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Demand for industrial and commercial electricity: evidence from Japan

Akihiro Otsuka

Correspondence:
akihiro@criepi.denken.or.jp
Socio-economic Research Center, Central Research Institute of Electric Power Industry, 1-6-1 Otemachi, Chiyoda-ku, Tokyo 100-8126, Japan

Abstract

This study aims to estimate electricity demand functions in Japan's industrial and commercial sectors. We adopt data from the Energy Consumption Statistics by Prefecture by the Ministry of Economy, Trade and Industry, Japan, to delineate the demand between the industrial and commercial sector. The results reveal that in both sectors, the price elasticity of demand is extremely low in the short and long run and production elasticity is greater than price elasticity. Thus, price elasticity is not a key determinant in electricity demand fluctuations. Furthermore, an analysis of the factors influencing changes in electricity demand in the industrial sector suggests that the declining demand growth in large metropolitan areas is mainly attributable to declining production factors, not increasing electricity rates. By contrast, the commercial sector is experiencing an increasing demand for electricity and significant growth nationwide, which can be attributed to an increase in commercial floor space and advances in office automation.

JEL Classification: C33; C36; Q41; Q43; Q48

Keywords: Electricity demand; Industrial sector; Commercial sector; Demand price elasticity; Dynamic panel model; Japan

1 Background

In Japan, the industrial and commercial sectors account for a significant portion of electricity demand (about 70 %). Against this background and given that the nation's recent power market reforms increasingly focus on such users, understanding the demand for electricity in the two sectors is crucial from a regulatory policy viewpoint. In particular, determining the extent to which the demand for electricity in Japan fluctuates in response to a rate hike by each supplier company is a key political concern for energy policy makers. Moreover, changes in the composition of electric power generation, following the suspension of nuclear power plants and the introduction of renewable energy sources, are likely to increase electricity rates in the future. Therefore, determining the effects of fluctuating electricity rates on electricity demand in each region is critical for energy policy formulation in Japan.

That electricity demand is inelastic is conventional wisdom, and thus, related research has often hypothesized that the price elasticity of electricity demand is significantly low (e.g., −0.1 or almost 0). For instance, Kanemoto et al. (2006) and Tanaka (2007) conducted simulations using a general equilibrium model for electricity market deregulations and hypothesized a price elasticity of −0.1 for electricity demand, drawing on their assertion that the absolute value of elasticity is extremely low in Japan. Although such a hypothesis may be rational in the national aggregated market for electricity, it may not be appropriate when analyzing electricity demand using sectoral data. This is because the reactions of economic entities to changing rates may significantly differ across, for example, the industrial and commercial sectors. In Japan, especially, existing empirical studies have largely adopted aggregated data and neglected sectoral differences in electricity demand. Thus, to empirically validate the price elasticity of electricity demand, a re-evaluation of price elasticity using sectoral data is needed.

To the best of our knowledge, limited research analyzes Japan's sectoral data from this perspective. For example, Hosoe and Akiyama (2009) conducted an empirical analysis of electric power demand; however, they do not distinguish electricity demand between the industrial and commercial sector. In Japan, since the deregulation of retail electric power in March 2000, electricity demand by customers with electric contracts larger than a specified amount has been classified as "special-scale demand." However, the 10 electric power companies in Japan disclose only large-scale industrial and commercial demand data. Therefore, an economic analysis of electricity demand using stable regional time-series data requires the classification of electricity sales volume into two categories: residential sector and non-residential sector.

The Ministry of Economy, Trade and Industry (METI) recently released a statistics report, Energy Consumption Statistics by Prefecture, which provides time-series data by energy sector for each prefecture. The statistics clearly distinguish between industrial and commercial electricity demand, thus making it possible to conduct a sector-based demand analysis; however, it only reports data on total electricity demand by prefecture. The total electricity demand, nevertheless, includes not only sales volume but also the power generated and consumed by privately owned power facilities.[1] Therefore, we focus on the trend of total electricity demand as a whole and not electricity sales volume in particular. To the best of our knowledge, this study is the first to use sectoral data from the Energy Consumption Statistics by Prefecture to measure the price elasticity of industrial and commercial electricity demand and analyze factors that increase electricity demand.

