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Regional Electric Power Demand in Japan

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Regional Electric Power Demand in Japan

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Abstract

In the assessment and review of regulatory reforms in the electric power market, price elasticity is one of the most important parameters that characterize the market. However, price elasticity has seldom been estimated in Japan; instead, it has been merely assumed to be as small as 0.1 or 0 without examining the empirical validity of such a priori assumptions. We estimated the regional power demand functions for nine regions in order to quantify the elasticity, and found the short-run price elasticity to be 0.100–0.300 and the long-run price elasticity to be 0.126–0.552. Inter-regional comparison of our estimation results suggests that price elasticity in rural regions is larger than that in urban regions. Popular assumptions of small elasticity such as 0.1 could be suitable for examining Japan's aggregate power demand but not the power demand functions that focus on the respective regions. Furthermore, assumptions with smaller elasticity values such as 0.01 and 0 could not be supported statistically.

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1. Introduction

1.1 Motivation for the Empirical Analysis of Power Demand in Japan

The electric power industry is an industry that requires large-scale supply facilities in order to provide its services. It involves huge fixed costs, while the variable costs are small. This feature makes this industry a natural monopoly sector. Authorities regulate the rates of return of power companies and impose obligations of universal service on them. At the same time, they permit power companies to act as monopolistic service providers within their jurisdictions. These regulatory measures are effective and efficient only when the economies of scale are significantly large and information on the power companies' true costs is available to the authorities for charge regulations. However, these assumptions are not always consistent with reality. For example, the technological progress in recent years has improved the efficiency of small-scale thermal power plants, which were previously less competitive than large-scale ones. That is, economies of scale have been decreasing in the power generation sector. Moreover, the regulatory authorities cannot obtain complete information on the true cost structures of power companies as it is considered to be private information. Poor charge regulations and a lack of (potential) competitive pressures lead to inefficient resource allocation, such as a so-called X-inefficiency and overcapitalization found by Averch and Johnson (1962).

In the 1990s, European countries and several states in the US had initiated regulatory reforms to reduce the inefficiency caused by monopolies. These reforms were designed to promote competition in order to improve the efficiency of resource allocation through the market mechanism rather than the use of direct and indirect controls by the authorities. In liberalized markets, players, particularly incumbents, attempt to exploit the monopolistic power they are endowed with as their legacy from the old regime; hence, we require a deeper understanding of the market for effective surveillance. In Europe and the U.S., theoretical insights and empirical findings about their markets were available and supported their reforms.

The recent "lost decade" after the bubble burst compelled the Japanese government to implement structural reforms through deregulation in order to facilitate a recovery from the severe recession. As part of the structural reform package, various regulatory reforms have been implemented in the power market, which had long been regionally monopolized. The power market reforms were, however, mostly planned on the basis of research and conclusions drawn from countries other than Japan. Such conclusions might be informative; however, they could be irrelevant for Japan. It is essential to empirically understand the various features of Japan's power market. In particular, in quantitative assessments of reforms, there are some critical parameters such as the price elasticity of power demand. While it is widely recognized that the results of assessments are significantly sensitive to assumptions about such a key parameter, quantitative analyses on Japan's power market have often employed a priori assumptions of 0.1 or 0 for the price elasticity of power demand.

There have been several empirical analyses on Japan's power market in connection with the recent power market reforms. Kanemoto et al. (2006, Ch. 5) and Tanaka (2007) simulated cases in which incumbents exercise their market power in order to rig the market at a peak hour in summer. They assumed the price elasticity of demand to be 0.1 in an a priori manner. In contrast, Hattori (2003) conducted a similar analysis; however, he assumed a wide range for price elasticity—0.1 to 1.0. He chose to conduct this type of sensitivity analysis due to the scarcity of literature on the price elasticity of power demand in Japan.

1.2 Literature Survey

Although there are many empirical analyses on the power demand in Europe and the US, they mostly deal with residential demand and aim to examine whether deregulation has benefited both large-scale users and small-scale ones, particularly residential users.

In Japan, in 2000, deregulation in the retail sector was introduced in the market segment of large-scale users of extra-high-voltage power services—mainly factories and office buildings. In recent years, the scope of deregulation has been gradually enlarged to cover smaller-scale users of high-voltage power services. In 2007, however, the authorities decided to suspend further enlargement of the reform scope to small-scale users, including residential ones, considering the disappointing outcome of the recent regulatory reforms. This was because the market shares of the entrants were too small (about 2%) to have significant impacts on the market. Therefore, it is important for the current policy discussions to understand the power demand of industrial and commercial users rather than that of residential users.

Our review of the analyses of industrial and commercial power demand revealed only a small amount of research on the topic (Table 1). For example, as Taylor (1975) surveyed, Anderson (1971) and Mount et al. (1973) analyzed industrial and commercial power demand and found small elasticity close to the a priori assumption[1]. Later, Pindyck (1979) also conducted a similar analysis. Using the recent time series dataset for the US, Hisnanick and Kyer (1995) found the price elasticity of power demand at 0.185, while Kamerschen and Porter (2004) found it between 0.34 and 0.55. These findings suggest that the price elasticity of power demand in Japan is obviously larger than the common a priori

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[1] Fisher and Kaysen (1962) also estimated industrial demand using cross-sectional state data for the US in 1956.

assumptions.

In the case of Japan, Pindyck (1979) estimated the energy cost functions in 10 countries using time series data. In Pindyck's study, electric power demand was considered as one of the energy inputs, and the price elasticity of power demand was found to be 0.12. Using regional data for Japan, Matsukawa et al. (1993) estimated the price elasticity of the power demand of the manufacturing sector. They assumed translog energy composite demand functions with four energy inputs (oil, gas, coal, and electricity). They estimated the energy cost share functions using the pooled data from 1980 to 1988 for nine regions in Japan (i.e., all the jurisdictions except Okinawa). They found the price elasticity of power demand to be 0.63[2]. The Cabinet Office (2001), (2007) estimated the demand functions of total electric power (including residential as well as industrial and commercial ones) for Japan, excluding Okinawa, and found the price elasticity to be 0.441 for the period 1981–1998 and 0.373 for the period 1986–2005[3].

