Theories of Dynamic Pricing and the Tokyo Retail Gasoline Market

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Abstract: The purpose of this paper is to estimate models for the retail price of gasoline in Tokyo based on predictions derived from infinitely repeated game theory. The predictions imply that both current and future expected changes and current unexpected changes in the economic environment that firms face will have an impact on the current retail price of gasoline. Using monthly time series data on retail gasoline prices in Tokyo for the 1990s, this paper provides some evidence consistent with the predictions of these theories. In addition, evidence about the impact of abolishing a law restricting the importation of gasoline into Japan on retail gasoline prices is also provided.

***Keywords*:** Gasoline; Collusion; Deregulation; Repeated game; Unexpected shocks.

1. INTRODUCTION

The purpose of this paper is to model the behaviour of the retail price of gasoline in the Tokyo metropolitan area (*Tokyo-to*) using predictions from several models of dynamic pricing. These models employ infinitely repeated game theory, supergame theory. The theories suggest that current and future expected changes and unexpected changes in the economic environment that firms face (for example, changes in demand or cost conditions) will affect firms' current price setting if the firms engage in competition in a repeated game context [see, for example, Green and Porter, 1984; Rotemberg and Saloner, 1986; and Haltiwanger and Harrington, 1991]. A second purpose of the paper is to examine the impact of a particular piece of deregulation policy in the oil industry on the behavior of retail prices in Tokyo.

In Goto and McKenzie [2001], the authors drawing on the insights of Rotemberg and Saloner [1986] and Haltiwanger and Harrington [1991] estimated models for the retail prices of gasoline in Tokyo and Osaka using two-step estimation methods. This paper extends this earlier research in three directions: (1) following Green and Porter [1984], the impact of unexpected cost and demand shocks are incorporated into the retail price equation; (2) to avoid the loss of efficiency and problems in computing consistent estimates of the standard errors of two-step estimators [see Pagan, 1984 and 1986; and McKenzie and McAleer, 1997], a three-equation system is estimated by maximum likelihood (ML) following McAleer and McKenzie [1990, 1991]; and (3) formal statistical tests for the impact of a regulatory change on the retail price of gasoline are conducted.

This paper is organized as follows. In section 2, a brief survey of recent studies relating to the Japanese oil industry is presented. Section 3 discusses the implications for gasoline pricing that can be derived from several supergame theories. Section 4 details the models to be estimated and the estimation methods adopted, while section 5 describes the data used. Estimated results are presented in section 6.

2. RESEARCH ON THE OIL INDUSTRY

At the end of March 1996, the *Provisional Law Relating to the Importation of Specified Petroleum Products (Tokutei sekiyu seihin yunyu zantei sochiho*, called *Tokusekiho*) that restricted imports of specified petroleum products (gasoline, kerosene and light oil) to a certain number of refining companies was abolished. As a result, the importation of specified petroleum products was liberalized. In June 1994, it became clear that the *Tokusekiho* would be abolished at the end of March 1996 [see Goto, 2000]. Despite this liberalization, since June 1994, total imports of specified petroleum products relative to total production in Japan have been very small, and the number of new importers of these products has also remained rather small. It should be pointed out that the direct impact of the abolition of the *Tokusekiho* would be expected to be a fall in the *wholesale* price of gasoline. Such a fall could be expected to lead to a fall in the *retail* price of gasoline. This paper examines whether this deregulation had an impact on the retail price of gasoline over and above the impact that comes directly from changes in the wholesale price of gasoline.

At around the same time the government made the decision to abolish the *Tokusekiho*, the retail price of gasoline began to fall. As a result, the media and others have often suggested the abolition of the *Tokusekiho* was a successful case of deregulation (see also OECD [1996]).

There have been several recent studies that relate to the abolition of the *Tokusekiho* [for example, Goto, 1999a, b], and this evidence is reviewed in Goto and McKenzie [2001]. Nagaoka and Kimura [1999] provide a theoretical and empirical analysis of the impact of the abolition of the *Tokusekiho* on the difference between the retail price of gasoline (excluding taxes) and the price of crude oil (including tariffs and oil taxes). They observe a statistically significant decline in this difference in response to the announcement that the importation of gasoline would be liberalized. By examining the difference between the retail price of gasoline and the price of crude oil, their analysis cannot distinguish the separate impact of the liberalization at the wholesale and the retail level. In addition, the impact of the liberalization is modelled through a simple 0-1 dummy that takes the value 1 from December 1994, the time Nagaoka and Kimura believe the decision was made to liberalize the importation of oil [cf Goto, 2000]. Goto and McKenzie's [2001] results provide evidence that changes in the expected current and future environment firms face affects current retail prices, and evidence suggestive of a structural change in the retail price equations for Tokyo and Osaka in June 1994. However, as it is difficult for firms to perfectly forecast how the economic environment they face will change, it is natural to consider that retail gasoline prices may also be influenced by unexpected changes in the economic environment.