We first estimate the industrial and commercial electricity demand function to shed light on how a rate change affects overall demand. Second, to assess the price elasticity of electricity demand and fill the gaps in the extant literature, we adopt the dynamic panel estimation method, which also allows us to tackle the problem of an endogenous electric demand function. Third, we conduct a structural analysis of demand across Japan's regions, in particular electricity company jurisdictions. By identifying the factors influencing changes in electricity demand, we estimate the impact of a rate hike on such changes.

The remainder of this paper is organized as follows. Section 2 reviews the existing literature. Section 3 discusses the methodology and data. Section 4 estimates the electricity demand function and presents a structural analysis. Section 5 presents the conclusions and discusses the potential for future research.

2 Literature review

While most previous studies on the price elasticity of electricity demand have focused on residential electricity use, little attention has been given to the price elasticity of industrial and commercial electricity demand. For instance, Pindyck (1979) examined industrial and commercial electricity demand using 1959–1973 data from 10 developed countries to estimate price elasticity in each country and found that the price elasticity of the demand was significantly low (from −0.07 to −0.16). Similarly, Bohi and Zimmerman (1984) reviewed several previous studies conducted in the USA and found low price elasticity for industrial electricity demand in the short run (between −0.10 and −0.27) as well as in the long run (between −0.61 and −3.55). However, for commercial electricity demand, they found low price elasticity in the short run (−0.27) but high elasticity in the long run (between −1.05 and −4.56). Hisnanick and Kyer (1995) and Kamershen and Porter (2004) adopted time-series data from the USA. Hisnanick and Kyer (1995) used manufacturing industry data for 1958–1985 and found a low price elasticity value of −0.19. Using industrial and commercial sector data for 1973–1998, Kamershen and Porter (2004) derived price elasticity values ranging between −0.34 and −0.55 for industrial and commercial electricity demand.

Pindyck (1979), the first researcher to employ Japanese data, revealed extremely low price elasticity (−0.12) for Japan's industrial electricity demand. Matsukawa et al. (1993) conducted an empirical analysis using pooled data from Japan's electric power companies (excluding Okinawa Power) for 1980–1988 and obtained a price elasticity value of −0.63 for manufacturing electricity demand. Japan's Cabinet Office (2001, 2003, 2007) estimated overall electricity demand functions (residential as well as industrial and commercial) for nine regions (excluding Okinawa) and obtained price elasticity values of −0.44, −0.47, and −0.37, respectively, for the fiscal years 1981–1998, 1986–2002, and 1986–2005. Estimating electricity demand functions for non-residential electricity demand by region, Hosoe and Akiyama (2009) reported low price elasticities between −0.1 and −0.3 in the short run and between −0.13 and −0.56 in the long run. However, they found price elasticity to be greater in rural areas than in urban areas. Clearly, the price elasticity of electricity demand in the industrial and commercial sectors is inelastic in the short run but relatively elastic in the long run.

Although Hosoe and Akiyama (2009) analyzed non-residential demand for electricity as a single series, they did not distinguish between industrial and commercial demand. In addition, they adopted a partial adjustment model with an ordinary least squares (OLS) estimator. According to Bond (2002), however, the standard results for omitted variable bias indicate that the OLS estimator is upward biased. In other words, the long-run price elasticities estimated in studies using the OLS estimator might be higher than actual price elasticities. To avoid this bias, Okajima and Okajima (2013) estimated the short- and long-run price elasticity of electricity demand using the generalized methods of moment (GMM) estimator; however, they did so for residential electricity and not industrial and commercial electricity. Drawing on Okajima and Okajima, this study adopts the GMM estimator and, to the best of our knowledge, is the first to apply their partial adjustment model to industrial and commercial electricity demand.

Finally, previous studies on industrial and commercial electricity demand have ignored the endogeneity issue in electricity price. Because electric power prices are calculated by dividing the monetary value of electric power sales by the volume of electric power consumption, electricity prices correlate with the error term, resulting in an endogeneity problem that cannot be successfully resolved using estimation methods adopted in existing studies. To this effect, we expect the estimates of short-run price elasticities to be biased (omitted variable bias), unless instrumental variables are used for the electricity price variable. Thus, this study includes instrumental variables for lagged electricity price variables to avoid omitted variable bias.

3 Methods

3.1 Methodology

To estimate the electricity demand function, this study adopts a partial adjustment approach (e.g., Cuddington and Dagher 2015), an effective method when dealing with datasets with micro panels such as a large J (number of groups) and small T (time series). Since our dataset covers a relatively short period (20 years), we believe a partial adjustment approach is suitable. However, most previous studies using a partial adjustment approach have failed to recognize the possibility of an endogenous lagged dependent variable in the regressors (Hosoe and Akiyama 2009). By contrast, this study accounts for this endogeneity to avoid any bias.

