Mixed Duopoly: Empirical Evidence from Gasoline Market in Taiwan*

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September 14, 2020

Abstract

This paper studies the transition from monopoly by a public firm to mixed duopoly, in which public firm and private firm have heterogeneous objective functions. With different constant marginal costs, my theoretical model shows that the market prices and outputs do not change after entry by the private firm. The result is driven by the fact that the public firm has incentives to produce more in the market. Using data from the gasoline market in Taiwan, the empirical analysis provides consistent results with the model predictions. Conditional on input prices, equilibrium prices stay unchanged before and after the private firm's entry. The estimated supply in the market indicates that firm do not respond to positive shocks on demand.

1 Introduction

This paper empirically investigates how mixed duopoly, in which firms have heterogeneous objective functions, affect competition and market outcomes in a gasoline market.

*Financial support is gratefully acknowledged from Ministry of Science and Technology project MOST-109-2410-H-194-087. I am responsible for any remaining errors.

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In particular, I focus on the transition from monopoly by a public firm to mixed duopoly. To address this question, I first use a simple Cournot model based on previous literature with few modifications. This model provides two important predictions: first, equilibrium prices are, with a public firm in the market, the same before and after private firm's entry; second, since public firm will price at marginal cost, the supply won't respond to demand shocks. The empirical analysis provides evidence consistent with theoretical predictions.

The literature of oligopoly has been mostly established on the assumption that firms have identical profit maximizing objective. However, in many markets, the assumption doesn't hold. Markets such as banking, health, eduction, pension, insurance, housing or telecommunication could experience the interactions between public and private competitors, where heterogeneous objectives could induce very different market outcomes. is also policy relevant

Merrill and Schneider (1966) first explore the market structure with public control and private control. Since then the literature has recognize three types of market structures in terms of ownership: monopoly by public firm, mixed oligopoly with public firm and private firms, and private oligopoly with only private firms. The early literature aims to answer two important questions: Which market structure is socially optimal? How to use public firm to achieve higher total social welfare? Despite different settings in the model, one consistent finding in the theoretical literature (e.g., Harris and Wiens (1980); De Fraja and Delbono (1989); Cremer et al. (1989)) is that the existence of public firm, either monopoly by public firm or mixed oligopoly, is more socially beneficial than pure private oligopoly. Empirically, Barros and Medesto (1999) find evidence of regulatory intervention, which aim at reducing the equilibrium interest rate, from public banks in Portuguese banking sector. The market performance could be improved by the entry of public firm. The intuition behind this is that the government can instruct public firm to achieve desirable objective functions, such as maximizing total welfare, and use public firm as an instrument to regulate the market.

However, the literature doesn't have a clear idea about entry by private firms. That is, what could happen when the government decided to deregulate the market to allow entry by private firms but still keep public firm in the market? De Fraja and Delbono (1989) show that given all firms with identical increasing marginal cost, nationalization of the whole industry has the higher welfare than mixed oligopoly. The results imply that entry of private firm could raise the market prices. Cremer et al. (1989) allow cost heterogeneity where public firm has higher constant marginal cost, and analyze the entry problem for public firm. Their results imply that mixed oligopoly is preferred when the cost difference is small. When the cost difference is large, it would be better to nationalize the whole industry. Both studies show some predictions of private firm's entry. But the results rely on some particular assumptions. While the theoretical predictions are not consistent about the entry of private firm, I would like to address this question empirically. Besides, to my knowledge, there is no empirical study addressing similar questions.

Instead of focusing on entry of public firm, this paper analyzes the transition from monopoly by public firm to mixed duopoly, in which the government deregulates the market and allows for entry by private firm. More specifically, this paper ask the following question. Given the existence of a public firm, how does market respond to the entry of private firm?

The theoretical model here follows the framework in previous literature, featuring linear demand, constant marginal cost, and quantity competition in a homogeneous product market. The model here is most close to Cremer et al. (1989), but with few modifications, which will be discussed in detail in Section 3. While the setting is relatively simplified, it does capture the essences of the market facts in my empirical analysis. Initially, only one public firm serves the market with welfare maximizing objective. The public firm would just price at marginal cost, make zero profit, and supply the quantity demanded. With entry of a more efficient private firm, two firms differ in objectives and cost structures. However, the equilibrium price and quantity is still the same as previous case. It results from the fact that public firm has incentive to produce more until the equilibrium

price equal to its marginal cost. More efficient private firm can maximize its profit by taking advantage of the costs difference between public and private firm. In contrast, if the firms' objectives are identical, both maximizing profits, the model will predict very different results. The prices would be lower since the number of competitors increases. The price reduction would be significant as the market structure shifts from monopoly to duopoly. The aggregate supply will also respond to demand shocks, where positive demand shocks will increase the prices.

The study uses market-level data from the gasoline market in Taiwan since the market provides a unique opportunity to gain insights from the basic theoretical model. The product in this market is homogeneous, and costs are exogenously determined. More importantly, the market experienced a transition from monopoly by one single public firm to mixed duopoly by one public and one private firm. This transition allows me to study the impact of change in market structure.