Estimating the price elasticity of power demand by using nationwide or pooled data

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[2] Matsukawa et al. (1993) also estimated residential demand and found the price elasticity to be 0.37.

[3] However, it should be noted that these two estimates were derived assuming different functional forms for power demand functions.

implies a presumption that all the regional power demand functions are identical and dependent on various exogenous factors in the same magnitude. However, vertically integrated regional power companies in Japan have a developed, self-sufficing power system, where the domestic load is almost fully met with domestic power supply in each jurisdiction even after deregulation. Based on company size, the Tokyo Electric Power Company (TEPCO) is the world's largest power company in terms of the volume of power supply; however, other regional power companies in Hokkaido, Hokuriku, and Shikoku are only one-tenth the size of TEPCO. Moreover, the demand structure can differ significantly by region due to climate conditions, as Japan comprises several islands that are spread over a long stretch from north to south. Therefore, we have to pay attention to the unique features of regional power markets rather than applying the same model to all the regional power markets in Japan. In this study, we estimated the power demand for each regional power market. Our results revealed some implications about the validity of the typical a priori assumptions on price elasticity.

2. Model and Data

There are 10 jurisdictions assigned to the same number of vertically integrated regional power companies in Japan. From among these 10 jurisdictions, in our study, we analyzed the power demand in nine regions (Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Chugoku, Shikoku, and Kyushu). The regional electric power demand function was specified as follows:

$$\log(Q_{i,t}) = \alpha_i + \beta_i \cdot \log(p_{i,t}) + \boldsymbol{\lambda}_i{}' \cdot \log(\mathbf{X}_{i,t}) + \delta_i \cdot \log(Q_{i,t-1}), \qquad (1)$$

where $Q_{i,t}$ denotes the power demand index in region *i* in year *t*; $p_{i,t}$ denotes the average power charges; and $\mathbf{X}_{i,t}$ denotes the other explanatory variables[4]. We introduced gross regional products ($GRP_{i,t}$) in order to control the impacts of the regional economic activity level, and introduced cooling degree days ($Cool_{i,t}$) and heating degree days ($Heat_{i,t}$) in order to control the impacts of climate conditions on power demand. A producer price index of petroleum products ($Ppet_t$) was employed as a typical substitute for electricity in energy demand. D_t denotes a dummy variable for deregulation in the retail sector starting in 2000. A lagged dependent variable ($Q_{i,t-1}$) was employed to consider a dynamic adjustment process with a Koyck-lag formulation. Given this functional form, we can obtain the short-run price elasticity β_i and long-run price elasticity $\beta_i/(1-\delta_i)$, which are constant through time. Values and prices were deflated using a domestic corporate goods price index.

These data were obtained from the database (*Denryoku-tokei-joho*) provided on the

[4] In this study, we focus on the sum of industrial and commercial power demand—that is, the power demand excluding that of residential users.

Web site of the Federation of Electric Power Companies of Japan (FEPC), the *Annual Report on Prefectural Accounts*, and the *Handbook of Energy and Economic Statistics in Japan*. For our estimation, we used these annual data for 28 years, from fiscal years 1976 to 2003. Details of these data are summarized in the Appendix.

3. Estimation

3.1 Estimation Results of Regional Power Demand Functions

We estimated the regional power demand function (1) using the ordinal least squares (OLS) method (Table 2). The coefficients of power charges (i.e., short-run price elasticity) were found to be significant and negative in all the regions; this was qualitatively consistent with our intuition. The ranges of the estimated price elasticity of power demand were between 0.100 (Kansai) and 0.300 (Shikoku) in the short run and between 0.126 (Kansai) and 0.552 (Hokkaido) in the long run. As a whole, the magnitude of these estimates was found to be similar to that in the previous studies summarized in Table 1.

On comparing the estimates among regions, the price elasticities of demand were found to be relatively low in the Tokyo, Chubu, and Kansai regions, where many large cities are located. Industrial and commercial users, which were analyzed in this study, are mostly large-scale users, and some of them are equipped with their own power plants. Electricity purchased from regional power companies is highly substitutable with electricity generated by the plants owned by large-scale users. As the share of power supplied by their own plants increases, the power demand function can be observed to become more price elastic. Other than facility costs, there were many region-specific cost factors and constraints for the installation and operation of self-owned power plants, such as environmental regulations and the availability of plant sites. Rural regions provide a better environment for such a purpose; hence, their power demand is more price elastic than that of urban regions. This finding was consistent with another finding that the coefficients of the petroleum products price index in rural regions were greater than those in urban regions. Although it would have been ideal for us to explicitly consider these factors as explanatory variables in our model, the availability of data was limited. The capacities of self-owned power plants and their share in the total regional power supply capacity were introduced as additional explanatory variables; however, they were not found to be significant. This may be because these capacity variables did not successfully function as good proxy variables of the volume of power generated for self-consumption.

With regard to coefficients other than those of price elasticity, the coefficients of gross regional products were generally found to be 0.3–0.4 among the different regions. This result implied that this explanatory variable effectively controlled the impacts of regional economy sizes on power demand. The coefficients of the cooling degree days were not statistically significant in Chugoku and Shikoku, while those of the heating degree days were not significant in Hokkaido and Shikoku. Except for these cases, the coefficients of variables controlling the climate conditions were found to be significant and positive as expected. The insignificance of the coefficient of heating degree days in Hokkaido could be attributed to the fact that its energy demand for heating is heavily dependent on kerosene, rather than electricity.

The coefficients of the dummy variables for deregulation in the retail supply of electric power were found to be significant and negative in all the regions, except Chubu. This implies that users had shifted their demand from services provided by the incumbents to those provided by entrants. However, we should exercise some reservation in accepting this interpretation. The users were supposed to have chosen power service providers after comparing the offers made by incumbents with those by entrants; however, in our estimation, we did not consider the details and differences of their offers. More detailed modeling will be needed when we intend to exactly evaluate the impacts of such factors.