A partial adjustment model of industrial and commercial electricity demand can be expressed using the following equation[2]:

$$\begin{aligned} \ln(\mathrm{ED})_{jt} = {} & \alpha_1 \ln\left(\mathrm{Pe}_{jt}/\mathrm{Pz}_t\right) + \alpha_2 \ln X_{jt} + \alpha_3 \ln\mathrm{COOL}_{jt} + \alpha_4 \ln\mathrm{HEAT}_{jt} \\ & + \alpha_5 \ln(\mathrm{ED})_{jt-1} + C_j + u_{jt}, \end{aligned} \quad (1)$$

where j is the prefecture ($j = 1, 2, \ldots, J$), t is time ($t = 1, 2, \ldots, T$), and ED on the left-hand side is the total electricity demand volume. The first term on the right-hand side is the price factor, with Pe as the aggregate unit price of electricity and Pz the domestic corporate goods price index (aggregate).[3] The second term on the right-hand side is the production factor, with X being the amount of real production. The third and fourth terms on the right-hand side are atmospheric temperature factors. COOL is the cooling degree days and HEAT the heating degree days. The fifth term is a one-period lag in the non-explanatory variable. C_j is the fixed effects and a constant that varies by prefecture and u_{jt} is an error term.

The partial adjustment model in Eq. (1) contains a lagged dependent variable in the regressors. The presence of such a variable is endogenous to the fixed effects in the error term, which creates a dynamic panel bias (Cameron and Trivedi 2009). However, a dynamic panel bias reduces the reliability of long-run price elasticities as it also makes the coefficient of a lagged dependent variable biased. To avoid such a bias, recent studies have adopted the GMM estimator (e.g., Okajima and Okajima 2013). Given its data structure, the present study requires an estimation method that can be applied to panel data with multiple individual effects over a short time period. Therefore, we adopt the Arellano and Bond (1991) estimator (the first-difference GMM estimator).[4]

To calculate the long-run effects, we first employ a lagged dependent variable, which correlates with the error term. To solve this problem, we use instrumental variables. Following Arellano and Bond (1991), we use the additional lags of the dependent variable as instruments for a lagged dependent variable. Second, the aggregate unit price of electricity can affect electricity consumption. However, estimating the relationship between prices and quantity by applying the OLS estimator can be difficult because demand fluctuates under the influence of various factors in addition to price. This causes the demand curve to shift along the supply curve. As a result, the price variable is likely to correlate with the error term. To solve this problem, we use a lagged price for residential electricity as an instrumental variable for electricity price, because an electricity price with a 1-year lag may correlate with the actual electricity price, not the error.

The equation for the dynamic panel estimation, which eliminates individual effects by calculating the first difference for Eq. (1), is as follows:

$$\begin{aligned}\Delta \ln(\mathrm{ED})_{jt} = {} & \alpha_1 \Delta \ln\left(\mathrm{Pe}_{jt}/\mathrm{Pz}_t\right) + \alpha_2 \Delta \ln X_{jt} + \alpha_3 \Delta \ln\mathrm{COOL}_{jt} + \alpha_4 \Delta \ln\mathrm{HEAT}_{jt} \\ & + \alpha_5 \Delta \ln(\mathrm{ED})_{jt-1} + \Delta u_{jt},\end{aligned} \tag{2}$$

where Δ denotes the first-difference operator. The parameter α needs to be estimated. Given this functional form, α_1 and α_2 are the short-run price and production elasticities of demand. The long-run price and production elasticities are obtained by dividing α_1 and α_2 by $(1 - \alpha_5)$.

Since this study adopts Okajima and Okajima's partial adjustment model to estimate industrial and commercial electricity demand, Eq. (2) is similar to their model, which was used to estimate only residential electricity demand. However, this study attempts to identify causes underlying changes in power demand using the estimated long-run elasticity, an extension that has not been made in Okajima and Okajima (2013) or any other study.