Based on the implication from theoretical model, I run regressions of price on oil price and other variables, and estimate the supply and demand equations to test the hypothesis drawn from the model. Since the prices and quantities are simultaneously determined, I need to use instrumental variables, supply and demand shifters, to identify the estimates. The empirical results show that prices don't seem to be affected by the change of market structure, which is consistent with model prediction. Supply estimation indicates that firms don't respond to positive demand shocks. In other words, they don't raise prices when there is increased demand, controlling for the input prices.

This paper contributes to the mixed oligopoly literature by providing empirical evidence on transition from monopoly by public firm to mixed duopoly. While Barros and Medesto (1999) find evidence of lower interest rates from mixed banking sector, this paper empirically shows that with public firm in the market prices don't change even after private firm's entry. The results are driven by the fact that public firm already prices at marginal cost based on its welfare maximization objective. The entry by private firm doesn't affect public firm's behavior. However, part of the production shifts from less

efficient public firm to more efficient private firm. The entry by the more efficient private firm induces a change in cost structure in production, producing part of the output with lower cost. Based on the theoretical model, the overall welfare has improved.

2 Related Literature

This paper builds on the theoretical literature of mixed oligopoly, in which firms have heterogeneous objective functions. This line of literature can be traced back to 1960s. Merrill and Schneider (1966) first explore mixed oligopoly with purchase-entry by public firm under quantity competition and budget constraint. They argue that the government can use public firm as an instrument to regulate the market. Other government supervision, such as antitrust laws or regulations, don't have inside information, costs and demand, from the market. Entry by public firms could improve market performance, i.e. lower prices and increased output.

Although this type kind of market structure is not uncommon in practice, the literature didn't pay much attention until 1980s. A series of papers in 1980s follow Merrill and Schneider (1966), and extend their work under different assumptions. Harris and Wiens (1980) argue that the first best allocation can be achieved by introducing a Stackelberg public firm, which commits and supplies the difference between socially optimal output and private firms' output. However, this solution could impose huge loss on public firm.

De Fraja and Delbono (1989) consider four market structures: monopoly by public firm, one public firm and private firms, Stackelberg public firm and private firms, and all private firms. With increasing marginal cost and public firm maximizing social welfare, they find that monopoly by public firm has highest total welfare and lowest market price. Mixed oligopoly has second highest total welfare and output with second lowest price in four cases. Their results imply that the entry of a private firm will raise the the market price, which is counter-intuitive. One weakness of their model is that the results rely on the value of cost parameters, including fixed cost and marginal cost.

Cremer et al. (1989) introduce cost heterogeneity under constant marginal cost, where

public firm pays fixed cost and a premium to workers and private firms pay only fixed cost. The premium is the cost difference between public and private firms. It becomes a transfer in the society, and thus it has no effect on total welfare. They found that mixed oligopoly with one single public firm is socially optimal under small cost difference, while nationalization the whole industry could be better if there is large cost difference. While they don't compare the market outcomes in their paper, the results seem to imply that the entry of private firms could induce lower price when the premium to the workers is low.

De Fraja and Delbono (1990) provide a comprehensive survey on earlier literature. Since then, the focus of this literature moves to differentiated products (Anderson et al. 1997, Cremer et al. 1991), and partial mixed oligopoly (Matsumura 1998). More recently, motivated by Linus and Windows, Casadesus-Masanell and Ghemawat (2006) present a dynamic mixed duopoly model to analyze mixed duopoly.

Although there are noticeable advance in theoretical work, mixed duopoly/oligopoly receives very little attention from empirical perspective, with the exception of Barros and Medesto (1999). Barros and Medesto (1999) find evidence of a regulatory intervention from public banks in Portuguese banking sector. The intervention results in lower equilibrium interest on loans. The empirical findings are consistent with the predictions from mixed oligopoly. While their findings provide empirical evidence for mixed market structure, the banking industry could be involved with other institutional details, regulation, as well as monetary policies. The results could be affected by these factors.

My work here mainly contributes to the empirical mixed duopoly literature with direct evidence based on the simple theoretical framework and industry facts. Estimation of supply and demand connects market behavior and theoretical mechanism. The empirical evidence shows that the basic theoretical setting still provides useful predictions in practice. The simple model in this paper also provides intuitive rationale why the government might prefer mixed duopoly to privatization, which is not addressed in previous literature.

This paper is also related to huge literature of gasoline market. In addition to the

estimation of demand for gasoline(Coyle et al. 2012, Sene 2012, Lin and Zeng 2013), this study adds empirical evidence of the impact from market structure on gasoline market outcomes, which is related to Hastings and Gilbert (2005) and Robert Clark et al. (2015).

3 Theoretical Model

In this section, I present a simple theoretical framework used in the previous literature. The analysis will focus on mixed duopoly and compare the market outcomes before and after entry by private firm. Privatization of the public firm is also considered in the model for completeness.