We found the coefficients of the lagged dependent variable to be significant, positive, and smaller than unity for all the regions. These findings were consistent with a standard assumption for partial adjustment models. The impact of the lagged dependent variable $\hat{\delta}_i^{\,s}$ on the power demand s years ago became less than 5% in four years for all nine regions. This suggests a time horizon for our "long-run" estimates.

3.2 Discussions about the Price Elasticity of Regional Power Demand

Experts in the power market have considered power demand to be very inelastic. Based on such a view, numerical simulation analyses have often employed a small price elasticity, such as 0.1 or 0; however, the validity of such assumptions has never been examined empirically. Technologically speaking, the power industry is unique in the sense that electricity cannot be stored but has to be delivered to users on time. As power companies are required to accurately meet the constantly fluctuating demand, it might be practical for power companies to conduct their daily operations assuming that power demand hardly responds to any incentive schemes that power companies may offer. Such an a priori assumption of price-inelastic power demand might be reasonable for discussions about very short-run situations in the power network largely governed by electrotechnological laws and constraints. In contrast, such an assumption might not be valid for policy discussions about regulatory reforms for the coming several years, when economic incentives are supposed to urge players in the power market to achieve better resource allocation. Using our estimation results, we discuss the validity of such a priori assumptions.

Figure 1 shows the point estimates and their 95% confidence intervals of price elasticity. There are three regions with relatively small price elasticity. In Tokyo and Kansai, it is highly probable (about 50%) for the price elasticity to be less than 0.1. There is a 14% probability for the price elasticity to be less than 0.1 in Chubu. In the other six regions, such a probability is found to be negligibly small and the highest probability, 0.6%, is found in Hokuriku. With these findings, we can conclude that there should be some justification for us to assume 0.1 as the price elasticity of the total power demand in Japan, since the three largest regions—Tokyo, Chubu, and Kansai—account for around two-thirds of the total power demand in Japan. In fact, as the 95% confidence intervals of the weighted average of short-run price elasticity were 0.077–0.251, we cannot reject the null hypothesis that this price elasticity is less than 0.1 at the 95% significance level[5].

In contrast, our estimation results of regional power demand functions did not support the assumption of 0.1 as the price elasticity of power demand in regions other than Tokyo, Chubu, and Kansai. Such an assumption of small price elasticity can mislead the analysis of regional power markets, particularly when the differences among regions have

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[5] The average price elasticity was computed at the sample means using regional power demand as the weight.

significance. We found much weaker support for a smaller price elasticity such as 0.01. The probability of the price elasticity being less than 0.01 was highest (3%) in the case of Kansai. The t-statistics of the coefficients of power charges in Table 2 indicated no significant probability for the price elasticity to be zero.

4. Conclusion

Discussions and debates over regulatory reforms for the power market in Japan have often been based on the findings of research on the power markets in Europe and the US, or on conclusions drawn from them. Since these studies were conducted on reforms in Europe and the US, their implications might not be valid for the situations in Japan. Indeed, it is ideal for us to employ views on the unique features of Japan's power market in discussions about its future reforms; however, to date, only a few studies are available on this topic. Even price elasticity of power demand, one of the key parameters characterizing the market, has rarely been estimated empirically. Instead, it has often been assumed to be a small value such as 0.1 in an ad hoc manner.

In our study, we econometrically estimated the regional electric power demand functions and derived the price elasticities. Price elasticity was found to be 0.100–0.300 for the short-run power demand functions and 0.126–0.552 for the long-run functions; power demand was found to be relatively more price elastic in the rural areas than in the urban areas. This result suggests that (1) there is some validity in an a priori assumption of 0.1 for the price elasticity of power demand in analyses of the nationwide market in Japan but not in analyses focusing on the characteristics of regional power markets, and that (2) there is little empirical support for a price elasticity of 0.01 or 0. It should be noted that while our findings were derived using an annual dataset, price elasticity can be found in a different magnitude using a dataset for another market setup, such as an hourly power market in peak load times, which was analyzed by some previous literature referred to in 1.1. In this sense, it is necessary to exercise some caution in accepting our findings and their implications.

Statistical examinations did not indicate any specification errors even without considering supply-side factors explicitly. This may be partly due to the sample period in our analysis, when power charges had long been regulated in almost all the sample years, except for the last few years when regulatory reforms were implemented in the retail sector. We attempted to control the shocks caused by the reforms using a dummy variable; however, we did not seriously consider the endogeneity of explanatory variables in our model. When the reforms are widespread and have created intense competition in the power market, we need to conduct a simultaneous estimation of power demand and supply functions. Moreover, our analysis, which focused on power demand by industrial and commercial users, can be extended to an analysis of power demand by residential users.

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Table 1: Estimates of the Price Elasticity of Power Demand

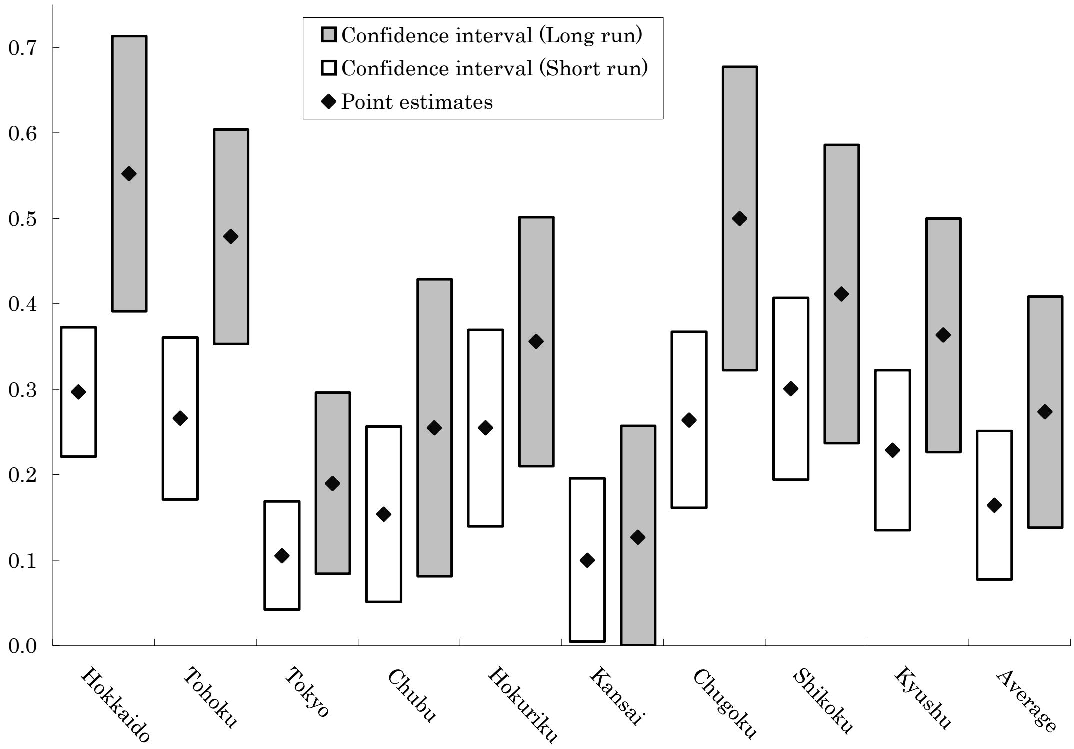
	Country	Type of users	Data	Estimates of price elasticity
Anderson (1971)	US	Industrial	Cross-sectional state-level data 1958, 1962	1.94
Mount et al. (1973)	US	Commercial	Pooled data from 47 states 1947–70	Short run: 0.17 Long run: 1.36
		Industrial		Short run: 0.22 Long run: 1.82
Pindyck (1979)	Canada	Industrial and commercial	Time series 1959–73	0.14
	France			0.16
	Italy			0.13
	Japan			0.12
	Netherlands			0.07
	Norway			0.08
	Sweden			0.12
	UK			0.15
	US			0.08
	West Germany			0.12
Matsukawa et al. (1993)	Japan	Industrial	Pooled data from 9 regions 1980–88	0.63
Hisnanick & Kyer (1995)	US	Manufacturing	Time series 1958–85	0.185
Kamerschen & Porter (2004)	US	Industrial and commercial	Time series 1973–98	0.34–0.55

<u>Table 2</u>: Estimation Results (Dependent Variable: Index of the Volume of Power Demand)

Region	Constant	Power charges	Gross regional products	Petroleum products price	Cooling degree days	Heating degree days	Deregulation dummy	Lagged dependent variable	Adjusted R^2	Durbin's h
Hokkaido	1.08981	–0.29650	0.37040	0.19822	0.00852	0.01361	–0.05291	0.46303	0.994	0.191
	[.048]	[.000]	[.000]	[.000]	[.005]	[.832]	[.003]	[.000]		[.849]
Tohoku	0.15965	–0.26583	0.41314	0.15366	0.00907	0.13215	–0.04222	0.44448	0.996	–0.781
	[.649]	[.000]	[.000]	[.000]	[.098]	[.012]	[.012]	[.000]		[.435]
Tokyo	0.13118	–0.10503	0.39612	0.06903	0.04826	0.07053	–0.02488	0.44674	0.999	0.267
	[.447]	[.003]	[.000]	[.005]	[.000]	[.005]	[.021]	[.000]		[.790]
Chubu	0.75692	–0.15385	0.37949	0.07743	0.04649	0.05172	–0.02123	0.39633	0.996	–0.189
	[.021]	[.005]	[.000]	[.022]	[.002]	[.068]	[.183]	[.001]		[.850]
Hokuriku	1.64525	–0.25447	0.34335	0.07470	0.02512	0.10417	–0.03626	0.28431	0.986	–1.117
	[.003]	[.000]	[.000]	[.025]	[.012]	[.028]	[.051]	[.020]		[.264]
Kansai	0.64188	–0.10001	0.48696	0.11808	0.06296	0.04253	–0.03736	0.20813	0.996	–0.227
	[.008]	[.041]	[.000]	[.000]	[.000]	[.048]	[.004]	[.089]		[.820]
Chugoku	0.95591	–0.26410	0.29245	0.16015	0.02364	0.06738	–0.05177	0.47152	0.985	–1.389
	[.025]	[.000]	[.000]	[.001]	[.160]	[.092]	[.022]	[.000]		[.165]
Shikoku	1.64683	–0.30033	0.33273	0.22593	0.03047	0.04951	–0.04421	0.26978	0.980	0.292
	[.003]	[.000]	[.000]	[.000]	[.117]	[.266]	[.038]	[.056]		[.770]
Kyushu	0.68918	–0.22854	0.47181	0.13176	0.02583	0.04767	–0.04323	0.37057	0.996	0.402
	[.008]	[.000]	[.000]	[.003]	[.045]	[.071]	[.013]	[.002]		[.688]

Note: P-values are shown in brackets.

Figure 1: Estimates and 95% Confidence Intervals of the Price Elasticity of Power Demand



Appendix: Data Sources and Compilation

Details and the sources of data used in our estimation are summarized in Table A.1. We obtained the data on regional power demand from *Denryoku-tokei-joho* [Statistical database of the power market] provided on the Web site of the FEPC. The regional power demand of industrial and commercial users was computed by subtracting the demand of residential users from the total regional power demand. With regard to our data compilation process, some may assume that it would have been more straightforward to use the sum of commercial and large- and small-scale industrial power demand as the data in our analysis. However, user categories in the original time series data were rearranged each time deregulation was implemented in the retail sector and its coverage was expanded. Thus, we could not use such a method in our data compilation. The power charges used in our estimation were the average charges for users defined above, which were computed by dividing the charge revenues by the volume of power demand.

Gross regional products were originally reported for 47 prefectures. We have aggregated these data for nine jurisdictions of the power companies (Table A.2). Shizuoka prefecture is served by two power companies due to historical reasons. The western and central areas are served by the Chubu Electric Power Company, while the eastern area is by served by TEPCO. We compiled the data on Shizuoka assuming that one-third of its gross regional product is attributed to Tokyo, and the rest to Chubu. This assumption was based on the fact that the shares of these two service areas in Shizuoka are almost 1:2 in terms of power demand, population, and the number of business establishments.

The cooling degree days and heating degree days are reported in the *Handbook of Energy and Economic Statistics in Japan*, where 22 °C and 14 °C are used as the bases of the heating and cooling degree days. We used these data for cities where the power company's headquarters are located. They are used to control power demand mainly for air-conditioning purposes. Further, the value of cooling degree days in some years was zero. As this would have caused a problem in the computation of their logarithms in our log-linear model, we redefined the cooling degree days variable by adding one. We deflated all prices and values using the domestic corporate goods price index [all commodities] provided by the Bank of Japan.

Table A.1: Data and Data Sources

Data	Unit [2/]	Source
Electric power demand	Index	Compiled by the authors
Total electricity sales	1,000 kWh	FEPC, *Denryoku-tokei-joho* [Statistical database of the power market]
Total lighting services		
Average power charges	Index	Compiled by the authors
Power service revenue	Million yen	FEPC, ibid.
Deregulation dummy	2000–2003 = 1	Compiled by the authors
Gross regional products	Index	Compiled by the authors [1/]
Gross prefectural products	Million yen	Cabinet Office, Government of Japan, *Annual Report on Prefectural Accounts*
Domestic corporate goods price index [petroleum products]	Index	Bank of Japan
Domestic corporate goods price index [all commodities]		
Cooling degree days	Degree days	Energy Data and Modeling Center, Institute of Energy Economics, Japan, *Handbook of Energy and Economic Statistics in Japan*
Heating degree days		

[1/] See Table A.2 for regional aggregation.

[2/] Indexes: 1995 = 100.

Table A.2: Jurisdictions of Power Companies and Locations of their Headquarters

Jurisdictions of power companies	Prefectures included	Location of headquarters
Hokkaido	Hokkaido	Sapporo
Tohoku	Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, and Niigata	Sendai
Tokyo	Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Yamanashi, and the eastern area of Shizuoka	Tokyo
Chubu	Nagano, Gifu, Aichi, Mie, and the western and central areas of Shizuoka	Nagoya
Hokuriku	Toyama, Ishikawa, and Fukui	Toyama
Kansai	Shiga, Kyoto, Osaka, Hyogo, Nara, and Wakayama	Osaka
Chugoku	Tottori, Shimane, Okayama, Hiroshima, and Yamaguchi	Hiroshima
Shikoku	Tokushima, Kagawa, Ehime, and Kochi	Takamatsu
Kyushu	Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, and Kagoshima	Fukuoka

Annex: Alternative Estimation

B.1 Panel Data Estimation

In Table B.1, the results of the panel data estimation and some supplementary test statistics were added to Table 2 in the main text. Hausman's specification test was conducted for the panel data model. Its statistics were $\chi^2(3)$ = 2.4300 [.0488] and supported a random effects model. However, the F-statistics of the tests for the equality of parameters were found to be F (56, 180) = 4.4233 [.000], and we rejected the null hypothesis of the equality of parameters in power demand functions among regions. That is, the results of the panel data estimation could not be accepted.

It should be noted that our model included a lagged dependent variable as an explanatory variable. Although this type of model required dynamic panel data estimation methods with special treatments and assumptions on fixed effects, time effects, data structure, etc., most of these factors are still insufficiently addressed. For example, the cross-section dimension has to be sufficiently large in order to ensure the consistency of estimates; however, it was actually limited to nine regions in Japan's power industry. The estimation methods and test statistics related to our panel data estimation in Table B.1 were not seriously examined from these viewpoints in this alternative estimation. Serial correlations between error terms had to be examined carefully. Nevertheless, we paid little attention to this problem because Durbin's h statistic for each regional power demand function did not indicate any problem.

[Table B.1 placed here]

Table B.2 shows the estimation results with an instrumental variable method for the Hausman specification test using instruments of one-period lagged explanatory variables, the number of users, gross regional products by sector (agriculture, manufacturing, and service), capacity of self-owned power plants, the ratio of their capacity to the total regional power demand, populations, number of households, and 6–13-period lagged dependent variables. (Our estimation results were found to be robust irrespective of the number of time periods of the lagged dependent variables.)

[Table B.2 placed here]

B.2 Alternative Specification 1: Sectoral Value Added Share Variables

Table B.3 shows the estimation results with an alternative specification of the demand function, where the share of the manufacturing and service sectors in gross regional products were included as additional explanatory variables. These new explanatory variables were not found to be significant at conventional significance levels; further, they had little impact on the estimates of other explanatory variables.

[Table B.3 placed here]

B.3 Alternative Specification 2: Linear Demand Function

Table B.4 shows the estimation results with another alternative specification where we employed linear demand functions rather than log-linear ones. In comparison with the original estimation results in Table 2 in the main text, there were a few points to be mentioned. The coefficients of power charges were not significant in Chubu and Kansai, while those of the lagged dependent variable were not significant in Hokuriku and Kansai. Given this linear functional form, price elasticity was computed as $\beta_i \cdot p_{i,t} / Q_{i,t}$ and was dependent on reference points, as shown in Table B.5. Price elasticity estimated with linear demand functions was found to be smaller than that estimated with log-linear functions. In contrast, our finding of relatively smaller elasticity in urban regions as compared to that in rural regions was robust even with this alternative specification.

[Table B.4 placed here]

[Table B.5 placed here]

B.4 Alternative Specification 3: HAC Covariance

Considering the possibility of a miss-specification of the model, we attempted another alternative estimation with the Newey-West (NW) heteroscedasticity and autocorrelation consistent (HAC) covariance estimator (Table B.6). The HAC estimates of covariance were found to be smaller than the original estimates by OLS. While these HAC covariance estimates made the originally insignificant coefficients of cooling degree days for Chugoku and Shikoku significant, our results regarding various statistical tests were not affected as a whole.

[Table B.6 placed here]

Table B.1: Estimation Results by OLS and Panel Estimation Methods (Dependent Variable: Index of the Volume of Power Demand)

Region	Constant	Power charges	Gross regional products	Petroleum products price	Cooling degree days	Heating degree days	Deregula-tion dummy	Lagged dependent variable	Adjusted R^2	Durbin's h	Durbin's h alternative	F (Zero slopes)
Hokkaido	1.08981	–0.29650	0.37040	0.19822	0.00852	0.01361	–0.05291	0.46303	0.994	0.191	0.235	692.218
	[.048]	[.000]	[.000]	[.000]	[.005]	[.832]	[.003]	[.000]		[.849]	[.814]	[.000]
Tohoku	0.15965	–0.26583	0.41314	0.15366	0.00907	0.13215	–0.04222	0.44448	0.996	–0.781	–0.959	939.488
	[.649]	[.000]	[.000]	[.000]	[.098]	[.012]	[.012]	[.000]		[.435]	[.337]	[.000]
Tokyo	0.13118	–0.10503	0.39612	0.06903	0.04826	0.07053	–0.02488	0.44674	0.999	0.267	0.043	3,088.550
	[.447]	[.003]	[.000]	[.005]	[.000]	[.005]	[.021]	[.000]		[.790]	[.966]	[.000]
Chubu	0.75692	–0.15385	0.37949	0.07743	0.04649	0.05172	–0.02123	0.39633	0.996	–0.189	–0.671	1,055.600
	[.021]	[.005]	[.000]	[.022]	[.002]	[.068]	[.183]	[.001]		[.850]	[.502]	[.000]
Hokuriku	1.64525	–0.25447	0.34335	0.07470	0.02512	0.10417	–0.03626	0.28431	0.986	–1.117	–1.166	268.256
	[.003]	[.000]	[.000]	[.025]	[.012]	[.028]	[.051]	[.020]		[.264]	[.244]	[.000]
Kansai	0.64188	–0.10001	0.48696	0.11808	0.06296	0.04253	–0.03736	0.20813	0.996	–0.227	–0.502	871.471
	[.008]	[.041]	[.000]	[.000]	[.000]	[.048]	[.004]	[.089]		[.820]	[.616]	[.000]
Chugoku	0.95591	–0.26410	0.29245	0.16015	0.02364	0.06738	–0.05177	0.47152	0.985	–1.389	–1.337	252.005
	[.025]	[.000]	[.000]	[.001]	[.160]	[.092]	[.022]	[.000]		[.165]	[.181]	[.000]
Shikoku	1.64683	–0.30033	0.33273	0.22593	0.03047	0.04951	–0.04421	0.26978	0.980	0.292	0.312	187.514
	[.003]	[.000]	[.000]	[.000]	[.117]	[.266]	[.038]	[.056]		[.770]	[.755]	[.000]
Kyushu	0.68918	–0.22854	0.47181	0.13176	0.02583	0.04767	–0.04323	0.37057	0.996	0.402	0.132	982.948
	[.008]	[.000]	[.000]	[.003]	[.045]	[.071]	[.013]	[.002]		[.688]	[.895]	[.000]
Panel (random effects)	0.65385	–0.18351	0.17349	0.06977	0.01355	0.03886	–0.03694	0.72577	0.989	(Durbin-Watson)		
	[.000]	[.000]	[.000]	[.000]	[.000]	[.000]	[.000]	[.000]		(1.427)		

Note: P-values are shown in brackets.

Table B.2: Estimation Results by IV (Dependent Variable: Index of the Volume of Power Demand)

Region	Constant	Power charges	Gross regional products	Petroleum products price	Cooling degree days	Heating degree days	Deregulation dummy	Lagged dependent variable	Adjusted R^2	Durbin's h	F (Over-identification restriction)	Hausman's specification test
Hokkaido	1.03454	−0.29543	0.36337	0.19296	0.00981	0.01863	−0.05230	0.47709	0.994	0.195	1.060	2.273
	[.051]	[.000]	[.000]	[.000]	[.001]	[.774]	[.002]	[.000]		[.845]	[.443]	[.971]
Tohoku	0.10788	−0.26014	0.40139	0.14833	0.00955	0.13450	−0.04340	0.46323	0.996	−0.587	1.247	1.141
	[.760]	[.000]	[.000]	[.000]	[.084]	[.008]	[.010]	[.000]		[.557]	[.317]	[.997]
Tokyo	0.08026	−0.10208	0.38429	0.06748	0.05448	0.07064	−0.02541	0.46024	0.999	0.371	1.014	1.922
	[.662]	[.001]	[.000]	[.003]	[.000]	[.003]	[.015]	[.000]		[.710]	[.480]	[.983]
Chubu	0.76270	−0.16177	0.37763	0.08242	0.04600	0.05142	−0.02494	0.40103	0.996	0.218	1.172	1.843
	[.028]	[.002]	[.000]	[.013]	[.001]	[.152]	[.162]	[.000]		[.828]	[.364]	[.985]
Hokuriku	1.69486	−0.26570	0.34950	0.08318	0.01883	0.10025	−0.04280	0.28384	0.985	−1.337	1.104	2.138
	[.001]	[.000]	[.000]	[.012]	[.065]	[.035]	[.028]	[.017]		[.181]	[.411]	[.977]
Kansai	0.64269	−0.10263	0.47825	0.12154	0.06744	0.03631	−0.03596	0.21879	0.996	0.008	1.205	1.282
	[.004]	[.039]	[.000]	[.000]	[.000]	[.086]	[.005]	[.072]		[.994]	[.343]	[.996]
Chugoku	0.87045	−0.29580	0.30290	0.18546	0.02503	0.07401	−0.07232	0.47466	0.984	−1.744	0.833	4.425
	[.039]	[.000]	[.000]	[.000]	[.155]	[.079]	[.003]	[.000]		[.081]	[.636]	[.817]
Shikoku	1.61493	−0.32236	0.32472	0.22665	0.02664	0.05155	−0.05510	0.30826	0.979	0.041	0.877	3.618
	[.004]	[.000]	[.000]	[.000]	[.163]	[.321]	[.012]	[.033]		[.967]	[.596]	[.890]
Kyushu	0.59764	−0.22033	0.44810	0.11828	0.03216	0.05529	−0.04302	0.40073	0.996	0.320]	1.066	2.536
	[.015]	[.000]	[.000]	[.004]	[.014]	[.037]	[.008]	[.000]		[.749]	[.439]	[.960]

Note: P-values are shown in brackets.

Table B.3: Estimation Results by OLS in Alternative Specification 1: Sectoral Value Added Share Variables

Region	Constant	Power charges	Gross regional products	Share of secondary industry	Share of tertiary industry	Petroleum products price	Cooling degree days	Heating degree days	Deregulation dummy	Lagged de-pendent variable	Adjusted R^2	Durbin's h	Durbin's h alternative	F (Zero slopes)
Hokkaido	0.46684	−0.28821	0.29638	2.00989	1.46057	0.16458	0.01026	−0.03245	−0.02483	0.44389	0.995	−0.094	0.022	641.191
	[.421]	[.000]	[.022]	[.132]	[.313]	[.007]	[.001]	[.657]	[.200]	[.000]		[.925]	[.982]	[.000]
Tohoku	−0.01571	−0.24479	0.42290	0.21126	−0.49361	0.16277	0.00857	0.14474	−0.02180	0.48124	0.996	−1.365	−1.458	768.025
	[.977]	[.000]	[.000]	[.815]	[.619]	[.000]	[.167]	[.007]	[.267]	[.000]		[.172]	[.145]	[.000]
Tokyo	−3.27292	−0.13444	0.33251	3.84583	3.92380	0.05308	0.04866	0.07658	−0.02480	0.44482	0.999	0.065	−0.142	2,227.120
	[.493]	[.018]	[.004]	[.476]	[.474]	[.108]	[.000]	[.006]	[.061]	[.000]		[.948]	[.887]	[.000]
Chubu	1.90558	−0.12977	0.38808	−1.37916	−1.65644	0.08032	0.04426	0.04634	−0.01509	0.45313	0.996	−0.300	−0.663	788.240
	[.555]	[.121]	[.006]	[.723]	[.677]	[.043]	[.004]	[.153]	[.400]	[.001]		[.764]	[.507]	[.000]
Hokuriku	−0.13652	−0.23682	0.27030	2.22298	1.56362	0.04876	0.02996	0.12491	−0.00791	0.33128	0.988	−2.649	−2.783	242.825
	[.922]	[.001]	[.012]	[.223]	[.395]	[.203]	[.004]	[.008]	[.713]	[.007]		[.008]	[.005]	[.000]
Kansai	−7.00566	−0.18276	0.37223	8.54279	8.15455	0.08452	0.06353	0.05990	−0.02322	0.28762	0.996	−0.775	−1.125	853.433
	[.203]	[.006]	[.001]	[.167]	[.187]	[.012]	[.000]	[.008]	[.076]	[.018]		[.438]	[.261]	[.000]
Chugoku	−1.63258	−0.29123	0.14427	3.49341	2.88735	0.13017	0.03941	0.08348	−0.03507	0.53266	0.986	−2.105	−2.223	211.168
	[.529]	[.000]	[.356]	[.331]	[.413]	[.024]	[.046]	[.041]	[.131]	[.000]		[.035]	[.026]	[.000]
Shikoku	0.61475	−0.29823	0.24999	1.71798	1.19922	0.20720	0.03915	0.04324	−0.03159	0.30652	0.978	−0.270	−0.052	137.179
	[.696]	[.000]	[.164]	[.529]	[.623]	[.004]	[.101]	[.355]	[.229]	[.048]		[.787]	[.959]	[.000]
Kyushu	0.93286	−0.22038	0.50895	−0.34145	−1.02176	0.14357	0.02466	0.06168	−0.03024	0.41905	0.996	0.615	0.313	767.586
	[.538]	[.001]	[.010]	[.899]	[.712]	[.022]	[.139]	[.040]	[.131]	[.001]		[.538]	[.754]	[.000]

Note: P-values are shown in brackets.

Table B.4: Estimation Results by OLS in Alternative Specification 2: Linear Demand Function

Region	Constant	Power charges	Gross regional products	Petroleum products price	Cooling degree days	Heating degree days	Deregulation dummy	Lagged dependent variable	Adjusted R^2	Durbin's h	Durbin's h alternative	F (Zero slopes)
Hokkaido	16.71200	−0.21775	0.43686	0.11854	0.02664	0.00121	−2.83837	0.46998	0.994	0.532	0.570	661.953
	[.021]	[.000]	[.000]	[.001]	[.004]	[.587]	[.049]	[.000]		[.594]	[.569]	[.000]
Tohoku	8.96409	−0.19607	0.52013	0.10318	0.01350	0.00601	−1.89662	0.37873	0.997	−0.817	−0.856	1,236.380
	[.035]	[.000]	[.000]	[.000]	[.003]	[.010]	[.121]	[.000]		[.414]	[.392]	[.000]
Tokyo	2.82394	−0.04173	0.50163	0.04229	0.01417	0.00508	−2.16999	0.37440	0.999	−0.009	−0.155	2,737.470
	[.236]	[.079]	[.000]	[.006]	[.000]	[.017]	[.015]	[.000]		[.993]	[.877]	[.000]
Chubu	14.51160	−0.05685	0.48793	0.03592	0.01314	0.00247	−2.49528	0.31797	0.996	0.196	−0.074	882.102
	[.008]	[.170]	[.000]	[.113]	[.001]	[.296]	[.077]	[.024]		[.844]	[.941]	[.000]
Hokuriku	39.99010	−0.17717	0.44722	0.04820	0.01228	0.00426	−2.94464	0.18692	0.986	−0.180	−0.382	270.335
	[.000]	[.001]	[.000]	[.035]	[.003]	[.121]	[.074]	[.159]		[.857]	[.702]	[.000]
Kansai	10.82290	−0.02005	0.52865	0.05663	0.01280	0.00342	−2.34962	0.23659	0.994	0.806	0.356	637.698
	[.016]	[.654]	[.000]	[.011]	[.000]	[.142]	[.049]	[.108]		[.420]	[.722]	[.000]
Chugoku	20.06100	−0.20086	0.36661	0.11064	0.01019	0.00661	−4.03346	0.41310	0.988	−1.798	−1.604	330.365
	[.002]	[.000]	[.000]	[.001]	[.014]	[.037]	[.022]	[.000]		[.072]	[.109]	[.000]
Shikoku	33.64490	−0.24614	0.40342	0.15283	0.01022	0.00378	−2.67183	0.28090	0.984	1.169	1.011	236.148
	[.000]	[.000]	[.000]	[.000]	[.028]	[.306]	[.132]	[.045]		[.242]	[.312]	[.000]
Kyushu	11.15590	−0.15038	0.53105	0.08131	0.00762	0.00397	−2.70278	0.36062	0.998	−0.422	−0.454	1,556.450
	[.001]	[.000]	[.000]	[.000]	[.002]	[.055]	[.015]	[.001]		[.673]	[.650]	[.000]