3.2 Data

This study uses panel data for 47 prefectures for the period of 1990–2010 to estimate an electricity demand function. Data on the total electricity demand volume for the industrial and commercial sectors are obtained from the Energy Consumption Statistics by Prefecture (METI). To determine electricity prices, we utilize the lighting rates and electric power rates listed in the security reports of the electric power companies. Specifically, we apply the aggregate unit price, which is the rate of electric power (value of electric power sold) divided by electricity volume. We derive the real gross production from the Cabinet Office's Annual Report on Prefectural Accounts.

To identify particularly hot and cold days, we use data from weather stations located in municipal capitals.[5] The annual number of cooling degree days is the cumulative difference of temperatures between 22 °C and the average temperature on each day in a year whose average temperature exceeds 24 °C. Similarly, the annual number of heating degree days is the cumulative difference of temperatures between 14 °C and the average temperature on each day in an annual period whose average temperature is below 14 °C.

The basic descriptive statistics are presented in Table 1. The average electricity demand for the industrial sector is almost twice as that of the commercial sector. Although the total electricity demand for the industrial sector in the 1990s and 2000s increased marginally, electricity demand in the commercial sector grew rapidly, with most of the commercial sector showing a significant increase. Meanwhile, the average electricity price declined in the 1990s and 2000s, a factor that may have contributed to the increase in demand. To the effect of production trends, the overall output by the industrial sector showed a declining trend; thus, we may infer that production levels did not significantly contribute to the increase in electricity demand. By contrast, the

Table 1 Descriptive statistics

		Electricity demand (in million kWh)		Relative price (2005 = 100)	Real output production (in million JPY)		Cooling degree days	Heating degree days
		Industrial sector	Commercial sector		Industrial sector	Commercial sector		
Average	1990	10,112	4,262	117	8,943,656	10,049,099	413	1,048
Std. dev		9,392	5,396	6	9,889,648	18,385,003	163	411
Maximum		42,792	31,506	133	46,138,439	121,863,337	864	2,239
Minimum		1,500	844	106	1,375,526	1,811,306	45	5
Average	2000	11,022	5,735	113	8,432,465	11,948,567	412	1,140
Std. dev		9,622	6,683	2	8,255,411	19,724,913	140	533
Maximum		43,723	38,927	115	38,401,273	129,514,356	840	2,769
Minimum		1,983	1,267	105	1,518,385	2,242,982	66	3
Average	2010	10,263	6,517	98	7,399,825	12,716,041	492	1,267
Std. dev		7,893	8,148	2	7,140,113	21,573,747	137	467
Maximum		36,498	46,915	101	38,685,024	142,662,585	909	2,591
Minimum		2,234	1,358	95	919,587	2,238,356	124	122
Average	1990–2010	10,308	5,600	111	8,320,428	11,739,197	367	1,106
Std. dev		8,970	6,912	10	8,417,260	19,608,941	176	471
Maximum		44,794	51,064	138	48,409,634	150,583,835	1,186	2,769
Minimum		1,129	833	94	919,587	1,800,189	0	0

Source: Energy Consumption Statistics by Prefecture (METI) and Annual Report on Prefectural Accounts (Cabinet Office)

output in the commercial sector grew rapidly in the 1990s and 2000s. From this, we may infer that the increase in commercial electricity demand can be attributed to both lower prices and higher output. Finally, as for the effects of temperature, no major changes were observed in average cooling or heating degree days during the 1990s and 2000s.

4 Results and discussion

This section estimates the price elasticity of electricity demand in both the industrial and commercial sectors using the two-step GMM (Arellano–Bond) estimator with finite sample variance correction, as proposed by Windmeijer (2005). As is well known, although the two-step GMM estimator is more efficient than the one-step GMM estimator, standard errors in the former are downwardly biased in finite samples (Blundell and Bond 1998). However, Windmeijer (2005) estimates this finite sample bias and provides a better estimate of the standard errors using the two-step GMM estimator. Therefore, it is possible to use the two-step GMM estimator without any constraint.

4.1 Testing for over-identifying restrictions

Since we apply the GMM estimator, we use the Sargan–Hansen test to check for over-identifying restrictions. Under the null hypothesis that all instruments are valid, it can be shown that the test statistics have an asymptotic chi-squared distribution with a degree of freedom equal to the number of over-identifying restrictions. In column (1) of Table 2, the null hypothesis is not rejected. In addition, in column (2), we cannot reject the null hypothesis. Therefore, columns (1) and (2) are valid.

