DIFFUSION OF HOUSEHOLD GAS COGENERATION SYSTEMS AND THE ROLE OF INTER-ENERGY COMPETITION IN JAPAN*

Toru Hattori
Socio-economic Research Center
Central Research Institute of Electric Power Industry
2-11-1 Iwado Kita, Komae-shi, Tokyo 201-8511 JAPAN
Tel: +81-3480-2111
Fax: +81-3480-3492
E-mail: toru-h@criepi.denken.or.jp

Abstract

There has been a rapid diffusion of household gas cogeneration systems in Japan since 2003. This phenomenon is at least partly driven by increasing environmental awareness among household customers; however, the role played by competition seems to be important. In order to identify the major economic factors of the diffusion and to shed some light on the role of inter-energy competition, we apply count data regression models for the total number of household gas cogeneration systems installed from 2003–2006 in each service area of gas utility. Our results based on the Negative Binomial regression analysis revealed that a lower price of gas relative to electricity facilitates the diffusion of household gas cogeneration systems, indicating the substitution effect between gas and electricity and the potential for inter-energy competition for household customers under regulation. Since there exists a large price differential among the city gas companies, improving the efficiency of the industry would help accelerate the diffusion. Our results also suggest that municipal utilities may not be actively promoting gas cogeneration systems, and there exist some unobserved regional differences: customers in the western region are more likely to adopt a gas cogeneration system than those in the eastern region.

Keywords: Gas Cogeneration, Inter-energy Competition, Gas Utility, Count Data

JEL Classification: L95

*Work in progress

INTRODUCTION

There has been a rapid diffusion of household gas cogeneration systems (cogeneration systems for residential use that generate 1 kW of electricity with a small gas engine, known as “Eco-will”) in Japan since 2003. This diffusion is at least partly driven by increasing environmental awareness among household customers. However, the role played by competition also seems to be important. Gas utilities are promoting such a cogeneration system to compete with electric utilities that promote “all-electric” homes, intensifying inter-energy competition between gas and electricity for household customers, even though the customers are still regulated in both markets.

Earlier studies analyzed the adoption of industrial cogeneration, including Joskow and Jones (1983), Dismukes and Kleit (1995), Bonilla, et al. (2003), and Bonilla (2007). These studies suggest that industrial customers are responsive to the price of fuel relative to that of electricity in their decision to adopt cogeneration. Some studies analyzed household customers’ choice of highly efficient appliances, including Dubin and McFadden (1984), Revelt and Train (1995), and Train and Atherton (1995). They show that rebate programs are important in inducing these customers to own such appliances. However, few studies have analyzed households’ adoption of cogeneration systems, and the economic factors of the diffusion have not been analyzed quantitatively.

In order to identify the major economic factors of the diffusion and to shed some light on the role of inter-energy competition, we apply a count data regression model for the total number of household gas cogeneration systems (GCS) installed from 2003–2006 in each service area of about two hundred gas utilities. Of particular interest to us is whether the gas price relative to electricity price has a negative impact on the number of cogeneration systems per customer; in other words, we attempt to determine whether the substitution effect between electricity and gas is observed. While it is evident that the substitution effect is observed among industrial customers, it is less clear whether a similar effect is observed among household customers, especially in the early days of its commercialization. Our result would provide policy implications for liberalizing residential electricity and gas markets in the future. We also examine the impact of average household income and some attributes of gas utilities as determinants of the diffusion of GCS.