Consider the market for homogeneous good with linear demand:

$$Q = a - bp$$

where $a > 0,\ b > 0$, and Q is the total quantity demanded by the consumers when price is p. Initially, only one public firm serves the market demand possibly due to regulation to block entry. The public firm is the monopoly in the market but not necessarily with profit maximization objective. Let firm 1 be the public firm with cost function:

$$c(q_1) = c_1 q_1$$

where $c_1 > 0$ is firm 1's specific per unit cost, and q_1 is the quantity produced. In monopoly, obviously $Q = q_1$. Following the literature, public firm maximize the total welfare in the market with problem:

$$\max_{q_1} W = q_1(p - c_1) + \frac{q_1^2}{2b} \tag{1}$$

In (1), the first term is public firm's profit, and the second term is consumer's surplus, which is measured by the area between the demand curve and the price. After taking the

first-order condition, we can quickly see that the equilibrium price under monopoly pubic firm is just its marginal cost, $p^M = c_1$, and equilibrium quantity is equal $Q^M = a - bc_1$.

Let's consider entry by a private firm, firm 2, which is maximizing its profit and with more efficient cost function:

$$c(q_2) = c_2 q_2$$

where $c_1 > c_2 > 0$, and q_2 is quantity produced by firm 2. It becomes a mixed duopoly with one public firm and one private firm competing in the market.[1]

The equilibrium is the solution of two firms' problems:

$$\max_{q_1} W_1 = q_1(p - c_1) + q_2(p - c_2) + \frac{(q_1 + q_2)^2}{2b} \tag{2}$$

$$\max_{q_2} \pi_2 = q_2(p - c_2) \tag{3}$$

In addition to consumer surplus and own profit, public firm now also considers private firm's profit because it is part of the total producer surplus. After solving two simultaneous equations, we can get the equilibrium price and quantity under mixed duopoly: $p^D = c_1$, and $Q^D = a - bc_1$. Comparing the market outcomes before and after entry by private firm, the equilibrium price and quantity stay the same. More specifically, the prices are exactly the marginal cost of public firm. The result is also related other oligopoly literature.[2] However, the total welfare increases due to positive profit from

[1] The model here is different from Cremer et al. (1989) despite that both models feature more efficient private firm, constant marginal cost, and Cournot competition. Cremer et al. (1989) assume that public firm pays a constant premium per unit to its worker, while private does not. The premium becomes the difference in marginal cost, and has no effect on total welfare. Besides, both firms incur fixed cost in order to produce output.

[2] Interestingly, the results here coincide with those in typical Bertrand competition, where equilibrium price is the marginal cost of less efficient firm given constant marginal costs. We can also use Bertrand competition to analyze mixed oligopoly. First, with only public firm, the price would equal marginal cost because public firm can set the price directly. With entry by the private firm, the public firm still set price at its marginal cost, and the private firm price at public firm's marginal cost since it has lower marginal cost and can make positive profit. The equilibrium prices stay unchanged with entry by private firm. Since Bertrand competition gives same prediction, pricing at marginal cost, under both mixed duopoly and profit-maximizing duopoly, it's difficult to analyze the effects from heterogeneous objectives. For example, entry by a public firm will induce no change on the market outcomes because the market price is

private firm.

$$W^D = \pi_2 + W^M = b(c_1 - c_2)^2 + \frac{(a - bc_1)^2}{2b} > W^M$$

As long as the private firm is more efficient than public firm, it's welfare-improving for deregulation to allow for entry. The result is mainly driven by the fact that private firm is more efficient. If the efficiency is the same across two firms, there is no incentive to allow for entry since two firms are basically the same.

If we compare the equilibrium market shares for two firms, $q_1 = a + b(c_2 - 2c_1)$, and $q_2 = b(c_2 - c_1)$, public firm will produce more if the cost difference is small or the demand is not very price-sensitive.

$$q_1 - q_2 \geq 0 \;\; if \;\; \frac{a}{b} \geq 2c_2 - 3c_1$$

Since public firm try to maximize total welfare of the market, with consumer's surplus in the objective function, it has incentive to produce more to drive the market price equal its marginal cost. Thus, less efficient firm ends up producing more in the market most of the time.

As keeping public firm in the market can be regarded as one alternative to privatization, let's see what happen in the market with two private firms. To simplify the analysis, I assume that the privatized public firm will gain some efficiency, which reduce the cost c_1 to c_2.[3] With constant cost across firms, the privatized firm's problem becomes:

$$\max_{q_1} \pi_1 = q_1(p - c) \tag{4}$$

the marginal cost under Bertrand competition. We can't even distinguish mixed oligopoly from general oligopoly under Bertrand competition. That's one reason why the literature tends to use Cournot competition to analyze mixed oligopoly. One similarity between Bertrand competition and mixed oligopoly is that both aim at a competitive outcomes. However, I can use Bertrand competition in my model since the paper focuses on the entry by private firm. In Bertrand competition, the equilibrium price in duopoly will be lower comparing to monopoly price. But with public firm, the mixed duopoly will have same price, marginal cost of public firm, as public monopoly. I use Cournot as my model because it is comparable to the literature.

[3] The improvement of performance and efficiency from privatization is widely supported by the literature of privatization from theoretical and empirical standpoints.

The competition becomes traditional Cournot competition with two firms. The equilibrium is given by

$$p^C = \frac{a+2bc}{3b},\ Q^C = \frac{2a-2bc}{3},\ W^C = \frac{2(a-bc)^2}{9b}$$

Comparing the total welfares between monopoly by public firm and privatization with two private firms, $W^C > W^M$ if and only if $c_1 - c_2 > \frac{a}{b}(1 - \frac{2\sqrt{2}}{3}) \equiv \phi$. That is, the efficiency improvement must be big enough to induce welfare improving outcome for privatization. If the demand is inelastic, very small b, the required efficiency gain could be very large and infeasible. Therefore, sometimes keeping a public firm in the market is a better alternative to privatization.

The theoretical model here simply implies one important equation: $p = p^M = p^C = c_1$. First, the equilibrium prices don't change with the entry of private firm. In traditional Cournot competition, as the number of competitors increase, the equilibrium prices will decrease. With social welfare-maximizing public firm, the market outcome behaves differently. Second, the equilibrium price is equal to the marginal cost of public firm. Third, while the market outcomes, price and quantity, are unchanged with entry by private firm, the total welfare increases because some quantities are produced by more efficient private firm.

4 Market Facts and Data

4.1 Market Facts

The gasoline market in Taiwan had been supplied by a state-owned oil company, Chinese Petroleum Corporation (CPC), since 1946. CPC is a vertically integrated firm, with upstream exploration and refining, as well as downstream retail gas stations. In 1996, the government deregulate the gasoline market by allowing private firms to produce, market, sell, and import/export petroleum products. Formosa Petrochemical Corporation

(FPCC) built the only privately owned refinery and entered the gasoline market in 2000. The market structure has become duopoly since then.[4]

The difference in ownership has resulted in different objectives for both firms. CPC is owned by the government. In the annual report of CPC, the major objectives are stabilizing domestic price levels, supplying relevant petrochemical products, and facilitating the development of petrochemical industry. It's fair to say that CPC didn't try to maximize its profit despite the monopoly position for several decades. Instead, it has offered lower gasoline prices comparing to other Asian countries for many years and incurred losses most of the time. On the other hand, FPCC is a publicly traded company owned by its shareholders, and has been the most profitable company in petrochemical industry in Taiwan. As FPCC has to respond to shareholders' interests, there is no clear evidence FPCC doesn't maximize its profit.

In addition to different ownership, two oil companies also differ in production costs. The major input for gasoline is crude oil. Since Taiwan doesn't produce any oil, crude oil needs to be imported from other countries. Besides, since Taiwan is a relatively small market. It's safe to say that two oil firms are price takers for crude oil. The total capacity of two firms are 1.26 million barrel per day, where FPCC accounts for 0.54 million barrel per day and CPC accounts for 0.72 million barrel per day. Both firms are operating under their full capacity. The production technology is stable in the industry, and doesn't exhibit increasing or decreasing return to scale. More crude oil is needed if firms want to produce more gasoline. Hence, the production costs is mainly driven by crude oil prices. CPC has three refineries, which were built during 1950s to 1970s. The maintenance costs are higher for CPC. More importantly these refineries can only use low-sulfur crude oil, which is more expensive than high-sulfur crude oil, as input. In contrast, FPCC built its refinery during 1990s with newer facilities and better desulfurization equipment, and it uses high-sulfur crude oil in the refinery process. Difference in ages of refineries and input prices

[4] Actually, ESSO, a company joint owned by Exxon Mobil and the Pan Overseas Corporation, entered the retail market in 2002. ESSO didn't have its own refinery. It relied on import of the gasoline product. Due to high transportation costs, low market prices for gasoline, and small market shares, ESSO eventually exited the market in less a year.

results in costs difference between public and private firm.[5] However, despite the fact that CPC has higher costs, CPC has accounted for 75% of the market share, while FPCC only supplies a quarter of the total market.

The wholesale and retail gasoline prices from CPC are closely monitored by the government. The prices from FPCC are determined by the private firm as there is no legal regulation to affect the private firm's pricing. FPCC also owns downstream retail gas stations as they follow the reference retail prices from FPCC. There are independent gas stations, which are required to contract with either CPC or FPCC and follow the retail reference prices set by either firms. There is very little price dispersion across local gas stations mainly because they need to follow the reference retail prices. Another reason is that the government conducts random checks in every administrative areas to make sure there is no price war or noticeable deviation from the reference prices.