Table 2 Estimation results for electricity demand function

	Industrial sector	Commercial sector
α_1	−0.0341**	−0.0074**
	(0.0013)	(0.0009)
α_2	0.2736**	0.3583**
	(0.0082)	(0.0057)
α_3	0.0202**	0.0012**
	(0.0007)	(0.0002)
α_4	0.0240**	0.0202**
	(0.0014)	(0.0004)
α_5	0.7660**	0.6759**
	(0.0030)	(0.0060)
Number of observations	893	893
J-statistic	46.5897	41.4341
Prob. (*J*-statistic)	0.33	0.54
m-statistic (m_1)	−4.22**	−4.64**
m-statistic (m_2)	−1.71	1.43
Instrument	ED($t-2$)	ED($t-2$)
	EP($t-1$)	EP($t-1$)

Notes: The regressions were estimated using panel data for each prefecture. The estimation method used is the two-step first-difference GMM. Standard errors are given in parentheses under the coefficients. The individual coefficient is statistically significant at the 1 % (**) and 5 % (*) level. The *J*-statistics are obtained from a Sargan test of the over-identifying restrictions for the two-step GMM estimators. The *m*-statistic tests are for the first- and second-order serial correlations (m_1 and m_2). *ED* electricity demand, *EP* electricity price

4.2 Tests for the first- and second-order serial correlations

The second step of our analyses is testing whether the error terms are serially correlated. The GMM estimator requires that the error term u_{jt} is serially uncorrelated. If u_{jt} is serially uncorrelated, then Δu_{jt} is correlated with Δu_{jt-1}, because $\mathrm{Cov}(\Delta u_{jt}, \Delta u_{jt-1}) = \mathrm{Cov}(u_{jt} - u_{jt-1}, u_{jt-1} - u_{jt-2}) = -\mathrm{Cov}(u_{jt-1}, u_{jt-1}) \neq 0$. However, Δu_{jt} may not be correlated with Δu_{jt-k} for $k \geq 2$. The test results on whether Δu_{jt} is correlated with Δu_{jt-k} for $k \geq 2$ can be calculated on the basis of the correlation of the fitted residuals, $\Delta \hat{u}_{jt}$. In other words, we expect to reject the null of no serial correlation for the first-order serial correlation, but not the null hypothesis for the second-order serial correlation. The test statistics are asymptotically standard normal. The *m*-statistics, denoted as m_1 and m_2 in Table 2, test the first- and second-order serial correlations. The model in columns (1) and (2) is appropriate because the null is rejected for the first-order serial correlation and cannot be rejected for the second-order correlation.

4.3 Japan's industrial and commercial electricity demand function

Table 2 presents the estimated coefficients. The variables expressing price, production, and temperature factors meet the sign conditions for both sectors, resulting in statistically significant values.

Table 3 shows price and production elasticities. The short-run price elasticity is −0.034 for the industrial sector and −0.007 for the commercial sector. The long-run price elasticity is −0.146 for the industrial sector and −0.023 for the commercial sector. By contrast, the short-run production elasticity is 0.274 for the industrial sector and 0.358 for the

Table 3 Price and production elasticities of demand

	Industrial sector	Commercial sector
Price elasticity of demand		
Short run	−0.034	−0.007
Long run	−0.146	−0.023
Production elasticity of demand		
Short run	0.274	0.358
Long run	1.169	1.106

commercial sector. The long-run production elasticity is 1.169 for the industrial sector and 1.106 for the commercial sector. These findings demonstrate that price elasticity is considerably lower than production elasticity for both sectors, implying that price elasticity is not a major determinant of electricity demand fluctuations.

Next, using the estimation results, we calculate the contribution of each factor to the inter-annual variability of electricity demand by region for 1990–2010. We hypothesize a long-run equilibrium in a partial adjustment model ($\mathrm{ED}^{*}_{jt} = \mathrm{ED}_{jt} = \mathrm{ED}_{jt-1}$). Given this equilibrium condition, we obtain Eq. (3) and consequently derive the contributions of each factor to the increase in electricity demand at the regional level:

$$\begin{aligned}\Delta \ln(\mathrm{ED})_{jt} &= \frac{\alpha_1}{1-\alpha_5}\Delta \ln\left(\mathrm{Pe}_{jt}/\mathrm{Pz}_t\right) + \frac{\alpha_2}{1-\alpha_5}\Delta \ln X_{jt} \\ &\quad + \frac{\alpha_3}{1-\alpha_5}\Delta \ln \mathrm{COOL}_{jt} + \frac{\alpha_4}{1-\alpha_5}\Delta \ln \mathrm{HEAT}_{jt} + \frac{1}{1-\alpha_5}\Delta u_{jt}.\end{aligned} \tag{3}$$

The left-hand side depicts the growth rate of total electricity demand, which is approximated by the finite difference in the logarithm. The terms on the right-hand side are in the order of price, production, cooling, heating, and other factors.