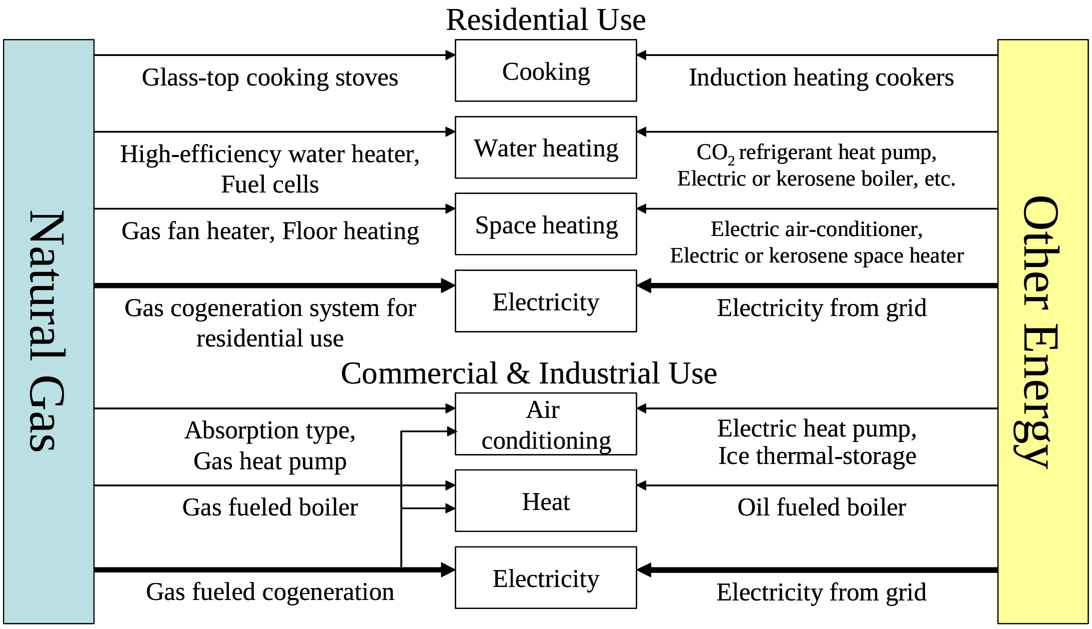
The paper is organized as follows: The next section provides some background of the inter-energy competition between gas and electricity in Japan. The third section presents our empirical model for the diffusion of household gas cogeneration systems in each service area of gas utility and the data set we use. The fourth section explains our estimation method. The fifth section discusses our empirical results. The final section concludes our analysis and points out some topics for future research.

BACKGROUND

In Japan, the electricity retail market and the gas market had long been served separately by distinct utility companies, namely, electric utility and gas utility[1]. The electricity retail market has been dominated by 10 electric utilities. In contrast, there have been more than 200 gas utilities in Japan, although the four largest utilities account for 70% of the market share. All of the electric utilities and the majority of gas utilities are privately owned, but 15% of the gas utilities are municipally owned. By 2000, both gas and electricity retail markets were partially liberalized for industrial and commercial customers: these customers are now able to choose their supplier of gas and electricity. As a consequence, electric utilities and gas utilities are now competing in each of the markets. While the market share of new entrants has been fairly small in both markets, these utilities play an important role as major competitors in each other's market[2]. A large gas utility entered the electricity market through subsidiaries and established itself as a competitive power supplier (known as Power Producers and Suppliers,

[1] To be precise, gas utilities here are the so-called "city gas utilities," who supply natural gas using pipeline networks in designated supply areas. The supply areas of city gas are limited to serving about 40% of residential customers in the country. The rest of the customers are served by LP gas companies who supply propane gas. Competition between electricity and LP gas is beyond the scope of this paper.

[2] However, there have been few instances of direct competition between electric utilities in the liberalized electricity retail market, and between gas utilities in the liberalized gas market.



Source: Japan Gas Association

Figure 1: Status of Inter-Energy Competition as Viewed from Gas Utilities

PPS). Some electric utilities entered the retail and wholesale gas market. In fact, electric utilities account for the largest share of new entrants in the gas market.

In addition to the direct competition in each market after liberalization, electric utilities and gas utilities have long been competing for various types of energy demand. Figure 1 shows how gas utilities are competing with other energy resource providers, especially with electricity. This is a type of inter-modal competition and has been taking place regardless of liberalization[3]. It is noteworthy that this is occurring in the residential sector that is still under regulation in both electricity and gas industries. In fact, inter-energy competition in the residential sector has been intensified in recent years due to some technological advances. The

[3] This type of competition existed in the United States during the 1970s. See Weiss (1975).

electric utilities are actively promoting all-electric homes equipped with induction heating cookers and CO_2 refrigerant heat pumps, totally eliminating the demand for gas. Such all-electric homes have been growing in number, accelerated by technological progress, for instance, in induction heating cookers. It is considered that the residential demand for natural gas has become stable in recent years because of the declining population and increasing number of all-electric homes (Toichi, 2008).

Against the spread of all-electric homes, gas utilities are promoting the gas cogeneration system for residential use as well as in various gas appliances. This cogeneration system generates 1 kW of electricity with a small gas engine and is being sold under the brand name of “Eco-will” since 2003. In this system, water is heated by exhaust heat recovered from the engine and stored in a water tank. The stored hot water is used not only for hot water supply but also for space heating, thereby helping conserve energy. The energy utilization rate of the entire system is said to be approximately 85%[4].

[4] See Takahashi (2006).

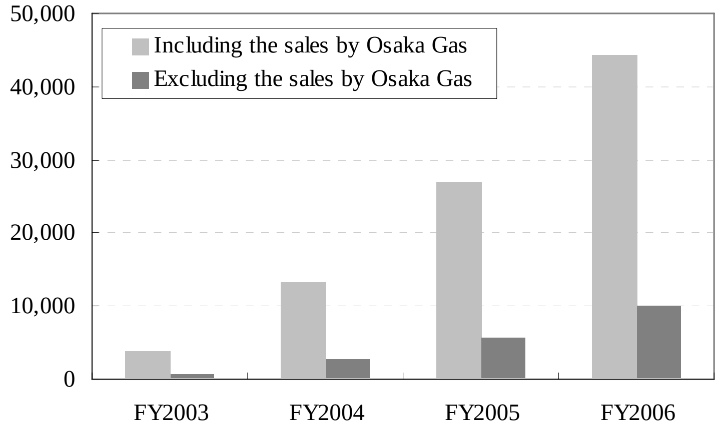


Figure 2: The Number of Installed GCS for Households

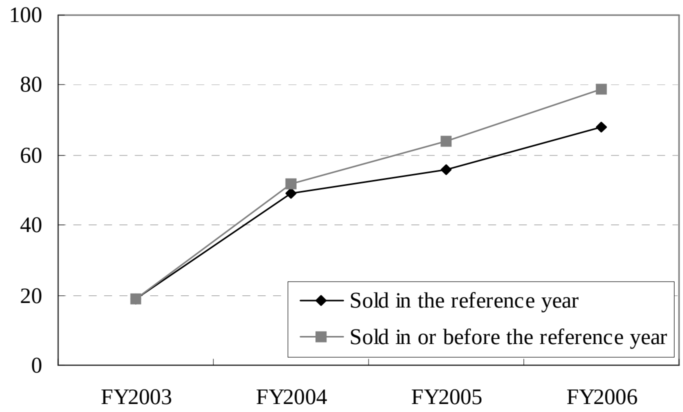


Figure 3: The Number of Gas Utilities whose Residential Customers Installed GCS

The number of households using this gas cogeneration system has increased in recent years, as shown in Figure 2, despite the high natural gas prices. The gas utility industry has set a target of 175,000 households by 2010. At this moment, most of them are sold by Osaka Gas, the second largest gas utility in the country, accounting for three quarters[5]. However, many other

[5] The largest gas utility, Tokyo Gas, had focused on marketing a fuel cell cogeneration system; however, in 2006, it changed the strategy to shift to promoting Eco-will.

gas utilities started to sell it, and the number of gas utilities whose residential customers have ever installed it is also increasing, as shown in Figure 3. While the total demand for electricity replaced by such systems is still fairly small relative to the total electricity demand, electric utilities are more or less conscious of inter-energy competition. The diffusion of the household gas cogeneration system may well be threatening the electric utilities in the future, depending on the future technological progress.