Essentially, the retail prices of two firms are identical for most of the time in the sample. There are total 43 price adjustments in the sample period of mixed duopoly. Only 8 adjustments resulted in different prices between two firms. The price differences are exactly the same for 92 unleaded and 95 unleaded. I also present a summary table of the difference of price adjustments in the Appendix. Typically, CPC will announce a price adjustment few days before it takes effect, and FPCC will, most of time, follow the price set by CPC with same effective date. During the sample period, the differences in prices occurred in two periods. First, when FPCC first entered the market, it had priced around 1% lower than CPC's prices for 6 months, total 6 adjustments. The pricing strategy could possibly result from the need to establish market shares. During mid 2005, as the oil prices rose, CPC didn't make any adjustment during that time. However, FPCC raised the prices twice, resulting in higher prices for two months. Therefore, the assumption of single price in the theoretical model is mostly satisfied in reality.

In summary, this market has several nice features that fit the theoretical model. First, the market structure is a mixed duopoly with heterogeneous objectives. Second, the prod-

[5] According to news report, the estimated average cost difference is \$0.74 per barrel of oil. Given recent oil price is around \$45 per barrel, the input cost difference is around 2%.

uct is homogeneous. Third, both firms are price takers for input, but they have a clear difference in costs, which is consistent with theoretical assumption. Last, two firms ended up with same prices in the market. Based on these facts and theoretical predictions, I would like to empirically test the model predictions.

4.2 Data

This paper uses data that has been collected by Bureau of Energy under Ministry of Economic Affairs in Taiwan. The data is publicly available. It contains monthly sales of gasoline and diesel, as well as listing wholesale and retail prices from two oil companies. The sample period ranges from January 1998 to December 2006. Before 1998, the data is not available online. The data is available after 2006. However, in 2007, due to the rising crude oil prices and upcoming presidential election, the government imposed price regulation on domestic gasoline market in order to stabilize consumer price level. Oil companies could not raise the price freely at that time. Therefore, I restrict the sample period till 2006 for consistency. The import crude oil prices are also available in the data set. The administration records the monthly quantities and total prices of imported crude oil. It allows me to better control the input prices for gasoline.

In addition to prices and quantities, I also obtain other controlling variables from Directorate General of Budget, Accounting and Statistics. The main controlling variables for demand is real monthly salary and total employment. Salary is a proxy for income as income has been recognized as an important demand shifter in the literature. Employment is also a shifter in my opinion since main gasoline consumptions come form the household car usage. As the employment grows, people would demand for commute and the higher car usages would push the demand.

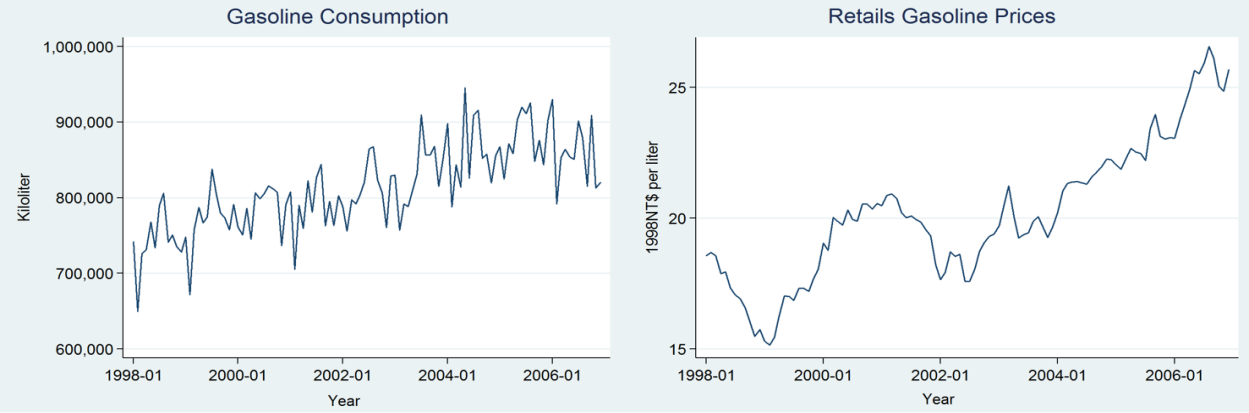
Table 1 present the summary statistics for the monthly variables in the data set I used. Details descriptions on construction of variables are provided in the appendix. In Figure 1, time series for gasoline consumption and retail prices are presented. For gasoline consumption, clearly there are some seasonality. A dip in consumption in a year is possibly

Table 1: Summary statistics

Variable	Mean	S.D.	Median	Max	Min
Quantity	813546	57317	809419	945573	649401
Gasoline Price-whole sample	20.172	2.630	19.947	26.564	15.143
Gasoline Price-before	17.657	1.528	17.327	20.320	15.143
Gasoline Price-after	21.231	2.250	20.815	26.564	17.583
Crude Oil Price	6.273	2.824	5.686	13.522	2.181
Monthly Salary	34360	1167	34718	36120	31366
Employment	9601	272	9502	10228	9245

the result of the Chinese New Year, sometimes in January or mostly in February. During Chinese New Year, people have a long vacation, similar to Christmas, and also there are less days in February. A spike seems to show up during the summer. Therefore, in later section, I will control for the seasonality. For gasoline prices, there is an upward trend. But it's mainly driven by the rise of crude oil prices.