3. MODELS OF DYNAMIC PRICING

Here, we represent the simplified version of Rotemberg and Saloner's [1986] model used in Goto and McKenzie [2001] to suggest what variables influence a gas station's price setting and also the direction of that influence. It is assumed there are n identical gas stations supplying identical gasoline. Bertrand competition is assumed so that the gas stands simultaneously choose their selling price. This competition is repeated infinitely. The marginal cost of gasoline to the gas stand at time t is assumed to be c_t. At time t, the market demand function for gasoline is

$$Q_t = Q_t(p_t, z_t), \tag{1}$$

where Q_t, p_t, z_t are, respectively, the quantity demanded, the price and the state which measures the size of demand shocks. Gas stations face strong demand in a boom and weak demand in a recession. In each period, the actual state of demand is realized after gas stands make their price decisions.

The collusive price is denoted by p_t^m. When this is the price each gas station sets, it is assumed that total demand is divided equally among the gas stations. In this case, the collusive price is a function of the current state, $p_t^m(z_t)$.

With Bertrand competition, if $p_{jt}(z_t)$ denotes the price posted by stand j at time t given the observed state z_t, then a trigger strategy for firm i at time t, $S_{it}(z_t, c_t)$, that will support the collusive price as a sub-game perfect equilibrium is

$$S_{it}(z_t, c_t) = \begin{cases} p_t^m(z_t) & \text{if } p_{j\tau}(z_\tau) = p_\tau^m(z_\tau) \\ & \forall \tau \in \{1, \ldots, t-1\} \forall j \in \{1, \ldots, n\} \\ c_t & \text{otherwise} \\ & \forall t \in \{2, 3, \ldots\} \end{cases} \tag{2}$$

The necessary and sufficient condition to support the collusive price given the trigger strategy is:

$$\sum_{\tau=t+1}^{\infty} \delta^{\tau-t} E\left[\frac{1}{n} Q_\tau(p_\tau^m, z_\tau)(p_\tau^m - c_\tau)\right] \geq \frac{(n-1)}{n} E[Q_t(p_t^m, z_t)(p_t^m - c_t)], \tag{3}$$

where δ and E are, respectively, the discount rate and the expectation operator. The term before the inequality is the expected net present value of the loss of future profits that would occur if a firm is found to be cheating in the current period. The term after the inequality is the expected profit gain a firm could achieve by cheating in the current period and supplying the whole market by itself. If the latter term is greater than the former, firms cheat. Depending on the value of δ, (3) may mean that the collusive price has to be set lower than the monopoly price to sufficiently reduce the temptation for firms to cheat. Assuming that the current collusive price lies somewhere between the monopoly price and marginal cost, an examination of (3) suggests that if

a) the expected current (future) state improves, the gain (penalty) from cheating becomes larger, so that collusion becomes more difficult (easier) and the current collusive price needs to be reduced (raised); and
b) the expected current (future) costs rise, the gain (penalty) from cheating falls, so that collusion becomes easier (more difficult) to maintain and the current collusive price can be raised (reduced).

For sufficiently large values of δ, the collusive price will be the monopoly price, and this will be unaffected by changes in future economic conditions. For sufficiently small values of δ, collusion is not possible and the retail price will be set at marginal cost.

In both Rotemberg and Saloner [1986] and Haltiwanger and Harrington [1991], the deterrent mechanism generated by the trigger strategies are never observed. In a situation where firms engage in Cournot competition, Green and Porter [1984] show that unexpected demand shocks can cause a tripping of the trigger strategy, even when all firms know that low prices reflect a demand shock rather than cheating by their competitors.

Although the potential responses of current and future prices to a current unexpected demand shock generated by Green and Porter's [1994] model are quite complicated, an intuitive explanation for some of their impacts is as follows. In Cournot competition, when firms commit to quantity before the unexpected shock occurs (the price elasticity of supply is zero in the very short-run), an unexpected increase (decrease) in demand merely causes an increase (decrease) in the current price with consequential increases (decreases) in firm profits. In the next period, while an unexpected increase in demand in the previous period may not trip the trigger strategy, an unexpected decrease in demand in the previous period will because the observed price will have fallen below the collusive price. As a result, prices in the next period could be expected to fall. In contrast, with Bertrand competition firms commit to a price before the unexpected shock occurs, so that an unexpected increase (decrease) in demand may lead to some change in output, but is unlikely to lead to a change in the existing price. If prices are unchanged in the current period, then the trigger strategy is not tripped in the next period.

