ABSTRACT

Title of Dissertation: ESSAYS ON PRICE COMPETITION AND FIRM STRATEGIES IN OLIGOPOLIES

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This dissertation is part of the effort to contribute to our understanding of Price Competition and Firm Strategies in oligopolistic markets with certain characteristics. It comprises of three chapters. Chapter 1 provides the introduction and background of the research and a brief summary of results.

Chapter 2: Firms practice poaching of their rival's customers in markets where they are able to identify between their own customers and those of the rivals. This practice results in inefficiently high switching. In some of these markets firms also use strategies that make poaching by rival firms harder. In this chapter I explore the practice of firms requiring customers to sign contracts that are of pre-specified duration specifying early termination charges (or breach penalty). If contract with breach penalty is available,

firms find it privately optimal to use it. However when all firms use it they are worse off and results in lower than efficient switching. Consumers may be better off or worse off.

Chapter 3: In this chapter we examine the pricing decision of a typical firm that sells more than one product in markets where products are strategic complements and the firms have some market power. We show that such a firm internalizes the strategic complementarities when optimally choosing its prices leading to higher prices. We then empirically test and confirm in the US wholesale market for unbranded gasoline that a major refiner charges a higher wholesale price for unbranded gasoline in cities where it also sells its brand gasoline at retail compared to cities where it does not. Furthermore, in the cities where the refiner has brand presence at retail we find empirical evidence that its wholesale price of unbranded gasoline is higher the higher is the market share of its brand in retail.

ESSAYS ON PRICE COMPETITION AND FIRM STRATEGIES IN OLIGOPOLIES

By

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DEDICATION

To my parents for their constant support.

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Chapter 1.

Introduction.

Starting from the seminal paper by Bertrand[1], which led to the introduction of the Bertrand Paradox, price competition among oligopolistic firms has always been a rich area of research for both Industrial Organization Theory and Applied Microeconomics. Unlike in perfect competition or a monopoly, firms in an oligopolistic market structure face an environment where rival firms anticipate their actions and counter them. Firms therefore need to make strategic decisions based on the information available to them. In the short run, one of the most important strategic choice variables is the price (others include advertising and sales intensity). The optimal choice of price is often the most important strategic decision facing businesses and therefore the study of strategic price competition not only has a strong academic appeal but also a useful practical side. However price competition never occurs in a vacuum. There always exist other instruments or conditions which either facilitate or hinder price competition. There is a vast economic literature, both theoretical and empirical which studies price competition in the presence of these other instruments or conditions dating back to Edgeworth[2] (1897) and Hotelling[3] (1929). Edgeworth looked at price competition with firms facing capacity constraints in the sense that they cannot sell more than they are capable of producing.

[1] Bertrand, J. 1883. Theory Mathematique de la Richesse Sociale. Journal des Savants, pp 449-508
[2] The Pure Theory of Monopoly, in *Papers Relating to Political Economy,* volume 1, ed. F. Edgeworth (London: Macmillan, 1925)
[3] Hotelling, H. 1929 “Stability in Competition” Economic Journal 39. 41-57

Hotelling introduced product differentiation in the form of transportation cost. Introducing these extra conditions led to the resolution of the Bertrand Paradox!

This dissertation is part of the effort to contribute to our understanding of price competition and firm strategies in oligopolistic markets with certain unique characteristics. It comprises of three chapters. Chapter 1 provides the introduction and background of the research work. In chapter 2 we study price competition in markets where firms can identify between its own customers and rival firms customers and where switching costs are present. In such markets, firms often compete for new and rival firm's customers by offering discounts to entice them to switch suppliers, a practice known as consumer poaching. This chapter looks at the common practice in the cellular phone service industry in the US of requiring customers to sign contracts with early termination fees as a means to counter consumer poaching.

Chapter 3 looks at price competition in markets where strategic complementarities are present and look at optimal pricing decisions of firms that sell two products that are strategic complements. In a simple model we show that such a firm internalizes these complementarities while optimally choosing prices and as a result charges a higher price compared to a firm that sell only one product. We then find empirical evidence for the above in the wholesale market for gasoline in the United States. In such local wholesale markets for unbranded gasoline, we find that refiners that sell both branded and unbranded gasoline charge a higher price for unbranded gasoline compared to refiners that sell only unbranded gasoline.

1.1 Motivation and Introduction to Chapter 2:

Chapter 2 looks at markets that have a unique feature commonly observed in subscription markets for services for example, the credit card market, cable and long-distance telephone service, insurance market, etc. In such market, firms that provide the services can usually identify between their own customers and rival firm's customers. Firms in these markets practice poaching, i.e., enticing the rival firm's customers to switch suppliers by offering discounts. We examine price competition in such markets in which consumers incur costs to switch between firms and are thus partially locked in. Firms on the other hand can price discriminate between its locked customers and new customers (or rival firm's customers).

Price Competition in the presence of switching costs has received wide attention in the literature[4]. Von Weiszacker[5](1984) first looked at a model with switching costs and showed that higher switching costs may make markets more competitive. The reason is that higher switching cost combined with uncertain consumer future tastes makes consumers more farsighted. Current choices are influenced more by the future, making current preferences less important and therefore making the products less differentiated. Klemperer[6] (1987) observes rightly that the above conclusion depends on the assumption that firms would charge the same prices in subsequent periods. In a model which allowed firms to charge a different price in later periods, Klemperer showed that the presence of switching costs make demand more inelastic in both the initial and subsequent periods and may make market less competitive in both periods. Chen[7](1997) extends

[4] See, for example, Klemperer (1987a, b), