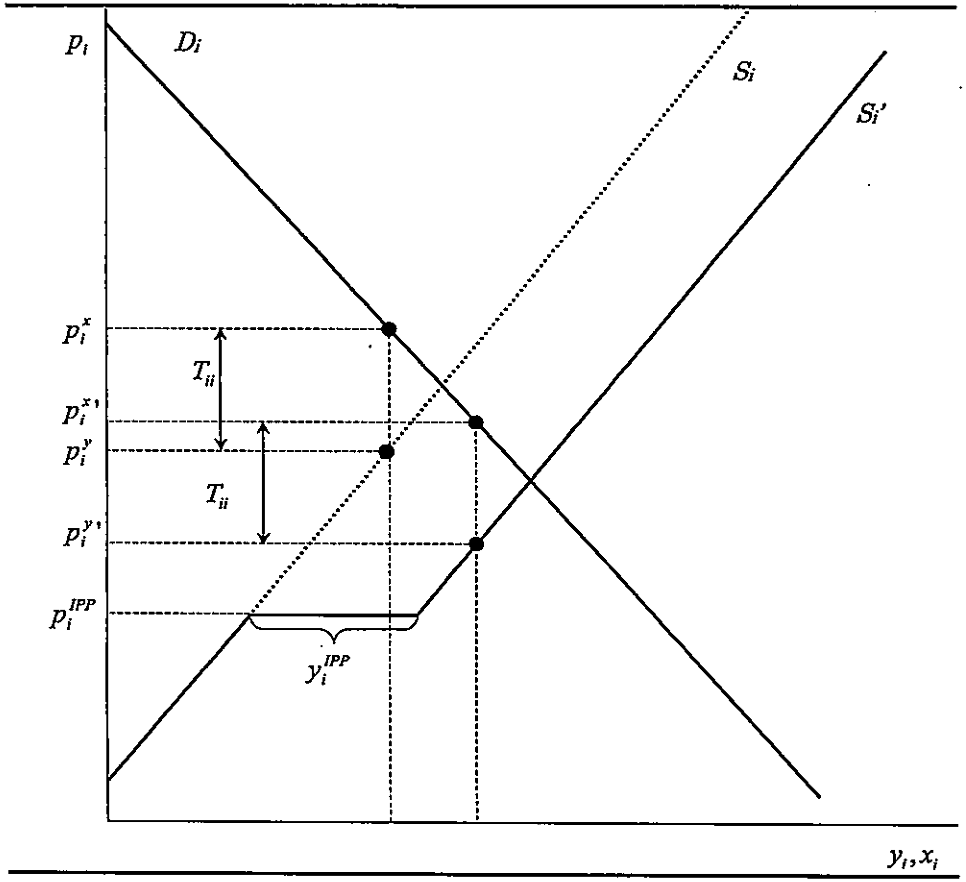
Source: CEPC (2002)

Figure 3.1: Shifts in the Supply Function caused by IPP Entry



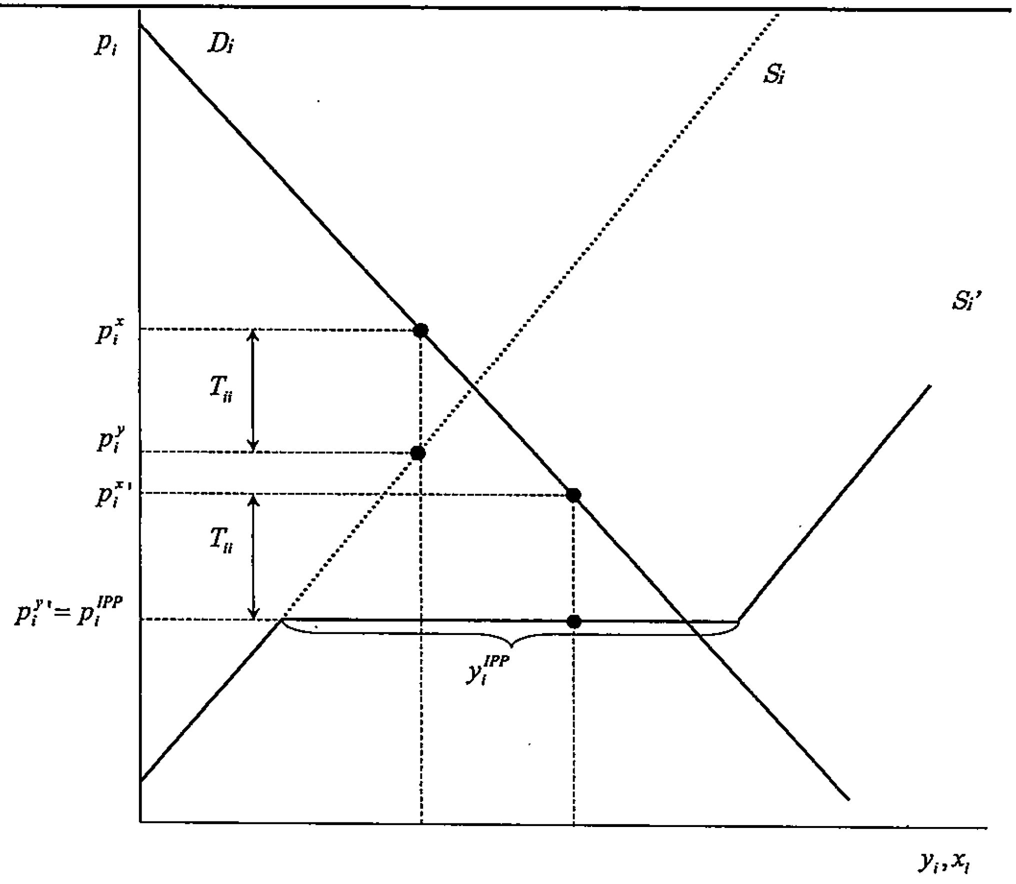
Note: $T_{ij} \equiv t_{ij} + tl_{ij}$.

Figure 3.2: The Case of Small IPP Capacity



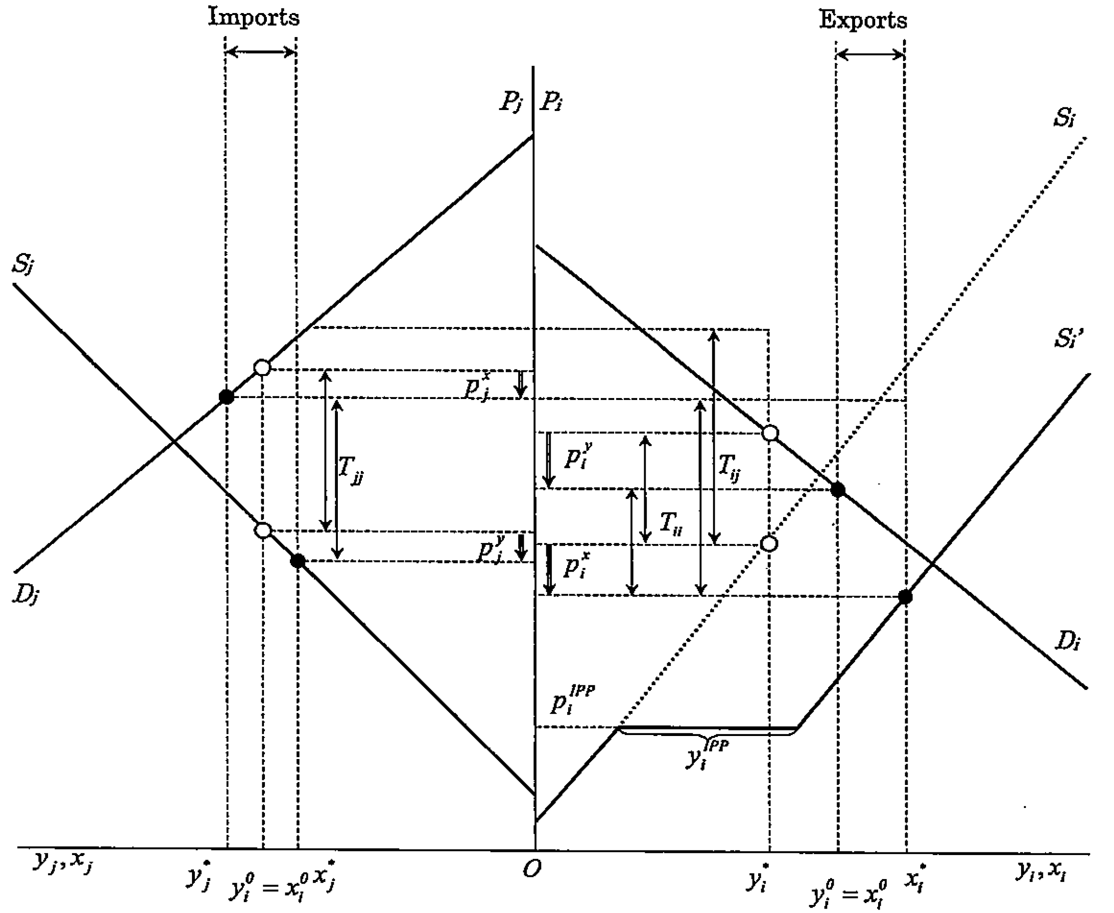
Note: $T_{ij} \equiv t_{ij} + tl_{ij}$.

Figure 3.3: The Case of Large IPP Capacity



Note: $T_{ij} \equiv t_{ij} + tl_{ij}$.

Figure 3.4: The Impact of IPP entry (A Two-region Diagram with Transmission Costs)



Note: $T_{ij} \equiv t_{ij} + tl_{ij}$.

Table 3.1: The Amount of Transmission in Long-term Contracts between GEUs (10,000 MWh)

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total
Tokyo	-	8	0	0	0	0	0	0	0	8
Chubu	0	-	1	0	0	0	0	0	0	1
Kansai	0	0	-	0	0	2	0	0	0	2
Chugoku	0	202	374	-	0	0	0	0	0	576
Hokuriku	39	195	370	0	-	1	0	0	0	605
Tohoku	1,073	1	0	0	0	-	0	0	0	1,074
Shikoku	31	58	384	0	0	0	-	0	0	473
Kyushu	0	6	55	0	0	0	0	-	0	62
Hokkaido	0	0	0	0	0	1	0	0	-	1
Total	1,143	470	1,184	0	0	4	0	0	1	2,801

Table 3.2: Actual Transmission Charges (yen/kWh)

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido
Tokyo	2.87	4.80	4.96	4.71	4.66	2.49	5.25	5.21	4.05
Chubu	4.88	2.70	2.86	2.61	3.89	4.50	3.15	3.11	6.06
Kansai	5.18	3.00	2.62	2.37	2.32	4.80	2.91	2.87	6.36
Chugoku	5.56	3.38	3.00	2.07	2.70	5.18	3.30	2.57	6.74
Hokuriku	5.40	4.51	2.84	2.59	2.02	5.02	3.13	3.09	6.58
Tohoku	3.29	5.22	5.38	5.13	5.08	2.19	5.67	5.63	3.75
Shikoku	6.04	3.86	3.48	3.24	3.18	5.66	2.08	3.74	7.22
Kyushu	5.87	3.69	3.31	2.38	3.01	5.49	3.61	2.19	7.05
Hokkaido	5.24	7.17	7.33	7.08	7.03	4.14	7.62	7.58	1.70

Source: Compiled by the authors (see Appendix II for details).

Table 3.3: Actual Transmission Losses (yen/kWh)

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido
Tokyo	0.38	0.77	0.89	0.80	0.76	-0.11	0.36	0.33	0.95
Chubu	0.94	0.30	0.41	0.32	0.28	0.47	-0.10	-0.13	1.51
Kansai	1.11	0.46	0.43	0.34	0.30	0.64	-0.09	-0.12	1.67
Chugoku	1.44	0.77	0.74	0.39	0.60	0.95	0.69	-0.08	2.01
Hokuriku	1.20	0.56	0.53	0.44	0.26	0.73	0.01	-0.01	1.75
Tohoku	0.49	0.90	1.03	0.93	0.88	0.30	0.47	0.44	1.40
Shikoku	1.29	0.60	0.57	0.60	0.43	0.79	0.46	0.11	1.89
Kyushu	1.73	1.02	0.98	0.61	0.84	1.21	0.94	0.24	2.34
Hokkaido	1.01	1.45	1.58	1.48	1.43	0.81	0.99	0.96	0.42

Source: Compiled by the authors (see Appendix II for details).

Table 3.4: The Assumed Scale of IPP Entry

	Case A		Case B		Case C		Supply Price by IPPs [yen / kWh]
	Capacity of IPPs [10,000 MWh]	IPP-GEU ratio [%]	Capacity of IPPs [10,000 MWh]	IPP-GEU ratio [%]	Capacity of IPPs [10,000 MWh]	IPP-GEU ratio [%]	
Tokyo	1,396	(4.8)	3,307	(11.4)	3,964	(13.7)	7.88
Chubu	305	(2.4)	788	(6.2)	1,270	(10.0)	6.98
Kansai	850	(5.9)	1,292	(9.0)	1,818	(12.7)	8.48
Chugoku	103	(1.6)	832	(13.1)	3,495	(54.9)	5.93
Hokuriku	0	(0.0)	44	(1.4)	131	(4.1)	7.55
Tohoku	140	(1.6)	876	(10.0)	1,993	(22.8)	7.55
Shikoku	94	(2.8)	175	(5.3)	285	(8.6)	5.90
Kyushu	251	(3.1)	1,467	(18.1)	1,708	(21.1)	6.95
Hokkaido	107	(3.5)	307	(9.9)	438	(14.2)	6.53
Total	3,247	(3.7)	9,089	(10.2)	15,102	(17.0)	

Note: Compiled by the authors.

Table 4.1: Scenario AZ Results: Summary

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total
Supply Quantity [10,000 MWh]	27,485	11,934	14,482	5,107	2,328	6,816	2,503	7,314	2,760	80,729
(Changes from the Base [%])	(2.8)	(0.9)	(4.2)	(-1.2)	(-3.0)	(-1.4)	(1.7)	(1.4)	(1.7)	(1.7)
o/w by GEU	26,089	11,629	13,632	5,004	2,328	6,676	2,409	7,063	2,652	77,482
(Changes from the Base [%])	(-2.5)	(-1.7)	(-1.9)	(-3.2)	(-3.0)	(-3.4)	(-2.2)	(-2.1)	(-2.2)	(-2.3)
o/w by IPP	1,396	305	850	103	0	140	94	251	107	3,247
(Share of Operating IPPs [%])	(100.0)	(100.0)	(100.0)	(100.0)	-	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)
(Share of IPPs [%])	(5.1)	(2.6)	(5.9)	(2.0)	(0.0)	(2.1)	(3.8)	(3.4)	(3.9)	(4.2)
Demand Quantity [10,000 MWh]	27,254	12,002	14,140	5,262	2,435	7,047	2,505	7,323	2,760	80,729
(Changes from the Base [%])	(1.9)	(1.5)	(1.7)	(1.8)	(1.5)	(1.9)	(1.7)	(1.6)	(1.7)	(1.7)
Supply Price [yen/kWh]	12.53	12.97	12.50	12.83	12.84	13.17	13.29	13.85	14.07	
(Changes from the Base [%])	(-17.2)	(-12.2)	(-15.4)	(-15.0)	(-12.2)	(-16.5)	(-15.8)	(-14.1)	(-16.3)	
Demand Price [yen/kWh]	15.78	15.96	15.55	15.30	15.12	15.66	15.83	16.28	16.19	
(Changes from the Base [%])	(-14.2)	(-10.1)	(-12.8)	(-12.9)	(-10.5)	(-14.3)	(-13.6)	(-12.3)	(-14.5)	
Change in Producer Surplus	-6,251	-1,923	-2,787	-1,085	-421	-1,696	-536	-1,449	-656	-16,804
o/w GEU Surplus	-6,900	-2,106	-3,129	-1,156	-421	-1,775	-606	-1,622	-737	-18,451
o/w IPP Surplus	649	183	342	71	0	79	70	173	81	1,647
Change in Consumer Surplus	7,052	2,139	3,187	1,185	430	1,823	618	1,652	752	18,838
Change in Welfare	801	216	400	100	10	127	82	203	96	2,034
(with Network Proprietor's Surplus)										2,424

Note: Units for surpluses and welfare are 100 million yen.

Table 4.2: Scenario AZ Results: Supply and Demand by Departure and Destination (10,000 MWh)

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total Supply
Tokyo	27,254	0	0	0	0	231	0	0	0	27,485
Chubu	0	11,934	0	0	0	0	0	0	0	11,934
Kansai	0	68	14,140	165	107	0	2	0	0	14,482
Chugoku	0	0	0	5,097	0	0	0	9	0	5,107
Hokuriku	0	0	0	0	2,328	0	0	0	0	2,328
Tohoku	0	0	0	0	0	6,816	0	0	0	6,816
Shikoku	0	0	0	0	0	0	2,503	0	0	2,503
Kyushu	0	0	0	0	0	0	0	7,314	0	7,314
Hokkaido	0	0	0	0	0	0	0	0	2,760	2,760
Total Demand	27,254	12,002	14,140	5,262	2,435	7,047	2,505	7,323	2,760	80,729

Figure 4.1: Scenario AZ Results: Physical Power Flow between Regions

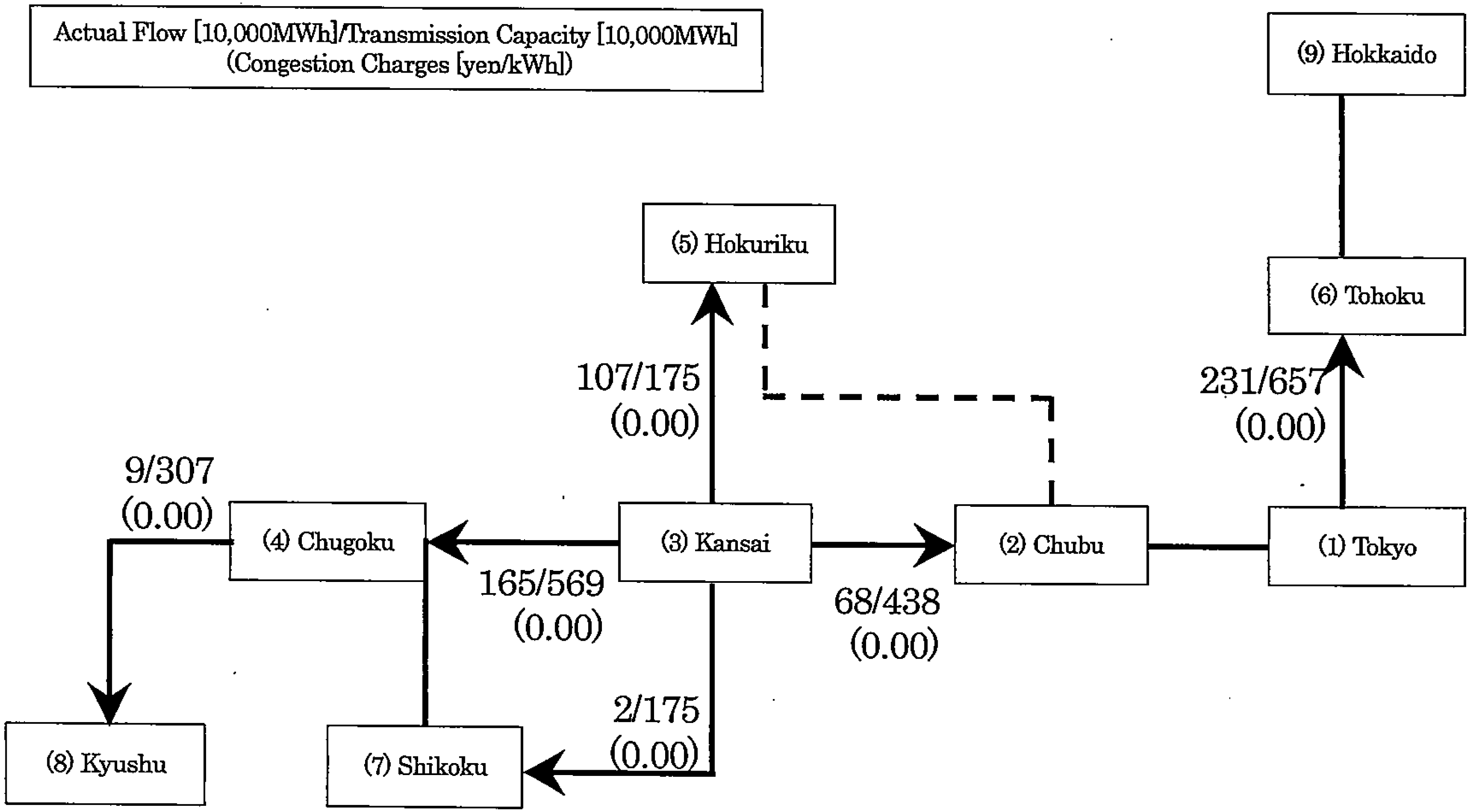


Table 4.3: Scenario AP Results: Summary

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total
Supply Quantity [10,000 MWh]	27,523	11,929	14,512	5,104	2,326	6,802	2,491	7,286	2,752	80,726
(Changes from the Base [%])	(2.9)	(0.8)	(4.4)	(–1.2)	(–3.1)	(–1.6)	(1.1)	(1.1)	(1.4)	(1.7)
o/w by GEU	26,127	11,624	13,662	5,001	2,326	6,662	2,396	7,035	2,644	77,479
(Changes from the Base [%])	(–2.3)	(–1.7)	(–1.7)	(–3.2)	(–3.1)	(–3.6)	(–2.7)	(–2.4)	(–2.5)	(–2.4)
o/w by IPP	1,396	305	850	103	0	140	94	251	107	3,247
(Share of Operating IPPs [%])	(100.0)	(100.0)	(100.0)	(100.0)	UNDF	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)
(Share of IPPs [%])	(5.1)	(2.6)	(5.9)	(2.0)	(0.0)	(2.1)	(3.8)	(3.5)	(3.9)	(4.2)
Demand Quantity [10,000 MWh]	27,289	12,022	14,122	5,245	2,426	7,036	2,507	7,327	2,752	80,726
(Changes from the Base [%])	(2.0)	(1.6)	(1.6)	(1.5)	(1.1)	(1.8)	(1.8)	(1.6)	(1.4)	(1.7)
Supply Price [yen/kWh]	12.68	12.92	12.76	12.79	12.79	13.02	12.72	13.42	13.70	
(Changes from the Base [%])	(–16.3)	(–12.5)	(–13.7)	(–15.3)	(–12.5)	(–17.5)	(–19.4)	(–16.7)	(–18.5)	
Demand Price [yen/kWh]	15.60	15.76	15.73	15.72	15.59	15.86	15.71	16.20	16.66	
(Changes from the Base [%])	(–15.2)	(–11.3)	(–11.8)	(–10.5)	(–7.7)	(–13.2)	(–14.2)	(–12.7)	(–12.0)	
Change in Producer Surplus	–5,836	–1,978	–2,418	–1,108	–432	–1,797	–680	–1,759	–758	–16,765
o/w GEU Surplus	–6,506	–2,159	–2,782	–1,179	–432	–1,874	–744	–1,922	–835	–18,431
o/w IPP Surplus	670	181	364	71	0	77	64	163	77	1,666
Change in Consumer Surplus	7,540	2,386	2,940	962	315	1,681	647	1,707	622	18,801
Change in Welfare	1,705	409	522	–146	–116	–116	–33	–52	–136	2,041
(with Network Proprietor's Surplus)										2,430

Note: Units for surpluses and welfare are 100 million yen.

Table 4.4: Scenario AP Results: Supply and Demand by Departure and Destination (10,000 MWh)

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total Supply
Tokyo	27,289	0	0	0	0	234	0	0	0	27,523
Chubu	0	11,929	0	0	0	0	0	0	0	11,929
Kansai	0	93	14,122	182	99	0	17	0	0	14,512
Chugoku	0	0	0	5,063	0	0	0	41	0	5,104
Hokuriku	0	0	0	0	2,326	0	0	0	0	2,326
Tohoku	0	0	0	0	0	6,802	0	0	0	6,802
Shikoku	0	0	0	0	0	0	2,491	0	0	2,491
Kyushu	0	0	0	0	0	0	0	7,286	0	7,286
Hokkaido	0	0	0	0	0	0	0	0	2,752	2,752
Total Demand	27,289	12,022	14,122	5,245	2,426	7,036	2,507	7,327	2,752	80,726

Figure 4.2: Scenario AP Results: Physical Power Flow between Regions

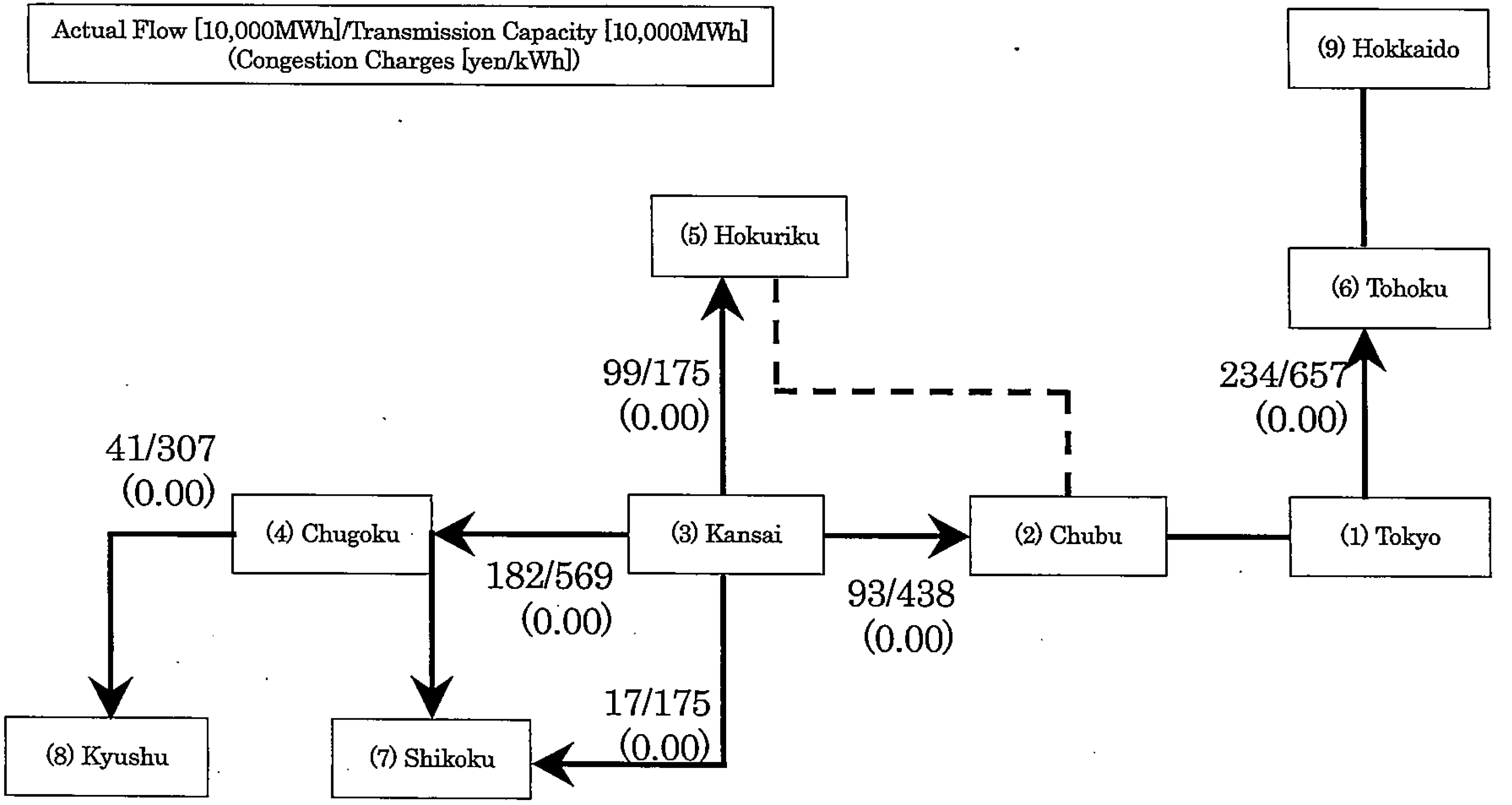


Table 4.5: Scenario BZ Results: Summary

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total
Supply Quantity [10,000 MWh]	28,260	12,022	14,507	5,509	2,297	7,142	2,507	8,133	2,847	83,224
(Changes from the Base [%])	(5.7)	(1.6)	(4.4)	(6.6)	(–4.3)	(3.3)	(1.8)	(12.8)	(5.0)	(4.9)
o/w by GEU	24,953	11,233	13,215	4,677	2,253	6,266	2,332	6,666	2,541	74,135
(Changes from the Base [%])	(–6.7)	(–5.1)	(–4.9)	(–9.5)	(–6.1)	(–9.4)	(–5.3)	(–7.6)	(–6.3)	(–6.6)
o/w by IPP	3,307	788	1,292	832	44	876	175	1,467	307	9,089
(Share of Operating IPPs [%])	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)
(Share of IPPs [%])	(11.7)	(6.6)	(8.9)	(15.1)	(1.9)	(12.3)	(7.0)	(18.0)	(10.8)	(12.3)
Demand Quantity [10,000 MWh]	28,127	12,341	14,514	5,453	2,472	7,275	2,567	7,628	2,847	83,224
(Changes from the Base [%])	(5.2)	(4.3)	(4.4)	(5.5)	(3.0)	(5.2)	(4.3)	(5.8)	(5.0)	(4.9)
Supply Price [yen/kWh]	8.03	9.43	8.96	8.27	10.97	8.67	9.73	7.74	8.97	
(Changes from the Base [%])	(–47.0)	(–36.1)	(–39.3)	(–45.2)	(–25.0)	(–45.1)	(–38.3)	(–52.0)	(–46.7)	
Demand Price [yen/kWh]	11.28	12.42	12.01	10.74	13.25	11.16	12.27	10.17	11.09	
(Changes from the Base [%])	(–38.7)	(–30.0)	(–32.6)	(–38.9)	(–21.6)	(–38.9)	(–33.0)	(–45.2)	(–41.5)	
Change in Producer Surplus	–18,334	–5,960	–7,819	–3,169	–835	–4,587	–1,383	–5,697	–1,987	–49,771
o/w GEU Surplus	–18,383	–6,153	–7,881	–3,364	–850	–4,686	–1,450	–5,813	–2,061	–50,641
o/w IPP Surplus	49	193	63	195	15	99	67	117	75	871
Change in Consumer Surplus	19,511	6,448	8,259	3,629	890	5,045	1,521	6,216	2,182	53,701
Change in Welfare	1,177	488	440	460	55	458	138	519	195	3,931
(with Network Proprietor's Surplus)										5,014

Note: Units for surpluses and welfare are 100 million yen.

Table 4.6: Scenario BZ Results: Supply and Demand by Departure and Destination (10,000 MWh)

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total Supply
Tokyo	28,127	0	0	0	0	134	0	0	0	28,260
Chubu	0	12,022	0	0	0	0	0	0	0	12,022
Kansai	0	319	14,188	0	0	0	0	0	0	14,507
Chugoku	0	0	326	4,948	175	0	60	0	0	5,509
Hokuriku	0	0	0	0	2,297	0	0	0	0	2,297
Tohoku	0	0	0	0	0	7,142	0	0	0	7,142
Shikoku	0	0	0	0	0	0	2,507	0	0	2,507
Kyushu	0	0	0	506	0	0	0	7,628	0	8,133
Hokkaido	0	0	0	0	0	0	0	0	2,847	2,847
Total Demand	28,127	12,341	14,514	5,453	2,472	7,275	2,567	7,628	2,847	83,224

Figure 4.3: Scenario BZ Results: Physical Power Flow between Regions

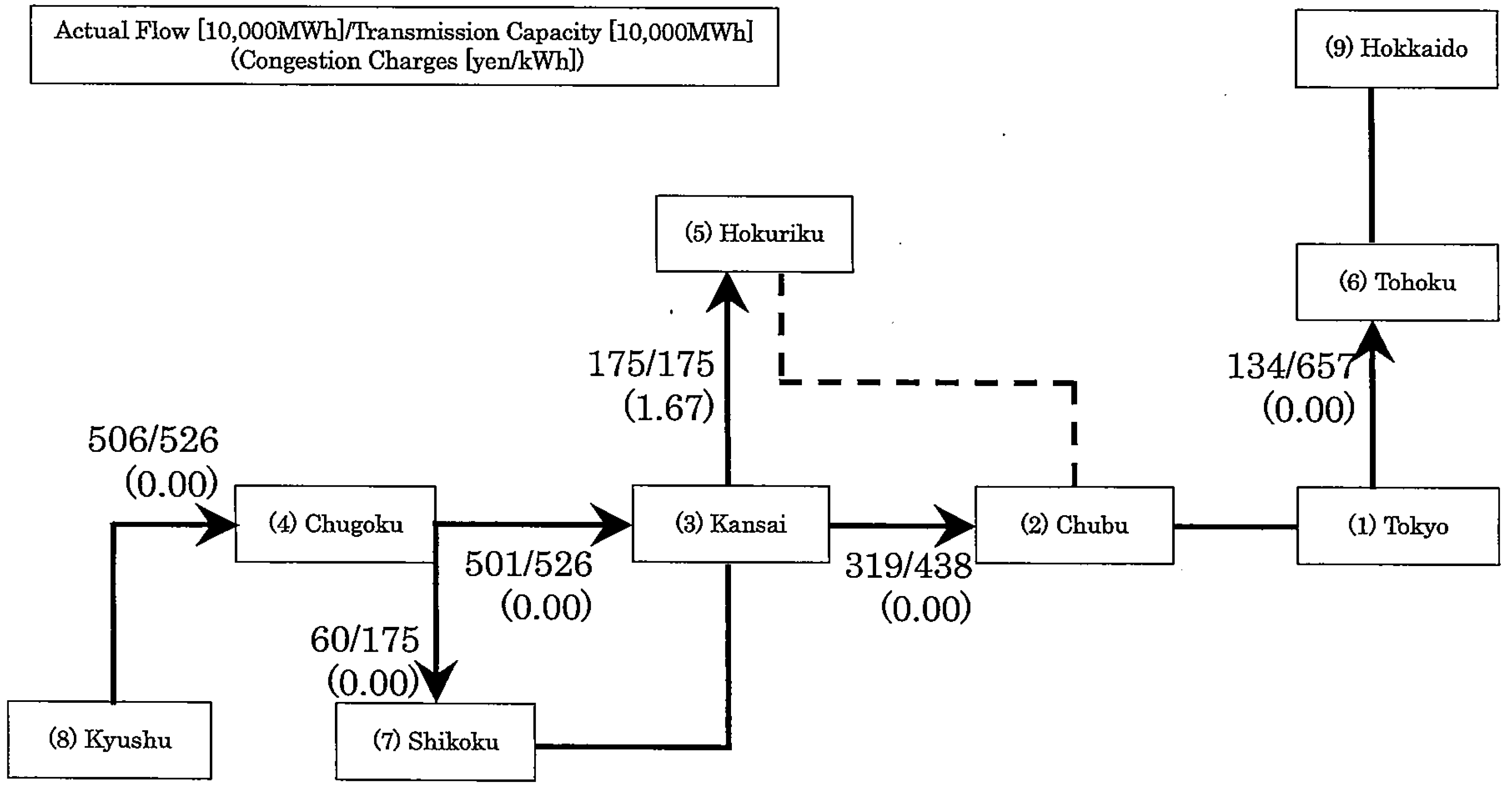


Table 4.7: Scenario BP Results: Summary

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total
Supply Quantity [10,000 MWh]	28,363	11,965	14,482	5,520	2,290	7,151	2,485	8,135	2,839	83,230
(Changes from the Base [%])	(6.0)	(1.1)	(4.2)	(6.8)	(–4.6)	(3.4)	(0.9)	(12.8)	(4.7)	(4.9)
o/w by GEU	25,056	11,176	13,190	4,688	2,246	6,276	2,309	6,667	2,533	74,142
(Changes from the Base [%])	(–6.3)	(–5.5)	(–5.1)	(–9.3)	(–6.4)	(–9.2)	(–6.2)	(–7.5)	(–6.6)	(–6.6)
o/w by IPP	3,307	788	1,292	832	44	876	175	1,467	307	9,089
(Share of Operating IPPs [%])	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)
(Share of IPPs [%])	(11.7)	(6.6)	(8.9)	(15.1)	(1.9)	(12.2)	(7.1)	(18.0)	(10.8)	(12.3)
Demand Quantity [10,000 MWh]	28,111	12,405	14,544	5,427	2,465	7,252	2,578	7,609	2,839	83,230
(Changes from the Base [%])	(5.1)	(4.9)	(4.6)	(5.0)	(2.7)	(4.9)	(4.7)	(5.5)	(4.7)	(4.9)
Supply Price [yen/kWh]	8.44	8.92	8.75	8.43	10.79	8.78	8.67	7.76	8.59	
(Changes from the Base [%])	(–44.3)	(–39.6)	(–40.8)	(–44.2)	(–26.2)	(–44.4)	(–45.1)	(–51.8)	(–48.9)	
Demand Price [yen/kWh]	11.36	11.75	11.72	11.36	13.60	11.62	11.67	10.55	11.56	
(Changes from the Base [%])	(–38.2)	(–33.8)	(–34.2)	(–35.3)	(–19.5)	(–36.4)	(–36.3)	(–43.2)	(–39.0)	
Change in Producer Surplus	–17,175	–6,572	–8,124	–3,082	–874	–4,509	–1,649	–5,679	–2,092	–49,756
o/w GEU Surplus	–17,359	–6,725	–8,159	–3,290	–889	–4,617	–1,697	–5,799	–2,155	–50,690
o/w IPP Surplus	184	153	35	208	14	108	48	120	63	934
Change in Consumer Surplus	19,285	7,277	8,679	3,287	804	4,710	1,676	5,932	2,048	53,699
Change in Welfare	2,110	704	556	205	–71	201	28	253	–44	3,943
(with Network Proprietor's Surplus)										5,024

Note: Units for surpluses and welfare are 100 million yen.

Table 4.8: Scenario BP Results: Supply and Demand by Departure and Destination (10,000 MWh)

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total Supply
Tokyo	28,111	152	0	0	0	100	0	0	0	28,363
Chubu	0	11,965	0	0	0	0	0	0	0	11,965
Kansai	0	288	14,194	0	0	0	0	0	0	14,482
Chugoku	0	0	350	4,901	175	0	93	0	0	5,520
Hokuriku	0	0	0	0	2,290	0	0	0	0	2,290
Tohoku	0	0	0	0	0	7,151	0	0	0	7,151
Shikoku	0	0	0	0	0	0	2,485	0	0	2,485
Kyushu	0	0	0	526	0	0	0	7,609	0	8,135
Hokkaido	0	0	0	0	0	0	0	0	2,839	2,839
Total Demand	28,111	12,405	14,544	5,427	2,465	7,252	2,578	7,609	2,839	83,230

Figure 4.4: Scenario BP Results: Physical Power Flow between Regions

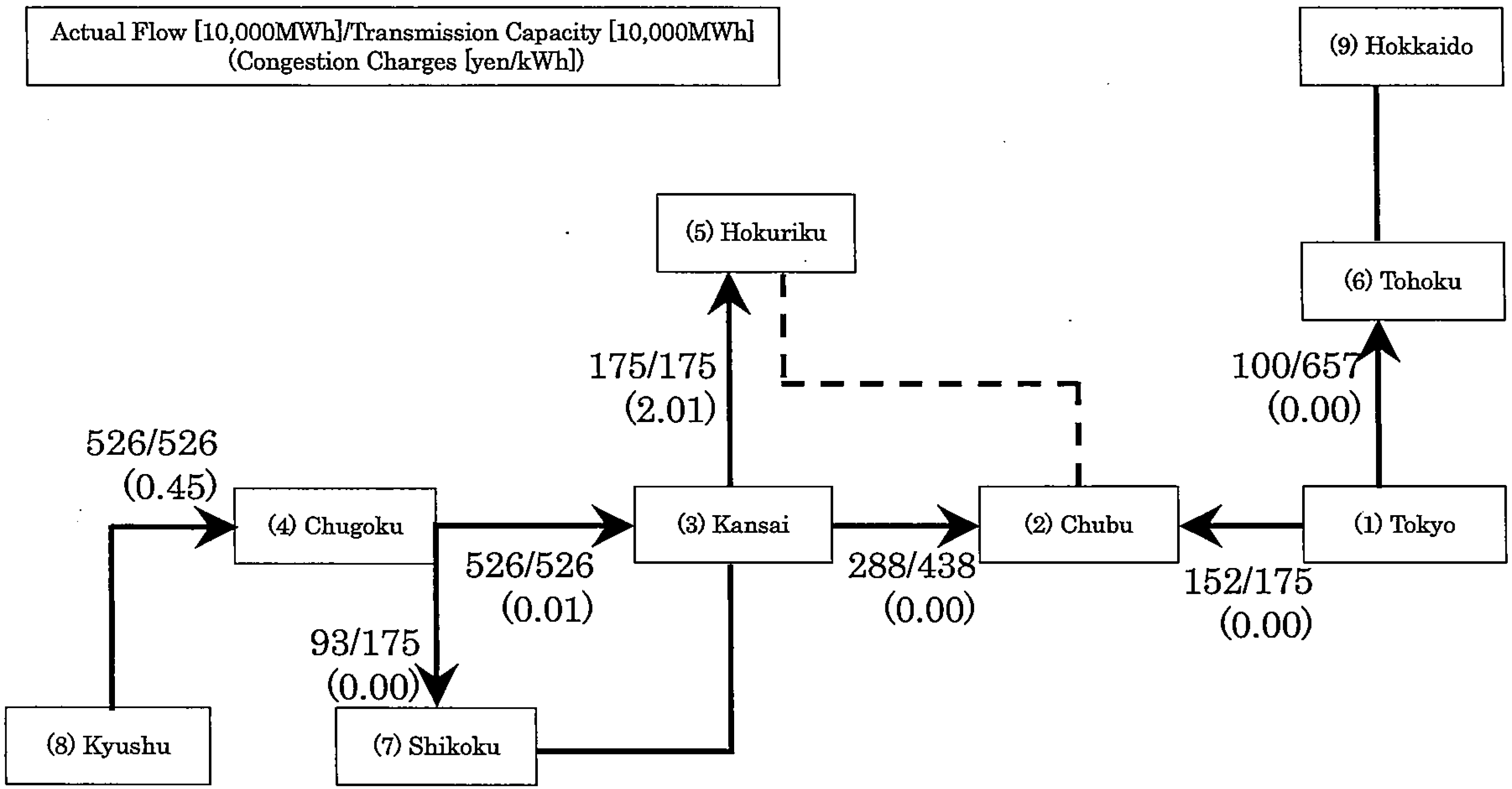


Table 4.9: Scenario CZ Results: Summary

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total
Supply Quantity [10,000 MWh]	28,155	12,416	14,171	6,468	2,326	7,332	2,567	7,361	2,889	83,685
(Changes from the Base [%])	(5.3)	(5.0)	(1.9)	(25.2)	(–3.1)	(6.0)	(4.2)	(2.1)	(6.5)	(5.5)
o/w by GEU	24,916	11,146	13,158	4,509	2,195	6,163	2,282	6,614	2,488	73,469
(Changes from the Base [%])	(–6.9)	(–5.8)	(–5.3)	(–12.7)	(–8.6)	(–10.9)	(–7.3)	(–8.3)	(–8.3)	(–7.4)
o/w by IPP	3,239	1,270	1,013	1,960	131	1,169	285	746	402	10,215
(Share of Operating IPPs [%])	(81.7)	(100.0)	(55.7)	(56.1)	(100.0)	(58.7)	(100.0)	(43.7)	(91.7)	(67.6)
(Share of IPPs [%])	(11.5)	(10.2)	(7.1)	(30.3)	(5.6)	(15.9)	(11.1)	(10.1)	(13.9)	(13.9)
Demand Quantity [10,000 MWh]	28,155	12,416	14,565	5,551	2,501	7,332	2,608	7,667	2,889	83,685
(Changes from the Base [%])	(5.3)	(5.0)	(4.8)	(7.4)	(4.2)	(6.0)	(5.9)	(6.3)	(6.5)	(5.5)
Supply Price [yen/kWh]	7.88	8.64	8.48	5.93	9.50	7.55	7.39	6.95	6.53	
(Changes from the Base [%])	(–47.9)	(–41.4)	(–42.6)	(–60.7)	(–35.0)	(–52.2)	(–53.2)	(–56.9)	(–61.1)	
Demand Price [yen/kWh]	11.13	11.64	11.53	8.40	11.79	10.04	9.93	9.38	8.65	
(Changes from the Base [%])	(–39.5)	(–34.5)	(–35.3)	(–52.2)	(–30.3)	(–45.1)	(–45.8)	(–49.4)	(–54.3)	
Change in Producer Surplus	–18,751	–6,817	–8,520	–4,438	–1,149	–5,386	–1,948	–6,341	–2,673	–56,022
o/w GEU Surplus	–18,751	–7,029	–8,520	–4,438	–1,175	–5,386	–1,990	–6,341	–2,673	–56,301
o/w IPP Surplus	0	211	0	0	26	0	42	0	0	279
Change in Consumer Surplus	19,927	7,417	8,963	4,916	1,253	5,867	2,127	6,824	2,879	60,173
Change in Welfare	1,176	600	443	478	104	482	179	483	206	4,151
(with Network Proprietor's Surplus)										5,429

Note: Units for surpluses and welfare are 100 million yen.

Table 4.10: Scenario CZ Results: Supply and Demand by Departure and Destination (10,000 MWh)

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total Supply
Tokyo	28,155	0	0	0	0	0	0	0	0	28,155
Chubu	0	12,416	0	0	0	0	0	0	0	12,416
Kansai	0	0	14,171	0	0	0	0	0	0	14,171
Chugoku	0	0	394	5,551	131	0	85	307	0	6,468
Hokuriku	0	0	0	0	2,326	0	0	0	0	2,326
Tohoku	0	0	0	0	0	7,332	0	0	0	7,332
Shikoku	0	0	0	0	44	0	2,523	0	0	2,567
Kyushu	0	0	0	0	0	0	0	7,361	0	7,361
Hokkaido	0	0	0	0	0	0	0	0	2,889	2,889
Total Demand	28,155	12,416	14,565	5,551	2,501	7,332	2,608	7,667	2,889	83,685

Figure 4.5: Scenario CZ Results: Physical Power Flow between Regions

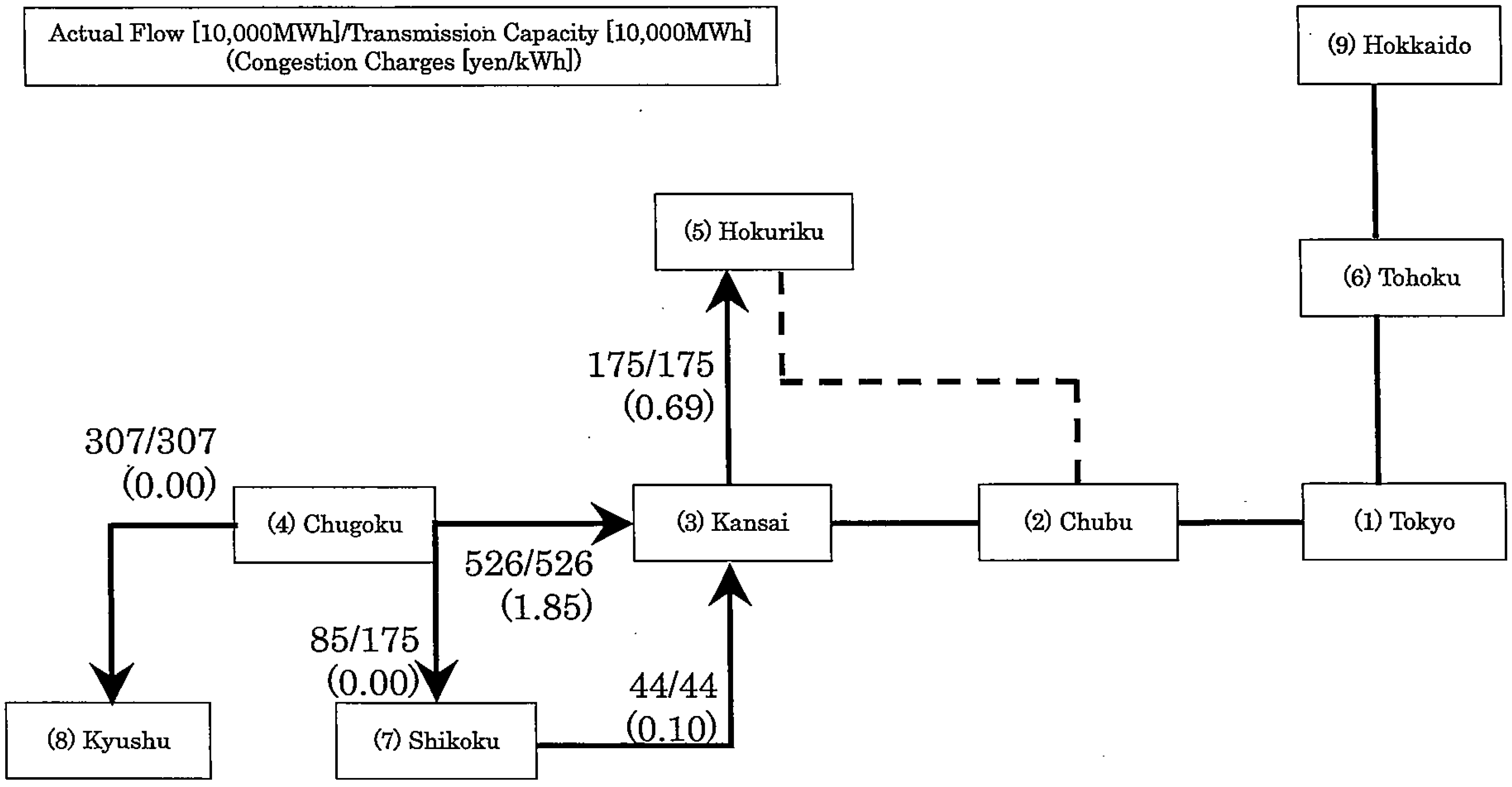


Table 4.11: Scenario CP Results: Summary

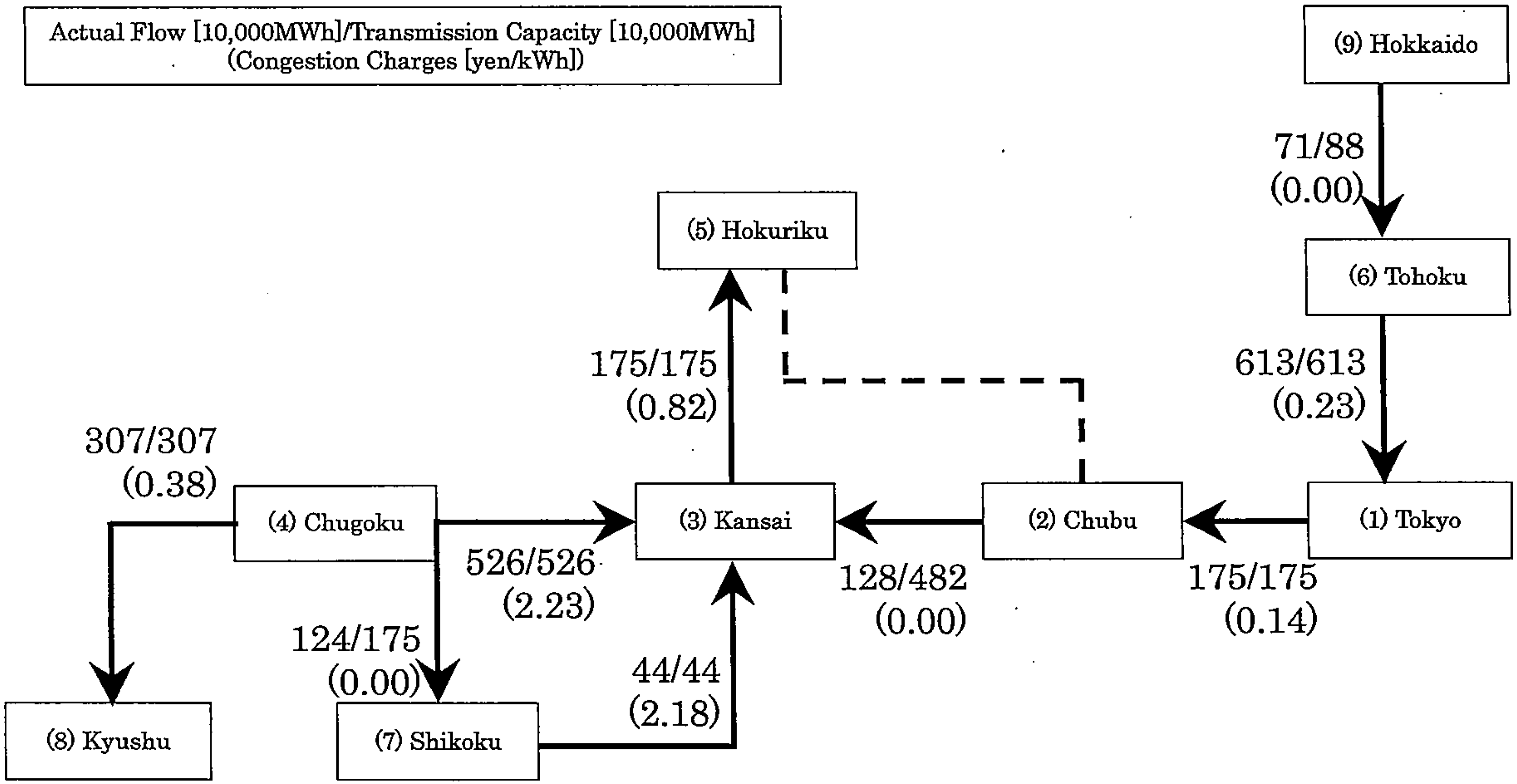
	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total
Supply Quantity [10,000 MWh]	27,782	12,399	14,051	6,488	2,319	7,857	2,540	7,343	2,937	83,718
(Changes from the Base [%])	(3.9)	(4.8)	(1.1)	(25.6)	(–3.4)	(13.6)	(3.2)	(1.8)	(8.3)	(5.5)
o/w by GEU	24,916	11,129	13,158	4,509	2,188	6,163	2,256	6,614	2,499	73,430
(Changes from the Base [%])	(–6.9)	(–5.9)	(–5.3)	(–12.7)	(–8.8)	(–10.9)	(–8.4)	(–8.3)	(–7.9)	(–7.5)
o/w by IPP	2,866	1,270	894	1,980	131	1,695	285	729	438	10,288
(Share of Operating IPPs [%])	(72.3)	(100.0)	(49.2)	(56.6)	(100.0)	(85.0)	(100.0)	(42.7)	(100.0)	(68.1)
(Share of IPPs [%])	(10.3)	(10.2)	(6.4)	(30.5)	(5.7)	(21.6)	(11.2)	(9.9)	(14.9)	(14.0)
Demand Quantity [10,000 MWh]	28,220	12,446	14,574	5,532	2,494	7,315	2,621	7,650	2,866	83,718
(Changes from the Base [%])	(5.5)	(5.2)	(4.8)	(7.1)	(3.9)	(5.8)	(6.4)	(6.1)	(5.7)	(5.5)
Supply Price [yen/kWh]	7.88	8.50	8.48	5.93	9.33	7.55	6.17	6.95	7.04	
(Changes from the Base [%])	(–47.9)	(–42.5)	(–42.6)	(–60.7)	(–36.1)	(–52.2)	(–60.9)	(–56.9)	(–58.1)	
Demand Price [yen/kWh]	10.80	11.32	11.44	8.86	12.13	10.38	9.16	9.72	9.99	
(Changes from the Base [%])	(–41.3)	(–36.2)	(–35.8)	(–49.6)	(–28.2)	(–43.2)	(–50.0)	(–47.6)	(–47.2)	
Change in Producer Surplus	–18,751	–7,003	–8,520	–4,438	–1,188	–5,386	–2,259	–6,341	–2,524	–56,410
o/w GEU Surplus	–18,751	–7,195	–8,520	–4,438	–1,212	–5,386	–2,267	–6,341	–2,547	–56,656
o/w IPP Surplus	0	192	0	0	23	0	8	0	22	246
Change in Consumer Surplus	20,874	7,809	9,089	4,659	1,167	5,615	2,327	6,560	2,494	60,593
Change in Welfare	2,123	807	568	221	–21	230	68	219	–31	4,183
(with Network Proprietor's Surplus)										5,463

Note: Units for surpluses and welfare re 100 million yen.

Table 4.12: Scenario CP Results: Supply and Demand by Departure and Destination (10,000 MWh)

	Tokyo	Chubu	Kansai	Chugoku	Hokuriku	Tohoku	Shikoku	Kyushu	Hokkaido	Total Supply
Tokyo	27,607	175	0	0	0	0	0	0	0	27,782
Chubu	0	12,271	128	0	0	0	0	0	0	12,399
Kansai	0	0	14,051	0	0	0	0	0	0	14,051
Chugoku	0	0	394	5,532	131	0	124	307	0	6,488
Hokuriku	0	0	0	0	2,319	0	0	0	0	2,319
Tohoku	613	0	0	0	0	7,244	0	0	0	7,857
Shikoku	0	0	0	0	44	0	2,497	0	0	2,540
Kyushu	0	0	0	0	0	0	0	7,343	0	7,343
Hokkaido	0	0	0	0	0	71	0	0	2,866	2,937
Total Demand	28,220	12,446	14,574	5,532	2,494	7,315	2,621	7,650	2,866	83,718

Figure 4.6: Scenario CP Results: Physical Power Flow between Regions



Annex: Model Estimation

We estimate the following panel data regression model to obtain the price elasticity of the supply and demand. We use the log-linear and Koyck lag form for the m-th type supply and the n-th type demand functions for each region i.

We specify the supply functions as follows:

$$\log\left(Q^{m}_{i,t}\right) = \alpha^{m}_{i} + \delta^{m}\left(\frac{\overline{p}_{i,t}}{c^{m}_{i,t}}\right) + \beta^{m}\log\left(K^{m}_{i,t}\right) + \gamma^{m}\log\left(\mathbf{X}^{m}_{i,t}\right) + \phi^{m}\log\left(Q^{M}_{i,t-1}\right)$$

$$\text{(A.1)} \qquad for \quad i = 1, \cdots, 9 \qquad m = H, T, N, P.$$

Subscript i is the index of regions with numbers from 1 to 9. Subscript t is the index of fiscal years of observation. Superscript m is the index of power plants (H: hydroelectric, T: thermal, N: nuclear, P: purchased from non-GEUs). Where $Q^{m}_{i,t}$ (10,000 MWh) is the supply quantity and $c^{m}_{i,t}$ (yen / MWh) is the unit cost of the m-th type of power plants in the i-th region. $\overline{p}_{i,t}$ (yen / MWh) is the average sales prices, then $\overline{p}_{i,t}/c^{m}_{i,t}$ is the average earning rate of the m-th type of power plant[1]. $K^{m}_{i,t}$ (MW) is the total capacity of the m-th type of power plant. $\mathbf{X}^{m}_{i,t}$ is the specific factor for the m-th type of power supply. That is, $RAIN_{i,t}$ (mm) is the annual precipitation for the hydroelectric power supply function. $Poil_{t}$ (1995 = 100) is the wholesale price index of heavy oil for the thermal power supply function. $Nmat_{i,t}$ (kg) is the amount of nuclear fuels consumed for the nuclear power supply.

We also specify the demand functions as follows:

$$\log\left(Q^{n}_{i,t}\right) = \alpha^{n}_{i} + \delta^{n}\log\left(p^{n}_{i,t}\right) + \beta^{n}\log\left(Y^{n}_{i,t}\right) + \gamma^{n}\log\left(\mathbf{X}^{n}_{i,t}\right) + \phi^{n}\log\left(Q^{n}_{i,t-1}\right)$$

$$\text{(A.2)} \qquad for \quad i = 1, \cdots, 9 \qquad n = L, C, S, B.$$

Superscript n is the index of the electric demand (L: lighting, C: commercial power, S: small-scale

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[1] We calculate the average sales prices by dividing total revenue with total quantity for each region.

industrial power, B: large-scale industrial power). $Q_{i,t}^{n}$ (10,000 MWh) is the demand quantity. $p_{i,t}^{n}$ (yen / MWh) is the average prices of the n-th type of power service in the i-th region[2]. $Y_{i,t}^{n}$ (100 million yen) is employed to control scale effects on demand. That is, the real regional income is employed for the lighting service demand. Real gross regional product of the commerce sector is employed for the commercial power service demand. Real manufacturing output is employed for the large-scale and the small-scale industrial power service demand[3]. $\mathbf{X}_{i,t}^{n}$ is the other specific factors for the n-th type of power demand. For the lighting and the commercial power service demand, there are two explanatory variables. $AC_{i,t}$ (%) is the average possessor rate of air-conditioners, which is employed because air-conditioners are one of the major electricity eaters[4]. $TEMP_{i,t}$ (centigrade) is the absolute gaps between the monthly means of maximum and minimum temperature at a representative city in each region, which is employed to control operation rates of air-conditioners. By the way, we do not employ any additional explanatory variables for the industrial power demand functions. Though we try such conventional variables as capital stock, labor uses, and so on, their estimates are not significant.

In the regression model, α_i^m and α_i^n are the individual effect parameters of the m-th type supply and n-th type demand in the i-th region. $\beta^m, \gamma^m, \phi^m, \beta^n, \gamma^n$, and ϕ^n are the parameters for the panel estimation. δ^m and δ^n are the estimated price elasticity of the m-th

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[2] We calculate the average prices by dividing revenues with quantities for each category of demand, and deflate them by the regional consumer price index.

[3] We distinguish between the large-scale industry establishments (with more than or equal to 100 employees) and the small-scale industry establishments (with less than 100 employees).

[4] In its compilation, we take the average of the possessor rates of prefectures in each region weighted with the number of households. As the possessor rates of air-conditioners for commercial buildings are not available, its possessor rates for households are employed as a proxy variable in estimation of the commercial power service demand function.

type supply and n-th type demand[5].