Table 4 presents the results for the industrial sector. As is shown, industrial sector demand grew marginally in this period by 0.41 % on average. Price, cooling, and

Table 4 Contribution to regional electricity demand in the industrial sector, 1990–2010 (%)

	Growth rate of electricity demand (total)	Price	Production	Cooling degree days	Heating degree days	Margin of error
Hokkaido	1.65	0.22	−1.05	1.02	0.04	1.43
Tohoku	1.07	0.14	−1.08	0.56	0.06	1.39
Tokyo	−0.93	0.11	−1.92	0.28	0.11	0.50
Chubu	−0.22	0.06	−0.28	0.15	0.14	−0.30
Hokuriku	−0.05	0.13	−0.81	0.30	0.12	0.20
Kansai	−0.36	0.09	−1.63	0.10	0.10	0.98
Chugoku	0.75	0.15	0.19	0.15	0.17	0.09
Shikoku	0.99	0.17	−0.33	0.10	0.11	0.93
Kyushu	0.79	0.20	0.11	0.10	0.18	0.19
Okinawa	1.66	0.03	−0.67	−0.05	1.92	0.42
Average	0.41	0.14	−0.75	0.31	0.11	0.60

Notes: The growth rate of electricity demand (total) is the finite difference approximation of the logarithm (annual average). The regional classification is as follows: Hokkaido (Hokkaido), Tohoku (Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, and Niigata), Tokyo (Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa, and Yamanashi), Hokuriku (Toyama, Ishikawa, and Fukui), Chubu (Nagano, Gifu, Shizuoka, Aichi, and Mie), Kansai (Shiga, Kyoto, Osaka, Hyogo, Nara, and Wakayama), Chugoku (Tottori, Shimane, Okayama, Hiroshima, and Yamaguchi), Shikoku (Tokushima, Kagawa, Ehime, and Kochi), Kyushu (Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, and Kagoshima), and Okinawa (Okinawa) heating factors account for a large portion of the increased demand. On the other hand, production factors placed significant downward pressure on demand growth to the extent that they almost eliminated the effect of factors contributing to such growth. In addition, the industrial sector in large metropolitan areas, such as Tokyo, Chubu, and Kansai, reported no growth in electricity demand. Moreover, a factor analysis showed that the production factors had the largest impact in these regions. Further, the hollowing out phenomenon was mainly observed in these areas during the measurement period. These findings suggest a stagnating trend in electricity demand owing to a production decline in the regions.

In contrast, the electricity demand of the commercial sector was rapidly growing nationwide (Table 5). The area with the highest growth rate is Tokyo. Rural regions such as Kyushu, Hokuriku, and Tohoku are also considered high-growth areas. Among the economic factors, production accounts for about 60 % of the increase. This result suggests that electricity demand has markedly increased in the commercial sector because of factors, such as an increase in the floor space used by businesses and developments in office automation across the country.

The electricity rate continued decreasing over time during the measurement period (Table 1), which led to an increase in the demand for power. However, this effect was marginal in both the industrial and commercial sector. These results suggest that the electricity rates had only minimal effects on fluctuations in the demand for power, as the observed price elasticity was extremely low. Therefore, we can infer that the current hikes in the electricity rate will not lead to a significant change in future power demands.

5 Conclusions

This study estimated electricity demand for industrial and commercial uses and is the first to do so separately. Experts in the power market have considered power demand to be inelastic. Given such a view, numerical simulation analyses have often employed low price elasticity (e.g., −0.1 or almost 0); however, these studies have failed to

Table 5 Contribution to regional electricity demand in the commercial sector, 1990–2010 (%)