Note: P-values are shown in brackets.

Table B.5: Estimated Price Elasticity with Linear and Log-linear Demand Functions

		Linear model	Log-linear model	
		Price elasticity	Price elasticity	Confidence intervals (α = 5%)
Hokkaido	Short run	0.199–0.243	0.297	0.221–0.372
	Long run	0.376–0.458	0.552	0.391–0.713
Tohoku	Short run	0.182–0.223	0.266	0.171–0.361
	Long run	0.293–0.359	0.479	0.353–0.604
Tokyo	Short run	0.040–0.049	0.105	0.042–0.168
	Long run	0.064–0.079	0.190	0.084–0.296
Chubu	Short run	0.055–0.066	0.154	0.051–0.256
	Long run	0.081–0.096	0.255	0.081–0.428
Hokuriku	Short run	0.168–0.190	0.254	0.139–0.369
	Long run	0.207–0.234	0.356	0.210–0.501
Kansai	Short run	0.020–0.022	0.100	0.005–0.195
	Long run	0.026–0.029	0.126	−0.002–0.255
Chugoku	Short run	0.188–0.221	0.264	0.161–0.367
	Long run	0.321–0.376	0.500	0.322–0.678
Shikoku	Short run	0.226–0.263	0.300	0.194–0.407
	Long run	0.315–0.365	0.411	0.237–0.586
Kyushu	Short run	0.140–0.170	0.229	0.135–0.322
	Long run	0.219–0.266	0.363	0.227–0.500

Table B.6: Estimation Results by NW in Alternative Specification 3: HAC Covariance

Region	Constant	Power charges	Gross regional products	Petroleum products price	Cooling degree days	Heating degree days	Deregulation dummy	Lagged dependent variable	Adjusted R^2	Durbin's h
	1.08981	−0.29650	0.37040	0.19822	0.00852	0.01361	−0.05291	0.46303	0.994	0.326
Hokkaido	[.013]	[.000]	[.000]	[.000]	[.000]	[.799]	[.000]	[.000]		[.744]
	(.048)	(.000)	(.000)	(.000)	(.005)	(.832)	(.003)	(.000)		
	0.15965	−0.26583	0.41314	0.15366	0.00907	0.13215	−0.04222	0.44448	0.996	−0.541
Tohoku	[.574]	[.000]	[.000]	[.000]	[.041]	[.001]	[.001]	[.000]		[.589]
	(.649)	(.000)	(.000)	(.000)	(.098)	(.012)	(.012)	(.000)		
	0.13118	−0.10503	0.39612	0.06903	0.04826	0.07053	−0.02488	0.44674	0.999	0.416
Tokyo	[.362]	[.000]	[.000]	[.000]	[.000]	[.000]	[.003]	[.000]		[.678]
	(.447)	(.003)	(.000)	(.005)	(.000)	(.005)	(.021)	(.000)		
	0.75692	−0.15385	0.37949	0.07743	0.04649	0.05172	−0.02123	0.39633	0.996	0.243
Chubu	[.003]	[.000]	[.000]	[.003]	[.000]	[.022]	[.101]	[.000]		[.808]
	(.021)	(.005)	(.000)	(.022)	(.002)	(.068)	(.183)	(.001)		
	1.64525	−0.25447	0.34335	0.07470	0.02512	0.10417	−0.03626	0.28431	0.986	−0.883
Hokuriku	[.000]	[.000]	[.000]	[.003]	[.001]	[.005]	[.011]	[.002]		[.377]
	(.003)	(.000)	(.000)	(.025)	(.012)	(.028)	(.051)	(.020)		
	0.64188	−0.10001	0.48696	0.11808	0.06296	0.04253	−0.03736	0.20813	0.996	−0.144
Kansai	[.000]	[.009]	[.000]	[.000]	[.000]	[.013]	[.000]	[.034]		[.886]
	(.008)	(.041)	(.000)	(.000)	(.000)	(.048)	(.004)	(.089)		
	0.95591	−0.26410	0.29245	0.16015	0.02364	0.06738	−0.05177	0.47152	0.985	−1.107
Chugoku	[.003]	[.000]	[.000]	[.000]	[.087]	[.039]	[.002]	[.000]		[.268]
	(.025)	(.000)	(.000)	(.001)	(.160)	(.092)	(.022)	(.000)		
	1.64683	−0.30033	0.33273	0.22593	0.03047	0.04951	−0.04421	0.26978	0.980	0.389
Shikoku	[.000]	[.000]	[.000]	[.000]	[.052]	[.175]	[.009]	[.017]		[.697]
	(.003)	(.000)	(.000)	(.000)	(.117)	(.266)	(.038)	(.056)		
	0.68918	−0.22854	0.47181	0.13176	0.02583	0.04767	−0.04323	0.37057	0.996	0.454
Kyushu	[.001]	[.000]	[.000]	[.000]	[.011]	[.024]	[.001]	[.000]		[.650]
	(.008)	(.000)	(.000)	(.003)	(.045)	(.071)	(.013)	(.002)		

Note: P-values for the estimation results by NW are shown in brackets, and P-values for those by OLS (in Table 2) are shown in parentheses.