MODEL

We consider a statistical model to examine the determinants of the total number of household gas cogeneration systems installed by supply area of gas utilities through 2006. The model we propose is as follows:

$$NHGCS = f\,(NCUST, RPRICE, HINC, PCTRES, MUNI, WEST, CICS, PCTNEW, PCTSGL) \qquad (1)$$

The dependent variable is the number of household GCS installed from 2003 through 2006. The explanatory variables are all for 2005. Note that ours is a cross-section analysis. Although we exclude the two largest gas companies from our sample as they are extremely large relative to the rest of the utilities, there remain some differences in size among the utilities. We include the logarithm of the number of household customers (*NCUST*) based on the number of meters installed, to control for such a difference.

Of particular interest in this study is examining whether the substitution between electricity and gas explains a part of the differences in the level of diffusion of household GCS. A household's decision to install GCS would depend on the future energy cost savings. As the price of gas relative to the price of electricity is lower, the average number of GCS installed in the area will be increased. Therefore, we include the relative price of gas to electricity for household customers (*RPRICE*) as an explanatory variable. The prices of gas and electricity are unit prices, that is, the total revenue from sales to residential customers is divided by the sales volume. If the coefficient on this variable is negative, the substitution effect accounts for a part of the diffusion of GCS. There are some price differentials among gas companies.

The decision to install GCS would also depend on the burden of initial cost. Virtually, there is no regional difference in the initial cost of GCS; it effectively depends on the level of income[6]: as the average household income is higher, it is likely that more customers install the GCS. Thus, we include the average household income (*AHINC*), calculated as the total taxable

[6] There may be some changes in initial cost over time.

income divided by the number of households in local municipalities in the supply area[7].

We also consider several attributes of gas utilities that may have some impact on the diffusion of GCS. Given the different structure of demand, gas utilities behave differently in promoting GCS for households. In order to account for structural difference by supply area, we include the share of household gas consumption (*PCTRSD*). The expected sign of the coefficient is positive. Municipally owned companies may not behave in the direction of maximizing profit, and would be less aggressive in promoting GCS. Thus, we also include the dummy variable for municipally owned gas companies (*MUNI*) to account for a possible difference in incentive to promote GCS. An earlier study based on a questionnaire survey showed that the preference for high efficiency appliances is higher in Kansai Area (in the western region) than in Tokyo Area (in the eastern region). In order to account for other unobserved regional differences, we include a dummy variable (*WEST*) taking unity if the supply area is in the western region[8]. We also take into account the past experience in installing GCS for commercial and industrial customers, since such an experience might help in promoting GCS for household customers. We include a dummy variable (*CIGCS*) taking unity if the gas utility had some industrial or commercial customers installing GCS before 2003.

---

[7] The supply area of a gas utility may include more than two municipal areas. In that case, we choose the municipality in which the headquarters of the utility is located.

[8] The eastern region includes the areas of Hokkaido, Tohoku, and Kanto.

The likelihood of installing a household gas cogeneration system would also depend on the residential characteristics. First, GCS is more likely to be installed in a newly built house. Thus, we include the number of newly built residential houses per total number of households (*PCTNEW*). Second, GCS is more likely to be installed in a single-family home rather than in multi-family buildings. We include the number of single-family homes per total number of residential houses (*PCTSGL*). The statistics on residential houses are not available for local municipalities with small populations (towns and villages), and are only available for 2003.

The data are all collected from publicly available sources. The descriptive statistics are shown in Table 1.

Table 1: Descriptive Statistics

	Mean	Standard Deviation
ln *NCUST* (the Number of Customers)	9.374	1.485
ln *RPRICE* (Relative Price)	2.043	0.251
ln *AHINC* (Average Household Income)	1.154	0.211
PCTRSD (Share of Residential Demand)	0.566	0.212
PUBLIC (Dummy for the Publicly Owned)	0.165	0.372
WEST (Dummy for the Western Region)	0.388	0.489
CIGCS (Dummy for the C&I Cogeneration)	0.316	0.466
PCTNEW (Share of Newly-built House)	0.021	0.011
PCTSGL (Share of Single-family House)	0.582	0.116

