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Detecting collusion in retail electricity markets: Results from Japan for 2005 to 2010

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ABSTRACT

This analysis investigates whether the Cournot model of imperfect competition holds true in the Japanese retail electricity market, using monthly data over the period 2005 to 2010. One concern about electricity markets that are open to retail competition is the potential for collusive behavior of some suppliers. A revealed preference test of the Cournot model is conducted, using market price and firm output data, as in Carvajal et al. (2013). The application of the revealed preference test to the retail electricity market in Japan indicates that the possibility of collusive behavior among the incumbents cannot be excluded.

1. Introduction

For countries that have liberalized the electricity supply market, the removal of restrictions on consumer choice of suppliers is a policy option to promote retail competition. For example, all consumers in France, Germany, Spain, Scandinavia, the United Kingdom, and more than a dozen states in the United States are allowed to choose their electricity supplier (Blumsack and Perekhodtsev, 2009). One of the concerns about competition in the retail electricity market is the exercise of market power, which deviates electricity prices from competitive levels. This concern is substantial because collusion among suppliers would cause as much efficiency loss as in a monopoly if these suppliers succeeded in maximizing their joint profits. For the retail electricity market to be competitive, regulators need to monitor the market and detect any sign of collusive behavior among suppliers.

Empirical studies on market power often employ information related to the cost functions of suppliers and demand functions of consumers in the industry (Bresnahan, 1989; Jacquemin and Slade, 1989). This information on cost and demand functions is used to estimate the markup of each supplier, which indicates how much market power it exerts on the industry. For instance, the literature on wholesale electricity markets examines the markup of suppliers using data on sellers' bids (Wolfram, 1998; Bushnell et al., 2008; Hortaçsu and Puller, 2008; Reguant, 2014). However, it is often difficult to measure the markup of suppliers because of the lack of reliable data associated with cost and demand functions.

Based on the revealed preference tests of demand theory in Afriat (1967), Famulari (1995), and Varian (1982), Carvajal et al. (2013a) developed an empirical procedure that tests if the Cournot model holds true in an industry that lacks information on cost and demand functions. Assuming convexity and no shift in the cost function of each supplier, this test examines the first-order condition for profit maximization of suppliers, which is derived from the Cournot model of imperfect competition. The requirement of data for this test is minimal; that is, it requires only the market price and each firm's output for at least two periods. The test can be implemented without any parametric assumptions on cost and demand functions in the industry. The rejection of the Cournot model provides robust indication of collusive behavior causing substantial loss of economic efficiency. The acceptance of the Cournot model indicates that there is no collusion among suppliers; however, there remains some efficiency loss because of the imperfect competition that is described by Cournot or a conjectural variations equilibrium. Although the test of the Cournot model cannot measure the ease of colluding in the industry, the test could serve as a basis for further analysis through the use of a more elaborate model for regulators.

This research involves applying the test of the Cournot model developed by Carvajal et al. (2013a), to the retail electricity market in Japan over fiscal years 2005–2010 (i.e., from April 1, 2005, to March 31, 2011). During this period, consumers contracting 50 kW (kW) or more could choose any supplier in the retail market, whereas consumers contracting less than 50 kW continued to receive electricity supply from the local utility that was privately owned and vertically integrated. Because ten local utilities were dominant in the Japanese retail electricity market, collusion among these incumbents, if any, may have caused substantial loss of efficiency in the market. Unfortunately,

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reliable information on cost functions of suppliers and demand functions of consumers is difficult to obtain for retail electricity markets, and publicly available data are confined to those on the market price and each firm's output. The lack of sufficient data for empirical investigation, accompanied by the presence of dominant retailers, is the main motivation to conduct this study on possible collusive behavior among incumbents in the Japanese retail electricity market, using the test of the Cournot model developed by Carvajal et al. (2013a).

To the best of the author's knowledge, this analysis is the first attempt to apply the test of the Cournot model developed by Carvajal et al. (2013a), to the retail electricity market. In contrast with wholesale electricity markets, there has been little empirical literature on the liberalized retail electricity market. Salies and Price (2004) evaluated retail electricity competition in the United Kingdom and found that incumbents exerted considerable market power in the retail segment. Su (2015) estimated the impact of retail competition on consumers in the U.S. retail market, finding that only residential customers reaped the benefits of lower prices. Hortaçsu, Madanizadeh, and Puller (2017) examined the choice of suppliers in the Texas residential electricity market and found that consumers would seldom search for alternatives because of search frictions and inattention. Further, there has been some theoretical analysis and policy discussion on the regulatory issues associated with retail electricity markets (Joskow and Tirole, 2006; Blumsack and Perekhodtsev, 2009; Defeuilley, 2009; Littlechild, 2009; Pollitt and Haney, 2014). This analysis focuses on the collusive behavior of suppliers, which has not been empirically investigated in the available literature on retail electricity markets.

The article proceeds as follows. Section 2 describes the test of the Cournot model developed by Carvajal et al. (2013a). Section 3 summarizes how the Japanese retail electricity market was opened to competition. Section 4 describes the data on electricity prices and output of electricity retailers in Japan. The empirical results of the test of the Cournot model are presented in Section 5. Finally, Section 6 concludes the article. The Appendix section provides an illustrative example of the algorithm that tests the dataset for the Cournot model. The supplementary materials provide additional test results.

2. Test procedure

2.1. Cournot rationalizability

Consider a retail electricity market where the retail price of electricity, P_t, and the output of supplier i, $Q_{i,t}$, are observed at time t by a regulator of the market who wishes to examine whether the suppliers in the market engage in collusive behavior. Supplier i's cost function, $\overline{C}_i$, is assumed to be unobservable, convex, twice differentiable, and fixed over T periods. The aggregate output of the retail electricity market, Q_t, is given by the summation of each supplier's output over I suppliers. The inverse demand function of the retail market at time t, $\overline{P}_t(Q_t)$, is assumed to be unobservable, twice differentiable, and downward sloping (i.e., $\overline{P}_t'(Q_t) \leq 0$). It is further assumed that $\overline{P}_t(Q_t) = P_t$.

The regulator can test whether the suppliers simply play a static Cournot game using the data related to the market price of electricity and the output provided by each supplier over T periods. Unlike the information on market demand and firms' cost functions, which is necessary for estimating the Cournot model, the data on market price and output are readily available. If each observation can be explained by a Cournot equilibrium that arises from a different market demand function under a fixed cost function for each supplier, the dataset is "Cournot rationalizable" (Carvajal et al., 2013a). Antitrust authorities who consider the Cournot equilibrium as a benchmark do not need to explore the possibility of collusion, which requires substantial regulatory costs, if the dataset turns out to be Cournot rationalizable.

For the observed data on market price and output over T periods to be consistent with a Cournot model with convex cost functions, the following condition, which is referred to as "the common ratio property," needs to hold for every t in the retail electricity market (Carvajal et al., 2013a):

$$\frac{P_t - \delta_{1,t}}{Q_{1,t}} = \frac{P_t - \delta_{2,t}}{Q_{2,t}} = \cdots = \frac{P_t - \delta_{I,t}}{Q_{I,t}} \geq 0, \tag{1}$$

where the unobserved marginal cost for supplier i at time t, $\delta_{i,t}$, is defined by the first-order condition for supplier i to maximize his profit, given the output of the other suppliers:

$$\delta_{i,t} = Q_{i,t}\overline{P}'_t(Q_t) + \overline{P}_t(Q_t). \tag{2}$$

Further, the following inequality, referred to as "the co-monotone property," needs to hold for every i over T periods if the dataset is Cournot rationalizable (Carvajal et al., 2013a):

$$(\delta_{i,k} - \delta_{i,t})\,(Q_{i,k} - Q_{i,t}) \geq 0 \tag{3}$$

Inequality (3) holds because the convexity of the differentiable cost function that is fixed over T periods indicates $\delta_{i,k} \geq \delta_{i,t}$ whenever $Q_{i,k} > Q_{i,t}$. The set of the observed price and output is a unique Cournot equilibrium if and only if the array $\{\delta_{i,t}\}$ becomes nonnegative and satisfies (1) and (3) for all suppliers over T periods. If the array $\{\delta_{i,t}\}$ violates (1) or (3), the data on price and output cannot be explained as a Cournot outcome and suppliers may have been exhibiting collusive behavior.

2.2. Algorithm testing for Cournot rationalizability

The upper bound algorithm in Carvajal et al. (2013a) allows regulators to test whether the array $\{\delta_{i,t}\}$ satisfies both the common ratio property in (1) and the co-monotone property in (3) for I suppliers over T periods. To begin with, $\delta_{i,t}^{ub}$, which denotes the upper bound of $\delta_{i,t}$ in the first step of the algorithm, is set equal to P_t for all (i, t). Because the market price gives the highest possible marginal cost, the common ratio property holds. However, it is not clear at this stage whether the co-monotone property holds.

Then, in the second step, the upper bound of $\delta_{i,t}$ is adjusted downward to $\gamma_{i,t}^{ub}$, which is given by

$$\min\left\{\min_{\{t' \neq t: Q_{i,t'} > Q_{i,t}\}}\{\delta_{i,t'}^{ub}\},\quad \delta_{i,t}^{ub}\right\}.$$

This adjustment of the upper bound makes the co-monotone property hold; however, the common ratio property does not necessarily hold this time. If $\{t' \neq t: Q_{i,t'} > Q_{i,t}\}$ is an empty set, then set

$$\min_{\{t' \neq t: Q_{i,t'} > Q_{i,t}\}}\{\delta_{i,t'}^{ub}\} = \infty.$$

In the last step, the upper bound of $\delta_{i,t}$ is again adjusted downward to $\gamma_{i,t}^{ub'}$, which is given by $P_t - \Lambda_t Q_{i,t}$, where

$$\Lambda_t \equiv \max_j \left\{\frac{P_t - \gamma_{j,t}^{ub}}{Q_{j,t}}\right\}.$$

This adjustment of the upper bound makes the common ratio property hold; however, the co-monotone property does not necessarily hold.

After the last step of the algorithm, if any $\gamma_{i,t}^{ub'}$ becomes negative, the algorithm stops, and the dataset is not Cournot rationalizable. If $\delta_{i,t}^{ub}$ is equal to $\gamma_{i,t}^{ub'}$ for all (i, t) after the last step, the algorithm stops, and the dataset is Cournot rationalizable. Else, we set $\delta_{i,t}^{ub} = \gamma_{i,t}^{ub'}$ for all (i, t), and go back to the second and last steps of the algorithm where the upper bound is first lowered using the co-monotone property and then lowered again using the common ratio property.

Given a Cournot rationalizable dataset, the array $\{\delta_{i,t}^{ub}\}$ is decreasing in the number of iteration and converges to some limit after no more than T iterations, and both the common ratio and the co-monotone properties hold at the limit (Carvajal et al., 2013a, Theorem 5). The appendix provides an illustrative example that shows how the upper bound algorithm works for the dataset comprising two firms and four periods.

2.3. Tests for collusion

Regulators can detect the possibility of collusion in the retail electricity market by applying the upper bound algorithm, as explained in Section 2.2, to the dataset on retail electricity prices and output, which are often publicly available. For example, electricity suppliers exhibit behavior that seems collusive when they simultaneously reduce output, thereby raising the market price of electricity. In this case, the upper bound algorithm enables the regulator to check for Cournot rationalizability of the dataset.

However, it must be noted that the common ratio and co-monotone properties are also satisfied at the conjectural variations equilibrium. At the conjectural variations equilibrium, the following property holds for all t:

$$(P_t - \delta_{1,t})/(\theta_1 Q_{1,t}) = (P_t - \delta_{2,t})/(\theta_2 Q_{2,t}) = \ldots = (P_t - \delta_{I,t})/(\theta_I Q_{I,t}) > 0, \quad (4)$$

Where θ_i denotes supplier i's conduct parameter that indicates the supplier's belief about how much the aggregate output Q_t changes with a change in the supplier's output. The Cournot model holds if $\theta_i = 1$ for all i. If the array $\{\theta_i\}$ satisfies (4), $\{\lambda\theta_i\}$ also satisfies (4) for any $\lambda > 0$. Thus, it is impossible to test the hypothesis that $\theta_i = 1$ by merely using the upper bound algorithm. However, the algorithm enables the regulator to test if θ_i is the same across all suppliers (i.e., the symmetry of market interactions). This implies that the rejection of Cournot rationalizability by the upper bound algorithm not only excludes the Cournot equilibrium, but also the conjectural variations equilibrium with symmetric market power. Thus, if the dataset fails the test, it could be highly indicative of collusive behavior by the suppliers. On the other hand, the acceptance of Cournot rationalizability by the algorithm indicates that the dataset is consistent with the conjectural variations equilibrium as well as the Cournot equilibrium.

3. The retail electricity market in Japan

The liberalization of the Japanese retail electricity market began in March 2000. Prior to that, all consumers were obliged to purchase electricity from a vertically integrated, privately owned utility in their regions. Because of a global trend toward liberalization and criticism of high electricity prices, the Japanese retail electricity market was opened to competition; that is, consumers contracting 2000 kW or more could choose any retailer, beginning from March 2000. These consumers included large factories, office buildings, and department stores.

The liberalized retail electricity market was extended to consumers contracting 500 kW or more in April 2004 and to those contracting 50 kW or more in April 2005. Consumers contracting 50 kW or more belonged to the commercial or industrial sectors, and their electricity consumption accounted for approximately two-thirds of the entire retail electricity consumption in Japan. This analysis focuses on the retail market associated with consumers contracting 50 kW or more.

The retail electricity market for consumers contracting less than 50 kW (i.e., households and small businesses) was subject to regulation until March 2016. The regulator combined cost-of-service regulation with yardstick regulation to control the retail prices set by each utility. The regulator first defined three categories regarding the productivity of the retail electricity business: "greater than average," "average," and "below average." The regulator then determined each utility's productivity category through a comparative evaluation. The incumbents labeled as "greater than average" could set their electricity prices equal to the average costs. However, those labeled as "average" were obliged to apply the prices that were lower than their average costs by 1%, and those labeled as "below average" were obliged to apply the prices that were lower than their average costs by 2%. Because the price that one utility could charge depended on the productivity of other utilities, yardstick regulation provided each utility with incentives for enhancing its productivity relative to others. Since April 2016, all consumers have been able to choose their retailer, and price regulations have been removed from the retail electricity market.

As of September 2016, more than 300 new entrants were registered as retail electricity suppliers in Japan. In April 2016, the Tokyo Electric Power Company, the largest utility in Japan, legally divided its business into three segments: generation; high voltage, long-distance transmission and regional distribution; and retail services. This vertical separation of the business across the remaining nine utilities is expected by 2020. While electricity generation and supply have been opened to competition, the transmission and distribution sectors will continue to local monopolies. Although the number of new entrants has steadily increased after liberalizing the retail market, the market share of the new entrants is fairly small compared to the incumbents (i.e., ten utilities). In 2015, the new entrants held approximately 7.6% of the retail electricity market share that was opened to competition. Retailers procure electricity from generators at the Japan Electric Power Exchange (JEPX), the wholesale market that began to operate in 2005. In addition, they procure electricity through bilateral contracts with generators.

The increasing number of new entrants is expected to promote competition in the retail electricity market in Japan. However, the small market share of new entrants raises concerns about the market power of the incumbents. The collusive behavior of the incumbents acting in concert to maximize joint profits, in particular, raises serious concerns about the loss of economic efficiency in the retail electricity market. To detect the possibility of collusion among the incumbents, the test of the Cournot model in Section 2 is applied to the dataset on the market price of electricity and the output of each incumbent after the liberalization of the retail electricity market in Japan. Because of the small market share of the new entrants, all the new entrants are assumed to be a competitive fringe, which cannot exert any market power, in the analysis.

4. Data

The test of the Cournot hypothesis is based on monthly data for the period starting from fiscal year 2005–2010, in which the liberalized retail market comprised customers whose contracted amounts of electricity were equal to or more than 50 kW. The test was not applied to the period after fiscal year 2010, because structural shifts in the cost functions of the incumbents, which violate the assumption of the test, possibly occurred after the East Japan earthquake in March 2011. After the earthquake, all nuclear power plants stopped their operations. This forced the then vertically integrated utilities to rapidly increase fossil-fired generation, which may have substantially affected costs.

The monthly data on the sales of electricity to retail customers were obtained from *Electricity Survey Statistics* (JANRE, various years). These data are available for the ultra-high voltage market and the high-voltage market from April 2005. Data were obtained for a period of 72 months (i.e., from April 2005 to March 2011) for 10 incumbent suppliers of electricity, thus yielding 720 firm-month observations. New entrants were excluded from the Cournot test, because their firm size was extremely small compared to that of the incumbents.

Figs. 1 and 2 show each firm's share of annual retail electricity sales in the ultra-high voltage and high-voltage markets during fiscal years 2005–2010. Okinawa exhibited no demand for the high-voltage market and it was excluded from Fig. 2. The incumbents were dominant in both the retail electricity markets. Among the incumbents, Tokyo, Chubu, and Kansai exhibited large shares in these markets. These incumbents were located in metropolitan areas. Despite the low portion of retail sales of new entrants in these markets, their share increased slightly during fiscal years 2005–2010 for both the markets. The size of the high-voltage market exceeded that of the ultra-high voltage market. Over fiscal years 2005–2010, the annual electricity consumption in the high-voltage market increased from 326 billion kilowatt-hours (kWh) to

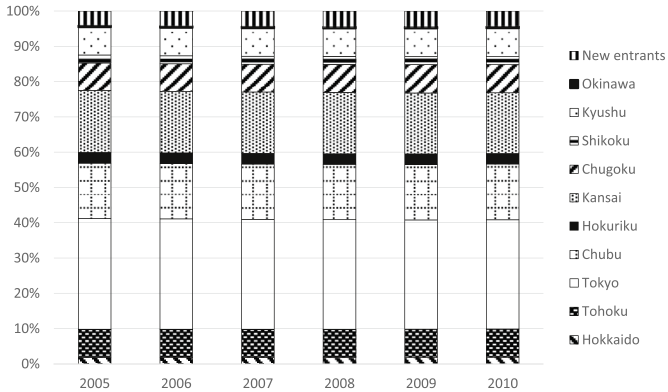

Fig. 1. Annual sales share of each electricity retailer in the ultra-high voltage market over the period 2005–2010.
Source: Japan Agency for Natural Resources and Energy, *Electricity Survey Statistics*.

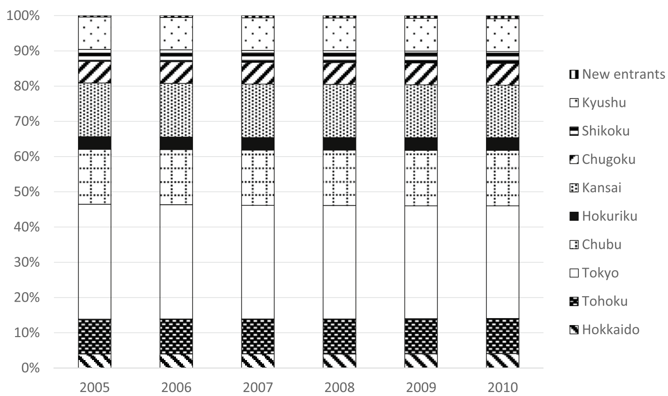

Fig. 2. Annual sales share of each electricity retailer in the high-voltage market over the period 2005–2010.
Source: Japan Agency for Natural Resources and Energy, *Electricity Survey Statistics.Note*: Okinawa exhibited no demand for the high-voltage market and it was excluded from Fig. 2.

333 billion kWh, while that in the ultra-high voltage market increased from 237 billion kWh to 247 billion kWh.

The monthly data on retail prices of electricity for the ultra-high voltage and high-voltage markets were obtained from *the Corporate Goods Price Index* (BOJ, various years). The data comprise the price indices for ultra-high voltage electricity, industrial high-voltage electricity, and commercial high-voltage electricity. The industrial and commercial high-voltage electricity price indices were aggregated into a single price index for the high-voltage electricity market. While aggregating these indices, monthly high-voltage electricity consumption of the industrial sector and that of the commercial sector were used as weights. The data on industrial and commercial electricity consumption, which were available only at the national level from April 2005 until March 2011, were obtained from *Electricity Demand Survey* (JANRE, various years). Each electricity price index was divided by the price index averaged over all corporate goods.

Fig. 3 presents the monthly retail electricity price index relative to the monthly price index of all corporate goods over fiscal years 2005–2010. The base year for each price index is 2005. Fig. 3 indicates that for both the ultra-high voltage and high-voltage markets, electricity prices rapidly increased at the beginning of 2009. The rapid increase in retail electricity prices, though not as much as at the beginning of 2009, was also observed in the middle of 2010. If these increased prices are irrelevant to any change in marginal costs, the rejection of the Cournot model implies the possibility of collusive behavior. Even if there exists any change in marginal costs, the

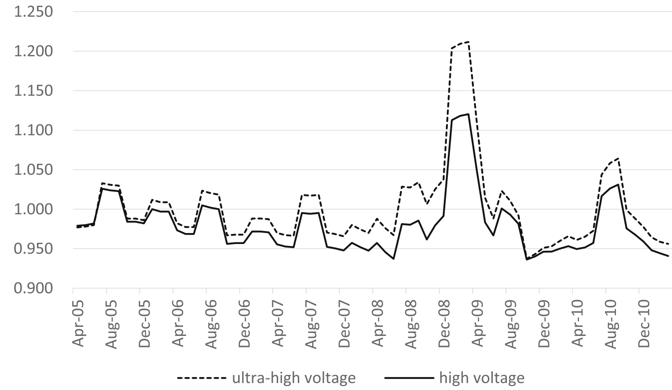

Fig. 3. Monthly price index of retail electricity in Japan over the period 2005–2010.
Source: Bank of Japan, *Corporate Goods Price Index.Note*: The monthly price index of retail electricity is divided by the monthly price index averaged over all corporate goods (2005 base).

rejection of the Cournot model still implies possible collusion if the cost changes are common across the industry (Carvajal et al., 2013a, p.2366). The policy question of interest is whether the rapid increase in electricity prices can be attributed to incumbent collusion in the retail electricity market.

5. Results

Before testing the data for Cournot rationalizability, the entire dataset is divided into multiple subsets. Following Carvajal et al. (2013a), this analysis reports test results for each subset consists of I incumbents (I = 2, 3, 6, or 10) and T consecutive months (T = 3, 6, or 12). As a reference, Tables S1 and S2 in the supplementary materials present test results for subsets consisting of four or five incumbents and four or five consecutive months in the ultra-high voltage market. Further, Section 5 involves tests of whether each subset of the data is consistent with the Cournot equilibrium being played by I incumbents over T consecutive months, using the algorithm in Section 2.2. This algorithm is obtained from the code mentioned in Carvajal et al. (2013b). Using data subsets over short time periods (i.e., 12 months or less) reduces the possibility of spurious rejections due to any shift in the cost functions of the incumbents. Moreover, it enables us to examine whether a particular subset of incumbents, if not all incumbents, are playing a Cournot game against each other.

5.1. Test of collusion for the entire group of incumbents

Table 1 summarizes rejection rates, defined as the proportion of cases that were rejected by the test of the Cournot model in Section 2, for ultra-high voltage (i.e., consumers contracting 2000 kW or more) and high-voltage markets (i.e., consumers contracting 50–2000 kW) over fiscal years 2005–2010. The number of subsets of the data, which is indicated within the parentheses in the tables, depends on the number of incumbents and the time windows over which Cournot behavior was tested. For example, in the entry for two incumbents and three months in Table 1, there are 72 + 1–3 = 70 three-months periods and 45 possible combinations of two out of 10 incumbents. This means that the entire dataset is divided into 70×45 = 3150 subsets. It should be noted that the number of incumbents is nine for the high-voltage market, where Okinawa recorded zero demand.

The test rejects the validity of the Cournot model for 37% of the three-month periods with two incumbents over fiscal years 2005–2010 in the ultra-high voltage market. The test in the high-voltage market rejects Cournot rationalizability for 26% of these data subsets. In both the markets, the rejection rates increased along with the number of

Table 1
Rejection rates of the Cournot hypothesis: all incumbents over the period 2005 to 2010.

Ultra-High Voltage Market		Number of Incumbents			
		2	3	6	10
Window	3 Months	0.372 (3150)	0.632 (8400)	0.918 (14,700)	1.000 (70)
	6 Months	0.794 (3015)	0.971 (8040)	1.000 (14,070)	1.000 (67)
	12 Months	0.990 (2745)	1.000 (7320)	1.000 (12,810)	1.000 (61)
High Voltage Market		**Number of Incumbents**			
		2	3	6	9
Window	3 Months	0.260 (2520)	0.449 (5880)	0.695 (5880)	0.771 (70)
	6 Months	0.705 (2412)	0.913 (5628)	0.998 (5628)	1.000 (67)
	12 Months	0.975 (2196)	0.999 (5124)	1.000 (5124)	1.000 (61)

Notes: One of 10 incumbents (i.e., Okinawa) exhibited no demand for the high-voltage market and it was excluded from the analysis. The number of the subsets of the data is in parentheses.

incumbents and consecutive months, and the test rejects Cournot rationalizability for more than 90% of the six-month periods with three incumbents. The rejection rates reached 100% for 12-month periods when at least six incumbents were considered. The results in Table 1 show that the behavior of incumbents in the Japanese retail electricity market cannot be explained by the Cournot model with convex costs.

Market size, which can be measured in terms of the total consumption of electricity, affects the possibility of collusion, as shown in Table 1. The annual electricity consumption in the high-voltage market consistently exceeded that in the ultra-high voltage market over 2005–2010. Except for the cases where the rejection rates reached 100%, given the number of incumbents and periods, the proportion of cases that were rejected in the high-voltage market was lower than that in the ultra-high voltage market. In fact, given the number of incumbents and periods, a statistically significant difference was observed between the rejection rates of the two markets: the absolute value of *t*-statistic ranged from 2.6 to 34.8, which indicates statistical significance at the 1% level, as shown in Table S3 in the supplementary materials. Thus, the larger the retail electricity market, the smaller is the possibility of collusive behavior.

5.2. Test of collusion for the subgroups of incumbents

To explore which factors, other than market size, affect the possibility of collusive behavior among incumbents, the test of the Cournot model was also applied to specific subsets of incumbents that are of similar firm size or are geographically proximate to each other. Table 2 reports the results for the subsets of three incumbents located in metropolitan areas (i.e., Tokyo, Chubu, and Kansai), whereas Table 3 reports those for the subsets of the remaining incumbents. Three incumbents in metropolitan areas were substantially larger in firm size compared to the rest of the incumbents; each of the "large" incumbents held a 15%–32% share in both the ultra-high voltage and high-voltage markets, whereas each of the "small" incumbents owned a maximum of 9% share in these markets. As a reference, Fig. 4 illustrates the regulated service (i.e., less than 50 kW) area of each incumbent.

Larger firm size helps to reduce the possibility of collusive behavior among incumbents. The test results in Tables 2 and 3 indicate that the rejection rates for the "large" incumbents are remarkably lower than those for the "small" incumbents in both the ultra-high voltage and high-voltage markets. In fact, given the number of incumbents and

Table 2
Rejection rates of the Cournot hypothesis: three incumbents in metropolitan regions over the period 2005–2010.

Ultra-High Voltage Market		Number of Incumbents	
		2	3
Window	3 Months	0.252 (210)	0.471 (70)
	6 Months	0.627 (201)	0.910 (67)
	12 Months	0.956 (183)	1.000 (61)
High Voltage Market		**Number of Incumbents**	
		2	3
Window	3 Months	0.086 (210)	0.200 (70)
	6 Months	0.363 (201)	0.552 (67)
	12 Months	0.874 (183)	1.000 (61)

Note: The number of the subsets of the data is in parentheses.

Table 3
Rejection rates of the Cournot hypothesis: seven "small" incumbents over the period 2005 to 2010.

Ultra-High Voltage Market		Number of Incumbents			
		2	3	6	7
Window	3 Months	0.358 (1470)	0.631 (2450)	0.929 (490)	0.957 (70)
	6 Months	0.797 (1407)	0.982 (2345)	1.000 (469)	1.000 (67)
	12 Months	0.995 (1281)	1.000 (2135)	1.000 (427)	1.000 (61)
High Voltage Market		**Number of Incumbents**			
		2	3	6	
Window	3 Months	0.332 (1050)	0.546 (1400)	0.771 (70)	
	6 Months	0.812 (1005)	0.972 (1340)	1.000 (67)	
	12 Months	0.997 (915)	1.000 (1220)	1.000 (61)	

Notes: One of seven "small" incumbents (i.e., Okinawa) exhibited no demand for the high-voltage market and it was excluded from the analysis. The number of the subsets of the data is in parentheses.

periods, there is a statistically significant difference between the rejection rates of "large" and "small" incumbents for each market; the absolute value of the t-statistic ranged from 2.0 to 12.4, which indicates statistical significance at least at the 5% level, as shown in Tables S4 and S5 in the supplementary materials.

To examine the effect of geographical proximity on collusive behavior, the test of the Cournot model employs subsets comprising the incumbents in either the eastern or western part of Japan and those comprising pairs of adjacent incumbents that are directly connected through transmission lines. The former subsets of data reflect the difference in frequency: the incumbents in the eastern part of Japan (i.e., Hokkaido, Tohoku, and Tokyo) use 50 Hz frequency whereas those in the western part of Japan (i.e., Chubu, Hokuriku, Kansai, Chugoku, Shikoku, and Kyushu) use 60 Hz frequency. The incumbents in each part of Japan often trade electricity with each other using interregional transmission lines. Okinawa is excluded from these subsets because it is not connected to any incumbent.

There seems to be no clear indication of the effects of frequency on the possibility of collusion in both the ultra-high voltage and high-voltage markets. Tables S10 to S13 in the supplementary materials summarize the test results for subsets comprising incumbents in either the eastern or western part of Japan. In the ultra-high voltage market, when two and three incumbents are considered for three-month and six-month periods, respectively, the subsets of the data seem to exhibit slightly higher rejection rates in both, the eastern and western parts of Japan (Tables S10 and S12), compared to those of the entire group of

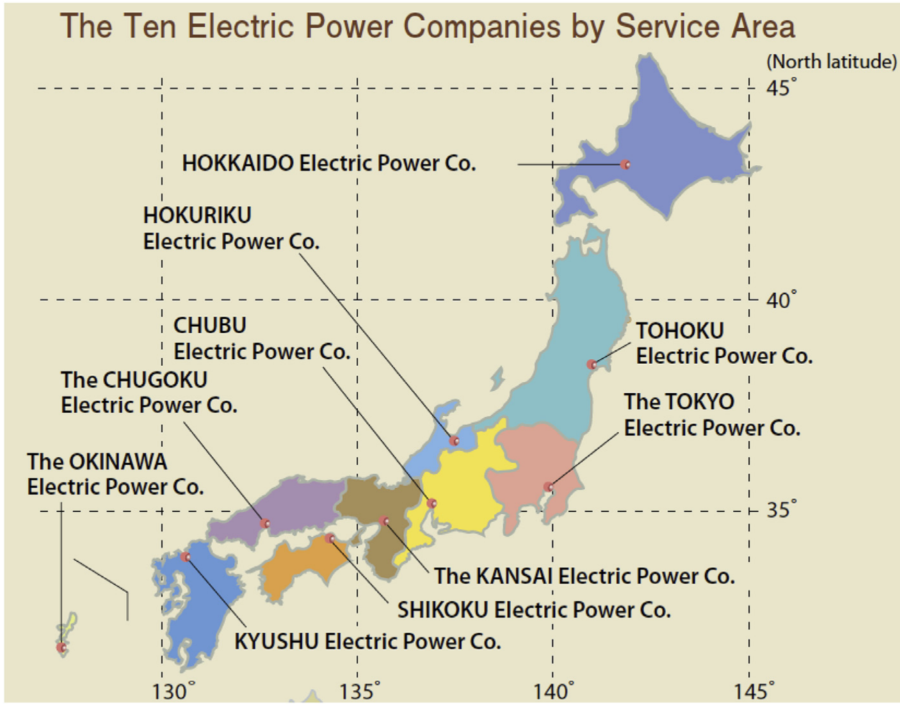

Fig. 4. Regulated service area of each incumbent.
Source: Federation of Electric Power Companies of Japan. *Electricity Review Japan 2008*.http://www.fepc.or.jp/english/library/electricity_eview_japan/index.html (accessed October 2016).

incumbents (Table 1). In the entries for two incumbents and three-to six-month periods, for instance, the absolute value of the *t*-statistic associated with the difference in rejection rates between the western part of Japan and the entire group was 2.6, which indicates a statistically significant difference in the rejection rates between these two groups for the ultra-high voltage market at the 1% level, as shown in Table S8 in the supplementary materials. However, in other entries for this market, no statistically significant difference in rejection rates was found between these two groups, as indicated by the absolute value of the *t*-statistic that was below 1 for these entries in Table S8. In addition, there was no statistically significant difference between the rejection rates in the eastern part of Japan and the entire group in most entries of the ultra-high voltage market, as shown in Table S6 in the supplementary materials.

With respect to the high-voltage market, rejection rates in the eastern part of Japan (Table S11) and the entire group (Table 1) did not differ significantly for most entries, as shown in Table S7 in the supplementary materials. For this market, rejection rates in the western part of Japan (Table S13) and the entire group (Table 1) significantly differed in the entries for two incumbents and six-to 12-month periods, and in the entry for three incumbents and six-month periods, as indicated by the absolute value of the *t*-statistic that ranged from 2.5 to 3.1 for these entries, as shown in Table S9 in the supplementary materials. However, in the entries for two to three firms and three-month periods, no statistically significant difference was found between the rejection rates in the western part and the entire group.

The effects of geographical proximity on the possibility of collusion were not found in both, the ultra-high voltage and high-voltage markets, when using data subsets consisting of pairs of adjacent incumbents that are directly connected through transmission lines. Tables S14 and S15 in the supplementary materials present the test results of the Cournot model for seven pairs of adjacent incumbents that were directly connected through transmission lines whose capacity was equal to or larger than 10% of a maximum of each incumbent's demand in 2005. In both markets, the rejection rates of the subsets comprising Chugoku (CH) and Shikoku (SH) in Tables S14 and S15, which are located in the western part of Japan, were remarkably higher than those of the subsets comprising two incumbents for three-to 12-month periods in Table 1. However, the subsets consisting of Chugoku (CH) and Kyushu (KY) in Tables S14 and S15, which are also located in the western part of Japan, exhibited rejection rates that were much lower than those of the subsets comprising two incumbents for three-to six-month periods in Table 1. For other pairs of the incumbents, there seems to be no clear indication of the effects of geographical proximity on the possibility of collusion in both markets.

6. Conclusions

This analysis attempts to detect the possibility of collusive behavior in the liberalized retail electricity market by testing the validity of the Cournot model of imperfect competition, using monthly data on the Japanese electric power industry over the 2005 to 2010 period. The application of the revealed preference test developed by Carvajal et al. (2013a) to the retail electricity market in Japan indicates that the possibility of collusive behavior among the incumbents cannot be excluded. Further, the test results imply that larger market size and firm size might reduce the possibility of collusion among incumbent retail electricity suppliers. Since fines for antitrust violations are proportional to sales of firms in Japan (JFTC, 2018), larger firms may feel more pressure from the antitrust authority to behave competitively.

Collusion among incumbent retail electricity suppliers, if any, could arise from yardstick regulation, which sets restrictions on product prices that are conditioned on the productivity of the retail business of each incumbent. The productivity of each firm, subject to yardstick regulation, is evaluated relative to other firms in the industry; this results in tight restrictions on prices for inefficient firms. During fiscal years 2005–2015, the regulated retail electricity market (i.e., consumers contracting less than 50 kW) in Japan was subject to yardstick regulation. While the incumbents labeled as “greater than average” could set their electricity prices equal to the average costs, those labeled as “average” or “below average” were obliged to set prices that were lower than their average costs by 1% or 2%. Although this form of regulation is expected to improve the productivity of the retail electricity business, allocative efficiency, could be undermined by the collusive behavior of firms in the industry (Shleifer, 1985; Laffont and Martimort, 1997, 2000; Tangerås, 2002; Potters et al., 2004; Dijkstra et al., 2017). An alternative form of economic regulation aimed toward improving the productivity of the retail electricity business, such as price caps, might produce better results than yardstick regulation because it is less vulnerable to collusive behavior.[1]

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Conflicts of interest

The author declares that he has no conflict of interest.

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Appendix. Example of the Upper Bound Algorithm

As an illustrative example, suppose that the dataset comprises the market price of electricity and output of two retail suppliers ($I = 2$) at four time periods ($T = 4$):

(i) At $t = 1$, $P_1 = 10$, $Q_{1,1} = 6$, and $Q_{2,1} = 10$.
(ii) At $t = 2$, $P_2 = 20$, $Q_{1,2} = 5$, and $Q_{2,2} = 6$.
(iii) At $t = 3$, $P_3 = 30$, $Q_{1,3} = 4$, and $Q_{2,3} = 5$.
(iv) At $t = 4$, $P_4 = 40$, $Q_{1,4} = 2$, and $Q_{2,4} = 2$.