What about an unexpected increase (decrease) in marginal costs? Green and Porter [1984] do not consider this extremely important and relevant case. In Cournot competition, provided marginal cost does not increase above price, there will be no change in price in response to an unexpected increase (decrease) in marginal costs, since the demand curve does not shift and firms have committed to producing a particular quantity. As a result, the trigger strategy is not tripped in the next period. That is, current and future prices will not respond at all to an unexpected change in the current marginal costs! In contrast, with Bertrand competition where firms commit to price, an unexpected increase (decrease) in marginal costs provides an incentive for firms to decrease individual output, even though if firms attempt this, they will be unable to maintain the price they have committed too. That is, there may be pressure on prices to increase (fall) if there is an increase (decrease) in marginal costs. If prices deviate from the collusive level, the trigger strategy may be tripped in the next period.

4. MODEL SPECIFICATION

The discussion in section 3 indicates that when gas stations are facing a state of mutual dependence, and behave cooperatively, the collusive price may result from firms forecasting their current and future economic environment and choosing their behavior accordingly. In addition, unexpected changes in demand and cost conditions are likely to impact on current prices as well. To take account of this behaviour, the following price equation was assumed:

$$p_t = \alpha_0 + \alpha_1 Q_t^e + \alpha_2 c_t^e + \alpha_3 Q_t^u + \alpha_4 c_t^u + \alpha_5 Q_{t+1}^e + \alpha_6 c_{t+1}^e + u_t, \quad (4)$$

where p_t is the retail price of gasoline in Tokyo at time t; Q_t^e (Q_t^u) is the expected (unexpected) quantity of gasoline to be sold in Tokyo at time t; c_t^e (c_t^u) is the expected (unexpected) national wholesale price of gasoline at time t, and u_t is a disturbance. The potential lagged impacts of unexpected demand and cost changes are ignored. The discussion in the previous section suggests the coefficients in (4) should have the following signs: $\alpha_1 < 0$, $\alpha_2 > 0$, $\alpha_3 \geq 0$, $\alpha_4 \geq 0$, $\alpha_5 > 0$, and $\alpha_6 < 0$.

In order to estimate the price equation specified in (4), it is necessary to calculate the expected current and future values of demand and wholesale prices, and the unexpected current values of demand and wholesale prices. Here, we estimate models for Q_t and c_t that are rather similar to those assumed by Borenstein and Shepard [1996]:

$$Q_t = Q_t^e + Q_t^u = \beta_0 + \beta_1 Q_{t-1} + \beta_2 t + \Sigma_{j=1}^{11} \theta_j S_{tj} + Q_t^u, \quad (5)$$

and

$$c_t = c_t^e + c_t^u$$
$$= \gamma_0 + \gamma_1 c_{t-1} + \gamma_2 c_{t-2} + c_t^u, \qquad (6)$$

where S_{tj} is a 0-1 seasonal dummy for the jth month, and Q_t^u and c_t^u are disturbances. Q_{t+1}^e and c_{t+1}^e are also computed as the two-step ahead forecasts from (5) and (6), respectively, using only information available at time t-1, namely,

$$Q_{t+1}^e = \beta_0 + \beta_1 Q_t^e + \beta_2 (t+1) + \Sigma_{j=1}^{11} \theta_j S_{t+1j}, \qquad (7)$$

$$c_{t+1}^e = \gamma_0 + \gamma_1 c_t^e + \gamma_2 c_{t-1}. \qquad (8)$$

A comparison of (6) and (8) indicates that c_t^e and c_{t+1}^e will be highly correlated when γ_2 is close to zero. Given the presence of both current expected and unexpected terms in (4), to ensure that all the parameters of (4) are identified it is necessary to assume that u_t, Q_t^u and c_t^u are contemporaneously uncorrelated [see Pesaran, 1987]. As a result, the structure of the system given by (4), (5) and (6) closely resembles the system estimated for unemployment and monetary policy in the United States by McAleer and McKenzie [1990, 1991]. The ML estimation procedure adopted here follows the procedure discussed in Appendix B of McAleer and McKenzie [1990].

5. DATA

The monthly data used in this paper run from October 1990 to October 1999. Data on retail gasoline prices at the prefectural level were obtained from the *Monthly Survey of the Market Situation of Oil Products (Sekiyu seihin shijo getsuji chosa)* produced by the Japan Energy Economic Research Institute's Oil Information Center (*Nihon enerugi keizai kenkyusho sekiyu joho senta*). This data is obtained from monthly surveys of the price of regular gasoline sold at gasoline stations. The surveys are carried out on the tenth day of each month. Data on wholesale gasoline prices were obtained from the Nikkei NEEDS database using the price paid by traders who purchase gasoline from refineries and distribute it to gas stations. Data on gasoline prices at the wholesale level are not available at the prefectural level, so the wholesale price is treated as being the same across Japan.

Data on retail sales of gasoline at the prefectural level were also obtained from the Nikkei NEEDS database. Although retail price and sales data are available for all 47 prefectures in Japan, the analysis in this paper is limited to the metropolitan area of Tokyo.

6. RESULTS

The results of estimating the system of (4), (5) and (6) by ML for Tokyo are presented in Table 1. Since it is only the parameters of (4) that are of primary interest, estimates of the coefficients of (5) and (6) are not presented. The system is estimated using three samples: all the data (1990:11-1999:10); the first-half of the data (1990:11-1994:5); and the second-half of the data (1994:6-1999:10). The time at which the sample is split, 1994:6, is when the abolition of the *Tokusekiho* was formally decided [see Goto, 2000]. A comparison of the maximized values of the log-likelihood functions for the three samples permits a formal test for structural change of the parameters of the model, and this test is denoted by SC. The hypothesis that the coefficients of the system are the same across the two periods is decisively rejected. This suggests that abolition of the *Tokusekiho* has had a significant impact on the gasoline industry.

A comparison of the signs of the estimated coefficients with their expected signs indicates that *most* estimated coefficients have signs that are consistent with a priori expectations. The only

Table 1: Estimated Retail Price Equations

Variable	Expected Sign	1990:11-1999:10 A	B	1990:11-1994:5 C	D	1994:6-1999:10 E	F
Q_t^e	-	-0.016		0.011		-0.006	
		(1.71)		(0.22)		(0.46)	
c_t^e	+	4.898	1.246	4.479	0.940	22.712	1.390
		(1.40)	(36.82)	(1.80)	(11.29)	(0.354)	(16.91)
Q_t^u	+/0	-0.012		-0.003		0.021	
		(0.52)		(0.07)		(0.74)	
c_t^u	+/0	0.859	0.766	0.334	0.123	0.703	0.624
		(3.60)	(3.24)	(1.33)	(0.49)	(2.10)	(1.90)
Q_{t+1}^e	+	-0.029	-0.043	-0.015	-0.007	-0.033	-0.041
		(2.87)	(5.60)	(0.31)	(0.61)	(2.22)	(4.54)
c_{t+1}^e	-	-3.816		-4.719		-22.72	
		(1.05)		(1.49)		(0.33)	
LL		122.50	118.83	131.02	124.15	67.43	66.13
W		347.87	2908.95	16.88	139.44	25.43	591.27
		(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	
W1		4.35	n.a.	2.23	n.a.	0.85	n.a.
		(0.23)		(0.53)		(0.84)	
SC		151.88	142.90				
		(0.00)	(0.00)				

Notes: LL is the maximized value of the log-likelihood function. Figures in parentheses for the variables are the absolute values of asymptotic t-statistics. W are Wald tests of the null hypothesis that all the coefficients of (4) (except the constant) are jointly zero, and are distributed as χ^2 variates with 6 and 3 degrees of freedom under the null hypothesis for cases A, C and E, and cases B, D and F, respectively. W1 are Wald tests of the null hypothesis that $\alpha_1 = \alpha_3 = \alpha_6 = 0$, and are distributed as χ^2 variates with 3 degrees of freedom under the null hypothesis. SC are likelihood ratio tests of the null hypothesis that all the parameters in (4), (5) and (6) are the same in the first-half and second-half of the sample period, and are distributed as χ^2 variates with 25 and 22 degrees of freedom under the null hypothesis in cases A and B, respectively. Figures in parentheses for W, W1 and SC are p-values. n.a. indicates not applicable.

major exception is the coefficient of Q^e_{t+1}, α_5, which is consistently negative, and significant in four of the six cases. Overall, this is a far better performance than Goto and McKenzie [2001] who report results for Tokyo and Osaka for (4) with $\alpha_3 = \alpha_4 = 0$ estimated by two-step methods. The significance of c^u_t when all the data and the second-half data are used suggests that the model estimated in Goto and McKenzie [2001] was misspecified. Although having estimated coefficients with the wrong sign, the significance of Q^e_{t+1} provides some evidence consistent with game theoretic models that suggest future changes in the economic environment will affect current price setting by firms if firms engage in competition in a repeated game context.

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