Figure 1: Times series for gasoline prices and quantities



5 Empirical Analysis

The objective of this empirical analysis is to test the predictions from the model in previous section. The results of theoretical model can be summarized as: $p = p^M = p^D = c_1$. The equilibrium price always equals the marginal cost of public firm. It implies: First, the equilibrium prices stay unchanged with entry by private firm; second, the supply doesn't respond to demand shocks; third, the price is equal to marginal cost. For the first implication, we can compare prices before and after entry. The traditional oligopoly theory will predict that the price drops as the number of competitors increase. In contrast, the mixed duopoly will predict that the price stay unchanged. For the second implication, we can estimate the supply curve to see that respond to quantity demanded. Normally, the supply would respond positive to increasing demand. But here the supply won't be affected by quantity. For third implication, ideally, we could compare marginal cost with the price to see if the prediction is true. However, we don't observe marginal cost empirically. Therefore, we need to find the components of marginal cost.

Oil price is an important input cost for gasoline. Although crude oil is the common input for a lot of petrochemical product in the refinery process, gasoline averaged around 45% (by volume) of the refinery output (Borenstein et al. 1997). Besides, oil price is often volatile, and will possibly lead to most of the variation for marginal cost. Therefore, the crude oil price should be the major driver for marginal cost. The relationship could be written as: $p = mc = \theta \times oil\ price + \epsilon$. Based on the equation, the gasoline price should be driven by oil price, and other variables, such as entry or quantity, are not relevant to the price because they don't impact the marginal cost of public firm.

I start with reduced-form regression of price on oil price, entry and quantity. In the regression, oil price captures around 90% of the price variations, and the coefficient, close to 1, is significant and positive. The regression results indicate that the price could be highly related to marginal cost, if we accept that the marginal cost is driven by oil price. But it doesn't necessarily mean that oil price equals marginal cost. Other components, such as labor cost, or maintenance cost, could be relevant even they might just contribute

Table 2: Reduced-Form Regression

Gasoline Price	(A)	(B)	(C)	(D)	(E)
Entry	3.575***	—	—	.384*	.507**
	(9.59)			(1.72)	(2.28)
Oil Price	—	.887***	—	.848***	.884***
		(33.36)		(26.92)	(24.29)
Quantity	—	—	$-3 \cdot 10^{5}$***	—	$-4 \cdot 10^{6}$*
			(7.73)		(-1.85)
Obs.	108	108	108	108	108
R^2	0.40	0.906	0.352	0.909	0.91

Notes: *:p-value<0.1, **: p-value<0.05, ***: p-value<0.01 T-statistics in parentheses below estimates.

a small portion of marginal cost. From theoretical perspective, the model would expect that the other variables, entry and quantity, have insignificant coefficients. For the entry dummy, the coefficients are positive, which is contradicting if we assume both firms are maximizing profits. Under profit-maximizing behavior for both firms, the price should go down if there are more firms in the market. The positive sign could be resulted from the positive trend for oil prices.[6] However, the magnitude is reduced when controlling for oil prices.

Next, I would like to estimate the linear demand and supply system with exogenous shifters.

$$Q_t = \beta_0^d + \beta_1^d P_t + \beta_2^d Y_t + \beta_3^d L_t + \alpha_{1-3}^d S_{1-3} + \varepsilon_t^d \tag{5}$$

$$P_t = \beta_0^s + \beta_1^s Q_t + \beta_2^s C_t + \beta_3^s E_t + \varepsilon_t^s \tag{6}$$

where subscript t stands for month t, Q_t is the monthly quantity, P_t is the per liter real

[6] Another explanation for the positive sign of entry coefficient is that the entry shifts the demand in the input market. As the demand for input increases, the input price could rise in response to that. However, it's unlike to be the case in this gasoline market since both firms are price takers in the oil market. Besides, the total amount of oil import in Taiwan is very small relative to the whole world.

price, Y_t is the monthly real salary, L_t is the monthly total employment, S_{1-3} are dummies for each season, C_t is the import crude oil prices, and E_t is dummy variable for entry.[7] Based on $p = mc = \theta \times oil\ price + \epsilon$, the only relevant variable in the regression should be oil price alone. However, I would like to see if other variables have any impact on the price. The demand curve is linear here because I assume a linear demand in the theoretical model.

Obviously, the price and quantity are simultaneously determined in the system of equations. That immediately creates endogenous problem. One common way to deal with that is to use instrumental variables. In other words, I need demand and supply shifters to identify supply and demand curves. The shifters need to satisfy two conditions: relevance condition, and exclusion condition. The variables included in the demand and supply are natural candidates for instrumental variables. Since they are exogenously determined outside the supply and demand system, they provide identification for the supply and demand curves by satisfying relevance condition. Here I first use two-stage least square estimation. Then I use three-stage least square because the equations are over-identified. It would be more efficient to use 3SLS.

Table 3 presents the estimation results under linear specification. The estimation for demand is expected in the sense that the signs of coefficients are consistent with tradition theories. The magnitude is difficult to interpret because I don't adjust the variables by rescaling. The estimates with 2SLS and 3SLS are similar.

For supply, essentially the theoretical model implies that the supply is a flat line which is driven by marginal cost of the public firm. The supply should not be affected by the entry and the quantity demanded. Here the coefficients of quantity are close to zero and somewhat negative. This is expected from the theoretical prediction as public firm don't respond to positive shocks on demand by raising prices. Instead, public firm produces more and meet the market demand by setting the prices equal to marginal costs. Input

[7] Here I assume that entry affect supply as a dummy. However, based on the theoretical prediction, the entry has no effect on supply. Therefore, I can also interact the dummy with other variables. The coefficients are expected to be insignificant. The regression results are presented in the Appendix.

Table 3: Estimation Results with linear specification

	2SLS		3SLS	
Variable	Demand (Quantity)	Supply (Price)	Demand (Quantity)	Supply (Price)
Price	-12382***	—	-12429***	—
	(-3.26)		(-3.30)	
Salary	29.048***	—	29.261***	—
	(6.76)		(6.85)	
Employment	158.355***	—	157.343***	—
	(4.78)		(4.79)	
Entry	—	.451**	—	.415*
		(1.99)		(1.85)
Quantity	—	-.000	—	-.000
		(-0.74)		(-0.72)
Oil Price	—	.868***	—	.871***
		(20.37)		(20.48)
Obs.	108	108	108	108
R^2	0.72	0.92	0.72	0.92

Notes: *:p-value<0.1, **: p-value<0.05, ***: p-value<0.01 T-statistics in parentheses below estimates.

price is significant and positively related to price. The coefficient is also close to 1. That is, the gasoline price is mainly driven by the oil price. The coefficients of entry are positive just like the results in reduced-form regression. One possible explanation is that some minor component of marginal cost have increasing trend, which is capture by the entry dummy. I also interact entry dummy with other variables in other regression. The results also indicate that the supply doesn't respond to the quantity, and entry doesn't affect the price in the market. Detailed regression results are presented in the Appendix.

$$ln(Q_t) = \beta_0^d + \beta_1^d ln(P_t) + \beta_2^d ln(Y_t) + \beta_3^d ln(L_t) + \alpha_{1-3}^d S_{1-3} + \varepsilon_t^d \tag{7}$$

$$ln(P_t) = \beta_0^s + \beta_1^s ln(Q_t) + \beta_2^s ln(C_t) + \beta_3^s E_t + \varepsilon_t^s \tag{8}$$

Table 4: Estimation Results with log-linear specification

	2SLS		3SLS	
Variable	Demand (Quantity)	Supply (Price)	Demand (Quantity)	Supply (Price)
Price	-.176**	—	-.180**	—
	(-2.12)		(-2.18)	
Salary	1.197***	—	1.253***	—
	(6.56)		(6.90)	
Employment	1.337***	—	1.282***	—
	(3.94)		(3.80)	
Entry	—	-.010	—	-.011
		(0.402)		(-0.89)
Quantity	—	-.204*	—	-.204*
		(-1.73)		(-1.73)
Oil Price	—	.301***	—	.302***
		(18.69)		(18.74)
Obs.	108	108	108	108
R^2	0.72	0.91	0.72	0.91

Notes: *:p-value<0.1, **: p-value<0.05, ***: p-value<0.01 T-statistics in parentheses below estimates.

In Table 4, I use log-linear specification for the demand and supply, which are presented in equation (7) and equation (8). Under this specification, the coefficients can be interpreted as elasticity. It helps in both interpretation and comparison. Demand elasticity is around -0.18, which is close to the elasticities found in other studies. Income elasticity, around 1.2, is also consistent with the results found in previous literature. Overall, the estimation results for demand seem to be on the right track. For supply estimation, similar to the linear specification, the coefficient for quantity is negative and marginally significant. For the entry dummy, the coefficients actually switch signs in log-linear specification. Although the signs are negative, they are not significant at all. This is consistent with the theoretical prediction: the market prices are driven by marginal costs, and change in the number of firms don't affect the equilibrium prices. Besides, one possible explanation for that result is that taking log on prices smooths the upward trend of prices. In previous linear model, the positive coefficient might capture some of the upward trend.

But here, the trend becomes smoother, and conditional on input prices the entry dummy doesn't account for much of the variation.

6 Conclusion

This paper studies the effects of mixed duopoly in a gasoline market. As the public firm aims at maximizing total welfare, the market outcomes would not change even with entry by private firm. Empirical evidence shows that before and after entry the market prices don't decrease due to competitive effects. The estimated supply also indicates that market supply doesn't respond to positive demand shocks. The market outcomes under mixed market structure are vastly different from those under traditional profit maximization assumption.