In the initial step of the upper bound algorithm, δ_1^{ub}, which denotes the matrix whose entry in row t and column i is $\delta_{i,t}^{ub}$, is given by

$$\delta_1^{ub} = \begin{bmatrix} 10 & 10 \\ 20 & 20 \\ 30 & 30 \\ 40 & 40 \end{bmatrix}.$$

In the second step of the algorithm, because the output of two retailers is greatest at $t = 1$, the market price at $t = 1$ must bound the marginal cost at all the observed levels of output so that the co-monotone property holds. Then, γ_1^{ub}, which denotes the matrix whose entry in row t and column i is $\gamma_{i,t}^{ub}$ in the second step, is given by

$$\gamma_1^{ub} = \begin{bmatrix} 10 & 10 \\ 10 & 10 \\ 10 & 10 \\ 10 & 10 \end{bmatrix}.$$

In the last step, the upper bound of the marginal cost of the retailer is lowered (i.e., $\Lambda_1 = 0$, $\Lambda_2 = 2$, $\Lambda_3 = 5$, and $\Lambda_4 = 15$) so that the common ratio property holds. This yields $\gamma_1^{ub'}$, which denotes the matrix whose entry in row t and column i is $\gamma_{i,t}^{ub'}$ in the last step:

$$\gamma_1^{ub'} = \begin{bmatrix} 10 & 10 \\ 10 & 8 \\ 10 & 5 \\ 10 & 10 \end{bmatrix}.$$

Because all entries in $\gamma_1^{ub'}$ are positive and $\delta_1^{ub} \neq \gamma_1^{ub'}$, set $\delta_2^{ub} = \gamma_1^{ub'}$ and repeat the second and last steps of the algorithm. δ_2^{ub} denotes the matrix whose entry is the upper bound of $\delta_{i,t}$ after the first iteration:

$$\delta_2^{ub} = \begin{bmatrix} 10 & 10 \\ 10 & 8 \\ 10 & 5 \\ 10 & 10 \end{bmatrix}.$$

In the second step of the second iteration, γ_2^{ub}, which denotes the matrix whose entry in row t and column i is $\gamma_{i,t}^{ub}$, is given by

$$\gamma_2^{ub} = \begin{bmatrix} 10 & 10 \\ 10 & 8 \\ 10 & 5 \\ 10 & 5 \end{bmatrix}.$$

The co-monotone property holds for γ_2^{ub}. In the last step of the second iteration, the upper bound of the marginal cost of the retailer is again lowered (i.e., $\Lambda_1 = 0$, $\Lambda_2 = 2$, $\Lambda_3 = 5$, and $\Lambda_4 = 17.5$) so that the common ratio property holds. This yields $\gamma_2^{ub'}$, which denotes the matrix whose entry in row t and column i is $\gamma_{i,t}^{ub'}$ in the last step of the second iteration:

[1] Although the article assumes that the retailers produce a single product, the revealed preference test could be applied to multi-product oligopolists. In fact, Carvajal et al. (2010) developed the concept of Cournot rationalizability in a multi-product oligopoly. Future research in this area could examine whether Cournot rationalizability holds true in the case of multi-product industries, using the data on product prices and firm output of each product.

$$\gamma_2^{ub'} = \begin{bmatrix} 10 & 10 \\ 10 & 8 \\ 10 & 5 \\ 5 & 5 \end{bmatrix}.$$

Because all entries in $\gamma_2^{ub'}$ are positive and $\delta_2^{ub} \neq \gamma_2^{ub'}$, set $\delta_3^{ub} = \gamma_2^{ub'}$ and repeat the second and last steps of the algorithm again. δ_3^{ub} denotes the matrix whose entry is the upper bound of $\delta_{i,t}$ after the second iteration:

$$\delta_3^{ub} = \begin{bmatrix} 10 & 10 \\ 10 & 8 \\ 10 & 5 \\ 5 & 5 \end{bmatrix}.$$

In the second step, γ_3^{ub}, which denotes the matrix whose entry in row t and column i is $\gamma_{i,t}^{ub}$ in the third iteration, is given by

$$\gamma_3^{ub} = \begin{bmatrix} 10 & 10 \\ 10 & 8 \\ 10 & 5 \\ 5 & 5 \end{bmatrix}.$$

The co-monotone property holds for γ_3^{ub}. In the last step of the third iteration, the upper bound of the marginal cost of the retailer is again lowered (i.e., $\Lambda_1 = 0, \Lambda_2 = 2, \Lambda_3 = 5$, and $\Lambda_4 = 17.5$) so that the common ratio property holds. This yields $\gamma_3^{ub'}$, which denotes the matrix whose entry in row t and column i is $\gamma_{i,t}^{ub'}$ in the last step of the third iteration:

$$\gamma_3^{ub'} = \begin{bmatrix} 10 & 10 \\ 10 & 8 \\ 10 & 5 \\ 5 & 5 \end{bmatrix}.$$

Because $\delta_3^{ub} = \gamma_3^{ub'}$, the array $\{\delta_{i,t}^{ub}\}$ converges to the limit after three iterations, and both the common ratio and the co-monotone properties hold at the limit. Thus, the dataset in this example is Cournot rationalizable.

Appendix B. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jup.2018.12.005.

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