	Growth rate of electricity demand (total)	Price	Production	Cooling degree days	Heating degree days	Margin of error
Hokkaido	1.59	0.03	0.79	0.04	0.02	0.70
Tohoku	1.71	0.02	1.14	0.02	0.04	0.49
Tokyo	2.04	0.02	1.38	0.01	0.06	0.57
Chubu	1.89	0.01	1.33	0.01	0.08	0.46
Hokuriku	1.79	0.02	1.04	0.01	0.08	0.63
Kansai	1.51	0.01	0.66	0.00	0.07	0.77
Chugoku	1.57	0.02	1.10	0.01	0.09	0.35
Shikoku	1.67	0.03	1.27	0.00	0.06	0.31
Kyushu	1.93	0.03	1.31	0.00	0.10	0.48
Okinawa	1.66	0.01	2.11	0.00	1.16	−1.61
Average	1.74	0.02	1.11	0.01	0.07	0.53

Notes: The growth rate of electricity demand (total) is the finite difference approximation of the logarithm (annual average). The regional classification is as follows: Hokkaido (Hokkaido), Tohoku (Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, and Niigata), Tokyo (Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa, and Yamanashi), Hokuriku (Toyama, Ishikawa, and Fukui), Chubu (Nagano, Gifu, Shizuoka, Aichi, and Mie), Kansai (Shiga, Kyoto, Osaka, Hyogo, Nara, and Wakayama), Chugoku (Tottori, Shimane, Okayama, Hiroshima, and Yamaguchi), Shikoku (Tokushima, Kagawa, Ehime, and Kochi), Kyushu (Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, and Kagoshima), and Okinawa (Okinawa) empirically examine the validity of such assumptions. The demand for electricity after 2000 is difficult to categorize by type of use, owing to the lack of data following the deregulation of retail electric power in that year. Consequently, an economic analysis of electricity demand in the industrial and commercial sectors is problematic. However, this study is unique in that it estimated the electricity demand functions of the industrial and commercial sectors and conducted a statistical analysis using recent data from the statistics report, Energy Consumption Statistics by Prefecture.

Our empirical analysis revealed that the demand for electricity in Japan's industrial and commercial sectors is inelastic to electricity rates. More specifically, the short- and long-run price elasticities of the demand are lower than previous estimates in both sectors. Furthermore, the price elasticity for the industrial and commercial sectors is considerably lower than the production elasticity of electricity demand in both the short and long run. Furthermore, our estimation results for the power demand functions support the assumption that the price elasticity of power demand should be −0.1 or almost 0. This has key implications for policy makers in Japan, that is, a hike in electricity rates can moderately reduce the demand for electricity in the industrial and commercial sectors in both the short and long run and price is not a major factor influencing the demand for electricity.

Analyzing the factors contributing to fluctuations in electricity demand in the industrial and commercial sectors reveals that the declining industrial sector growth rate in large metropolitan areas—such as Tokyo, Kansai, and Chubu—results from decreasing production, not increasing electricity rates. By contrast, the commercial sector is experiencing an increasing demand for electricity and significant growth nationwide. Thus, falling electricity rates have a relatively low impact on the demand growth for power in both the commercial and industrial sectors.

The findings from this study can be used to project future electricity demands. However, this study does not consider electricity demand as a substitute among alternative energy resources, which remains a topic for future analysis, along with the need for highly accurate estimations using a more refined and sophisticated method.

Endnotes

[1]Because the statistics record only total electricity demand, it is difficult to individually grasp the electricity sales volume and power generated and consumed by privately owned power facilities.

[2]For a theoretical background on partial adjustment models, see Nordhaus (1979) and Cuddington and Dagher (2015).

[3]This study does not consider substitution among energy resources such as electricity, city gas, and kerosene. See Kumar et al. (2015) on the substitution of energy in the industrial sector.

[4]Arellano and Bond (1991) estimated the finite sample performance of the proposed procedure by setting $N = 100$ and $T = 7$. However, they adopted a sample of UK companies, in which case increasing the number of companies is possible. By contrast, this study uses prefectural panel data, which means the number of prefectures in Japan is fixed at 47. Nevertheless, by power liberalization to accelerate in the future, we assume a further split of 47 prefectures (e.g., municipal and office level) to capture the power supply area. In this case, it is possible that the number of cross sections significantly

increases. In other words, the number of local governments under which power companies are subject to supply electricity significantly increases. Therefore, it is possible to consider the situation that N (cross section) reaches infinity under some fixed T (time series).

[5]Prefectural climate data are obtained from meteorological centers located in each municipal capital, which is equivalent to prefectural capital data.

Competing interests
The author declares that he has no competing interests.

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