While this study provides empirical evidence for mixed duopoly, the theoretical setting and market structure are relatively simplified. As most mixed markets feature differentiated products, more empirical work and theoretical models are needed to answer more interesting questions regarding heterogeneous objectives.

Possible extension emerge from this analysis. If we accept the argument that the price is the marginal cost of the public firm, then we can calculate the counter-factual prices under profit maximizing objective. Thus, welfare analysis can be done and the value of the existence of the public firm can be estimated. Besides, This study is restricted monthly market-level data, which forgoes price variation between two firms. In fact, both firms could adjust prices multiple times within one month. Given the timing of price adjustments, access to weekly or daily sales of gasoline could help the analysis of pricing strategies which potentially respond to the other firm's price and the volatility of crude oil prices.

Appendix

Table 5: List of Variables

Quantity	There are two types of gasoline, 92 unleaded and 95 unleaded, in the market. However, the data I got didn't distinguish these two products. So, I use the combined total monthly sales within the country. The unit is kiloliter. One kiloliter is equivalent to 264 gallons.
Gasoline Price	Since I can't distinguish the gasoline products, I need to construct the gasoline prices from available price data. First, before FPCC's entry, I can take the weighted average of retail prices for 92 and 95 unleade gasoline from CPC. The shares of gasoline sales is around 25% for 95 unleaded and 75% for 92 unleaded during my sample period. After entry, I need to take the weight average retail prices for two firms and then weigh the prices with their market shares. The retail prices from two firms are very close, mostly identical. The unit for price is NT$, the legal currency in Taiwan. I adjust the price with CPI to get real prices instead of nominal prices.
Crude Oil Price	Crude oil price are the imported prices. I convert the prices into NT$ by multiplying the monthly foreign currency rate released by the Central Bank. Also, the prices are adjusted with CPI to get real prices. The unit is the same as gasoline price.
Monthly Salary	The monthly salary is the regular real monthly salary, which don't include bonus, from employees within the country. Directorate General of Budget, Accounting and Statistics publishes the data monthly. The unit is NT$.
Employment	Employment is the monthly total number of people employed. The unit is thousand people.
Entry	The entry took place in September 2000. Before that month, the dummy variable is zero. Otherwise, the dummy is one.

Table 6: Summary statistics for the difference of gasoline prices between two firms

Variable	Mean	S.D.	Median	Max	Min	Q1	Q3	Obs.
Diff. 92 unleaded	-0.042	0.387	0	0.2	-2.4	0	0	43
Diff. 95 unleaded	-0.042	0.387	0	0.2	-2.4	0	0	43

Table 7: Estimation Results with lagged quantity

	2SLS		3SLS	
Variable	Supply	(Price)	Supply	(Price)
Entry	.636***	(2.83)	.542*	(1.85)
L.Quantity	-.000**	(-2.50)	-.000**	(-2.62)
Oil Price	.930***	(20.37)	.906***	(23.14)
Obs.	107		107	
R^2	0.91		0.92	

Notes: *:p-value<0.1, **: p-value<0.05, ***: p-value<0.01 T-statistics in parentheses below estimates.

It's possible that firms respond to the quantity in last month, and adjust prices accordingly in next month. That is, if there is higher demand in last month, firms might raise prices as they see some signs of increased demand. If that's the case in gasoline market, the regression of contemporaneous quantity on price might yield insignificant coefficient for quantity on price. Then firms could still adjust prices in response to demand, but in a lagged fashion. I think one way to check this issue is to use lagged quantity as independent variable and see how price respond to that. The regression is shown below. The results indicate that the price responds negatively to the quantity in last month. One possible explanation is that the public firm lowered the price in response to the increased demand due to instructions by the government. The response could possibly stabilize the domestic price level as the demand could drive the gasoline price up and in turn drive prices of other commodities. Overall, there are evidence for different short-term and long-term effects. But that doesn't change the conclusion that public firm is acting to induce a more competitive market outcomes.

Table 8: Estimation Results with interaction terms

	2SLS		3SLS	
Variable	Demand (Quantity)	Supply (Price)	Demand (Quantity)	Supply (Price)
Price	-15545***	—	-15353***	—
	(-4.49)		(-4.55)	
Salary	30.292***	—	32.34***	—
	(7.03)		(7.60)	
Employment	181.918***	—	169.20***	—
	(5.83)		(4.79)	
Entry	—	-4.61	—	7.05
		(-0.87)		(1.38)
Quantity	—	-.000*	—	-.000
		(-1.87)		(-0.19)
Oil Price	—	1.377***	—	1.184***
		(7.97)		(7.11)
Entry×	—	.000	—	-.000
Quantity		(1.24)		(-0.96)
Entry×	—	-.518***	—	-.282*
Oil Price		(-2.92)		(-1.66)
Obs.	108	108	108	108
R^2	0.72	0.92	0.72	0.92

Notes: *:p-value<0.1, **: p-value<0.05, ***: p-value<0.01 T-statistics in parentheses below estimates.