ESTIMATION

Since our dependent variable takes only non-negative integer values, we estimate the equation by using the count data model to account for these characteristics. With the Poisson regression model, we assume that the dependent variable (*Y*) follows a Poisson distribution with the mean $\mu_i = \exp(X_i'\beta)$, where *X* is a vector of the explanatory variables and β is a vector of the parameters to be estimated. The probability density function of the Poisson distribution is

$$f(Y_i) = \frac{\exp(-\mu_i)\mu_i^{Y_i}}{Y_i!}, \quad Y_i = 0, 1, 2, \ldots \tag{2}$$

The parameters of this basic Poisson regression model can be estimated by the method of maximum likelihood.

The restrictive assumption of the Poisson regression model is that the variance equals the mean, that is:

$$E(Y_i|X_i) = Var(Y_i|X_i) = \exp(X_i'\beta)\ . \tag{3}$$

A large number of empirical studies suggest the occurrence of over-dispersion, that is, the variance is greater than the mean. In order to relax this assumption, we employ the negative binomial regression model. With this model, we assume that the dependent variable (Y) follows a Negative binomial distribution with the mean $\mu_i = \exp(X_i'\gamma)$, where γ is a vector of the parameters to be estimated. The probability density function of the negative binomial distribution is as follows:

$$f(Y_i;\mu_i,\theta) = \frac{\Gamma(Y_i+\theta)}{Y_i!\Gamma(\theta)}\left(\frac{\theta}{\theta+\mu_i}\right)^{\theta}\left(\frac{\theta}{\theta+\mu_i}\right)^{Y_i}, \quad Y_i = 0, 1, 2, \ldots \qquad (4)$$

where $\Gamma(\cdot)$ represents the gamma function, and θ is the inverse of the dispersion parameter. The conditional variance in this negative binomial model is given by the following:

$$Var(Y_i | X_i) = \mu_i(1+\alpha\mu_i) \qquad (5)$$

where α is the dispersion parameter ($\alpha = \theta^{-1}$). When $\alpha = 0$, the negative binomial distribution collapses to the Poisson distribution, and thus, we can test the hypothesis of the absence of over-dispersion by checking the statistical significance of this parameter. The negative binomial model is also estimated by the method of maximum likelihood.

RESULTS

Parameter estimates of the negative binomial regression model of equation (1) are shown in column (A) of Table 2. The statistically significant estimate of the dispersion parameter indicated an over-dispersion, favoring the negative binomial model over the Poisson regression model. The parameters of the two variables associated with residential characteristics (*PCTNEW*, *PCTSGL*) are not statistically significant. Since including these variables precludes some observations, we estimate the model without these variables for our original sample. The result is indicated in column (B) in Table 2. There are no major differences in other parameter estimates. The parameter on the total number of customers is very close to unity; the number of installed household GCS increases in proportion to the number of customers, holding other things constant. The parameter on the average household income is positive as expected, but statistically insignificant. Instead of average household income, we used a fraction of middle-aged population as a proxy of income level; however it, too, was insignificant. The share of household customers' demand is statistically significantly positive as expected. The municipal ownership is statistically significantly negative, suggesting a weaker incentive to promote GCS among municipally owned utilities. The dummy variable for the western region is statistically significantly positive, consistent with the result of an earlier study (Nakajima, et al. 2006). Eco-will was first sold by Osaka gas, the second largest utility in the country located in

Table 2: Parameter Estimates of the Negative Binomial Regression Model

	A	B
Constant	–12.903***	–8.828***
	(4.019)	(2.741)
ln *NCUST* (the Number of Customers)	1.260***	1.077***
	(0.175)	(0.138)
ln *RPRICE* (Relative Price)	–2.038**	–2.332**
	(1.032)	(0.964)
ln *AHINC* (Average Household Income)	1.868	1.614
	(1.198)	(0.989)
PCTRSD (Share of Residential Demand)	1.783**	2.097**
	(0.907)	(0.852)
PUBLIC (Dummy for the Publicly Owned)	–2.348***	–2.425***
	(0.561)	(0.524)
WEST (Dummy for the Western Region)	2.176	2.327***
	(0.378)	(0.366)
CIGCS (Dummy for the C&I Cogeneration)	1.342***	1.420***
	(0.508)	(0.475)
PCTNEW (Share of Newly-built House)	–12.801	
	(29.623)	
PCTSGL (Share of Single-Family House)	3.424	
	(2.420)	
(Dispersion Parameter)	3.371***	3.535***
	(0.522)	(0.538)
Log-likelihood	–392.5	–409.0
# of observation	182	206

Standard errors in parentheses.