We employ the generalized method of moments (GMM) procedure for the regression[6]. Our estimation results satisfy overidentifying restrictions. All of our estimates of price elasticity and the other parameters are significant and seem reasonable in their sign (Table A.1)[7]. The supply price elasticity is bounded from 0.0397 (nuclear) to 0.6002 (purchase). Their magnitude seems to be consistent with our intuition based on the (whole country) average operation rates: 83.8 % (nuclear), 39.4 % (thermal) and 24.2 % (hydroelectric) in 1998. These operation rates imply their load type. Plants with high operation rates tend to be in base-load operation and have small price elasticity, and vice versa. In estimation results of demand functions, the price elasticity of the large-scale industrial power is the largest among the four types of demand. Other researches, such as Matsukawa, Madono, and Nakashima (1993), also provides similar estimation results.

Table A.1: Estimates of Price Elasticity

Supply Functions	Elasticity	t-value
Hydroelectric Power Supply	0.1922	(5.87)
Thermal Power Supply	0.1097	(11.01)
Nuclear Power Supply	0.0397	(6.43)
Supply with Purchased from Other Companies	0.6002	(11.57)
Demand Functions	**Elasticity**	**t-value**
Lighting Services	-0.1256	(-8.77)
Commercial Power Services	-0.0745	(-7.37)
Small-scale industrial Power Services	-0.0497	(-3.78)
Large-scale industrial Power Services	-0.2217	(-8.19)

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[5] Note that the nuclear power supply functions for Hokuriku, Tohoku, and Hokkaido are omitted in our estimation because their nuclear plants were not in operation in the beginning year of our estimation period of 1978.

[6] Chamberlain [1984] provides details of panel estimators. Baltagi [2001] provide details of GMM estimators for panel data.

[7] All the estimates of parameters are shown in Tables A.2-A.9.

Table A.2: Estimates and Test Statistics —— the Hydroelectric Power Supply Function

	estimate	(t-statistic)	
Supply Price	0.192	(5.87)	
Capacity of Power Plants	0.310	(7.85)	
Precipitations	0.364	(11.30)	
Lagged Dependent Variable	0.100	(1.62)	
Intercept Terms	estimate	(t-statistic)	Adjusted R^2
Tokyo	0.804	(1.78)	0.6910
Chubu	0.592	(1.38)	0.6528
Kansai	0.920	(2.02)	0.6110
Chugoku	0.011	(0.03)	0.8493
Hokuriku	0.373	(0.90)	0.6492
Tohoku	0.811	(1.88)	0.3593
Shikoku	-0.031	(-0.09)	0.5304
Kyushu	0.130	(0.33)	0.7405
Hokkaido	0.258	(0.68)	0.4871

Degrees of freedom are 104.

Test of overidentifying restrictions (P-value) is 89.097 (0.85).

Table A.3: Estimates and Test Statistics —— the Thermal Power Supply Function

	estimate	(t-statistic)	
Supply Price	0.110	(11.01)	
Capacity of Power Plants	0.134	(3.79)	
Price Index of the Heavy Oil	-0.094	(-5.25)	
Lagged Dependent Variable	0.744	(23.44)	
Intercept Terms	estimate	(t-statistic)	Adjusted R^2
Tokyo	1.370	(3.82)	0.8659
Chubu	1.227	(3.60)	0.9128
Kansai	1.240	(3.65)	0.6660
Chugoku	1.217	(3.90)	0.8228
Hokuriku	1.103	(3.92)	0.7284
Tohoku	1.212	(3.82)	0.9288
Shikoku	1.053	(3.61)	0.6291
Kyushu	1.167	(3.66)	0.7670
Hokkaido	1.068	(3.67)	0.7352

Degrees of freedom are 95.

Test of overidentifying restrictions (P-value) is 82.592 (0.81).

Table A.4: Estimates and Test Statistics —— the Nuclear Power Supply Function

	estimate	(t-statistic)	
Supply Price	0.040	(6.43)	
Capacity of Power Plants	0.055	(6.95)	
Nuclear Fuel	0.948	(92.61)	
Lagged Dependent Variable	0.020	(2.93)	
Intercept Terms	estimate	(t-statistic)	Adjusted R^2
Tokyo	-0.600	(-22.07)	0.9994
Chubu	-0.486	(-17.22)	0.9959
Kansai	-0.439	(-15.89)	0.9999
Chugoku	-0.398	(-18.57)	0.9996
Hokuriku	-	-	-
Tohoku	-	-	-
Shikoku	-0.427	(-16.04)	0.9806
Kyushu	-0.466	(-18.95)	0.9999
Hokkaido	-	-	-

Degrees of freedom are 68.

Test of overidentifying restrictions (P-value) is 59.149 (0.77).

Table A.5: Estimates and Test Statistics —— the Purchased Power Supply Function

	estimate	(t-statistic)	
Supply Price	0.600	(11.57)	
Capacity of Power Plants	0.596	(11.63)	
Lagged Dependent Variable	0.428	(9.30)	
Intercept Terms	estimate	(t-statistic)	Adjusted R^2
Tokyo	-1.241	(-5.13)	0.8771
Chubu	-1.215	(-5.57)	0.6087
Kansai	-0.947	(-4.62)	0.8906
Chugoku	-0.967	(-4.54)	0.8832
Hokuriku	-0.970	(-4.87)	0.9051
Tohoku	-1.079	(-5.01)	0.9080
Shikoku	-1.210	(-6.60)	0.9259
Kyushu	-1.029	(-5.07)	0.8465
Hokkaido	-1.139	(-6.18)	0.3282

Degrees of freedom are 96.

Test of overidentifying restrictions (P-value) is 95.878 (0.48).

Table A.6: Estimates and Test Statistics —— the Lighting Service Demand Function

	estimate	(t-statistic)	
Demand Price	-0.126	(-8.77)	
Household Income	0.130	(7.95)	
Air-Conditioners	0.021	(3.90)	
Temperature	0.051	(7.36)	
Gas charges	0.010	(4.96)	
Lagged Dependent Variable	0.841	(55.26)	
Intercept Terms	estimate	(t-statistic)	Adjusted R^2
Tokyo	0.619	(3.99)	0.9974
Chubu	0.627	(4.32)	0.9949
Kansai	0.600	(4.07)	0.9922
Chugoku	0.593	(4.29)	0.9949
Hokuriku	0.557	(4.32)	0.9972
Tohoku	0.618	(4.31)	0.9985
Shikoku	0.589	(4.46)	0.9951
Kyushu	0.612	(4.29)	0.9954
Hokkaido	0.628	(4.49)	0.9982

Degrees of freedom are 129.

Test of overidentifying restrictions (P-value) is 112.995 (0.84).

Table A.7: Estimates and Test Statistics —— the Commercial Power Demand Function

	estimate	(t-statistic)	
Demand Price	-0.074	(-7.37)	
Commercial Products	0.102	(8.19)	
Air-Conditioners	0.024	(4.49)	
Temperature	0.074	(11.72)	
Gas charges	0.867	(72.84)	
Lagged Dependent Variable	-0.074	(-7.37)	
Intercept Terms	estimate	(t-statistic)	Adjusted R^2
Tokyo	0.355	(0.14)	0.9984
Chubu	0.300	(2.89)	0.9975
Kansai	0.310	(2.91)	0.9972
Chugoku	0.276	(2.82)	0.9963
Hokuriku	0.261	(2.86)	0.9969
Tohoku	0.321	(3.13)	0.9988
Shikoku	0.271	(2.92)	0.9965
Kyushu	0.308	(3.02)	0.9974
Hokkaido	0.324	(3.16)	0.9987

Degrees of freedom are 121.

Test of overidentifying restrictions (P-value) is 102.597 (0.89).

Table A.8: Estimates and Test Statistics —— the Small-scale industrial Power Demand Function

	estimate	(t-statistic)	
Demand Price	-0.050	(-3.94)	
Manufacturing Output	0.022	(2.65)	
Lagged Dependent Variable	0.917	(97.02)	
Intercept Terms	estimate	(t-statistic)	Adjusted R^2
Tokyo	0.765	(6.34)	0.9678
Chubu	0.736	(6.37)	0.9674
Kansai	0.727	(6.28)	0.9465
Chugoku	0.679	(6.38)	0.9677
Hokuriku	0.645	(6.38)	0.8786
Tohoku	0.716	(6.52)	0.9862
Shikoku	0.650	(6.39)	0.9638
Kyushu	0.721	(6.62)	0.9810
Hokkaido	0.646	(6.39)	0.9907

Degrees of freedom are 78.

Test of overidentifying restrictions (P-value) is 76.060 (0.54).

Table A.9: Estimates and Test Statistics —— the Large-scale industrial Power Demand Function

	estimate	(t-statistic)	
Demand Price	-0.222	(-8.07)	
Manufacturing Output	0.117	(9.34)	
Lagged Dependent Variable	0.803	(43.26)	
Intercept Terms	estimate	(t-statistic)	Adjusted R^2
Tokyo	1.809	(7.86)	0.9840
Chubu	1.776	(7.94)	0.9796
Kansai	1.787	(8.01)	0.9606
Chugoku	1.705	(8.02)	0.8770
Hokuriku	1.698	(8.39)	0.8465
Tohoku	1.762	(8.25)	0.9280
Shikoku	1.648	(8.22)	0.4065
Kyushu	1.752	(8.22)	0.9263
Hokkaido	1.660	(8.40)	0.7007

Degrees of freedom are 78.

Test of overidentifying restrictions (P-value) is 71.920 (0.67).