***, **, and * are significant at the greater than 1%, 5%, and 10% levels of significance, respectively.

the western region. Since the largest gas utility in the country, Tokyo gas, located in the eastern region, did not promote Eco-will until the end of 2005, there has been a lack of publicity in the eastern region on a whole. The past experience with commercial and industrial cogeneration is statistically positive as expected.

The parameter on the relative price of gas to electricity is statistically significantly negative (at the 5% level of significance), indicating that the substitution effect explains a part of the diffusion of household GCS. Inter-energy competition has a role to play in facilitating energy efficient equipments among household customers. Based on the estimated parameter on the relative price, we examined the impact of changing the gas price on the difference in the number of GCS installed per customers at the mean in the range of the actual gas prices. The estimated impact (0 at the mean) is shown in Figure 4. The actual price differential leads to a difference of 2.5 units of household GCS. Moreover, we simulated the impact of efficiency gains in the industry on the total number of GCS installations. Since there is a large price differential among gas utilities, improving the efficiency in the future would be plausible. The efficiency of the industry will be improved if the less efficient gas companies with higher prices reduce their price. To examine the impact of such an efficiency gain on the diffusion of GCS, we consider that efficiency gains of 1% imply that the highest price will be lowered by 1% and the gas companies whose price is higher than that level would all reduce the price to the (new) highest price. With several levels of such efficiency gains, we computed the total predicted number of household GCS, keeping other things unchanged (including electricity price). The results of this exercise are shown in Figure 5, and they indicate that 40% of efficiency gains as defined above lead to an approximately 10% increase in the number of household GCS.

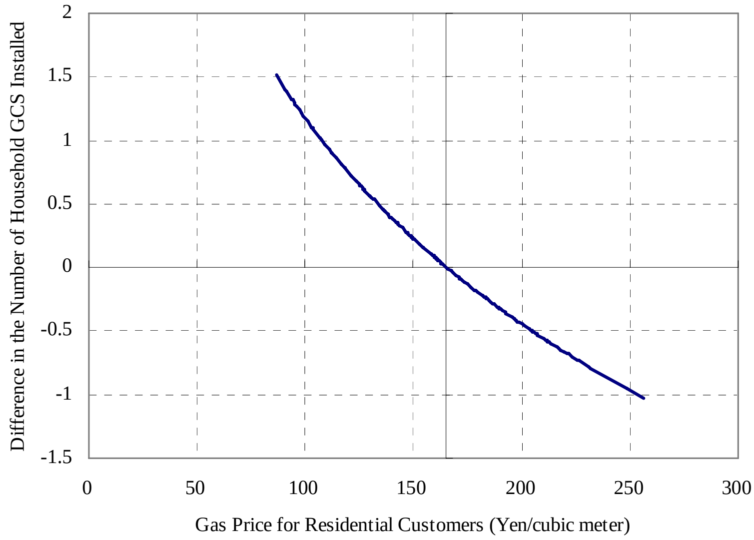


Figure 4: Impact of Gas Prices on the Installed Number of GCS for Households

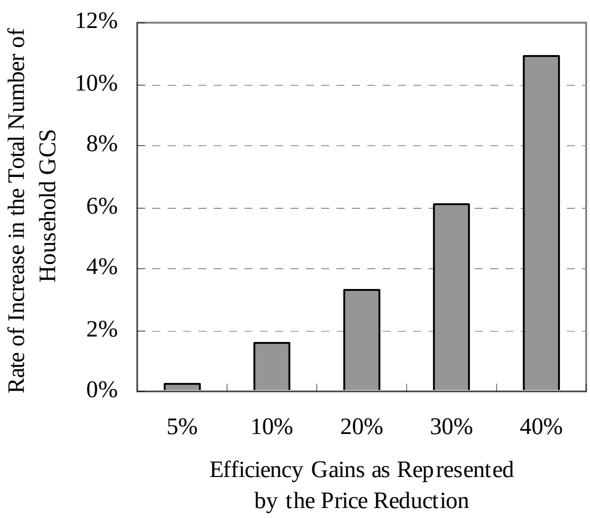


Figure 5: The Impact of Efficiency Gains in the Industry on the Total Number of GCS Installed

CONCLUSION

We estimate the regression model for the number of household gas cogeneration systems in each supply area to examine the determinants of the diffusion of such systems. Our results based on the negative binomial regression model revealed that a lower price of gas relative to electricity facilitates the diffusion of household gas cogeneration systems, indicating the substitution effect between gas and electricity and the potential for inter-energy competition for household customers under regulation. Since there exists a large price differential among the city gas companies, improving the efficiency of the industry would help accelerate the diffusion. Our results also suggest that municipal utilities may not be actively promoting gas cogeneration systems, and that there exist some unobserved regional differences: customers in the western region are more likely to adopt gas cogeneration systems than those in the eastern region.

As a future research, an econometric analysis utilizing the feature of panel data would be useful for investigating the changes over time. With the commercialization of the fuel-cell, the market for household cogeneration would be evolved in the near future. It will be interesting to examine if such a new technology would further accelerate inter-energy competition.

ACKNOWLEDGEMENT

This research was partially supported by the Ministry of Education, Science, Sports and Culture, a Grant-in-Aid for Young Scientists (B), No.19730213. The views expressed in this paper do not represent those of the author's affiliation.

REFERENCE

Bonilla, D. (2007). "Fuel Price Changes and the Adoption of Cogeneration in the U.K. and Netherlands," *Electricity Journal*, 20 (7), 59-71.

Bonilla, D., A. Akisawa, and T. Kashiwagi (2006). "Modelling the adoption of industrial cogeneration in Japan using manufacturing plant survey data," *Energy Policy*, 31, 895-910.

Dismukes, D.E. and A.N. Kleit (1995). "Cogeneration and Electric Power Industry Restructuring," *Resource and Energy Economics*, 21, 153-166.

Dubin, J.A. and D.L. McFadden (1984). "An Econometric Analysis of Residential Electric Appliance Holdings and Consumption," *Econometrica*, 52 (2), 345-362.

Joskow, P.L. and D.R. Jones (1983). "The Simple Economics of Industrial Cogeneration," *Energy Journal*, 4 (1), 1-22.

Nakajima, M., T. Ida, and S. Kinoshita (2006). "Kateiyou Enerugi Juyo No Konjointo Bunseki (Conjoint Analysis of Household Energy Demand)," *Koueki Jigyou Kenkyu* (Journal of Public

Utility Economics), 58 (2), 23-33. (in Japanese)

Revelt, D. and K. Train (1995). “Mixed Logit with Repeated Choices: Households’ Choices of Appliance Efficiency Level,” *Review of Economics and Statistics*, 80 (4), 647-657.

Takahashi, H. (2006). “GASEX2006 Country Report −City Gas Industry in Japan−,” presented at GASEX2006, Beijing.

Toichi, T. (2008). “Japan’s Energy Challenges and the Role of Gas,” Gastech 2008, Bangkok.

Train, K.E. and T. Atherton (1995). “Rebates, Loans, and Customers’ Choice of Applicance Efficiency Level; Combining Stated- and Revealed-Preference Data,” *Energy Journal*, 16 (1), 55-69.

Weiss, L.W. (1975). “Antitrust in the Electric Power Industry,” in Phillips, A. (ed.) *Promoting Competition in Regulated Markets*, The Brooking Institution, Washington D.C., 135-173.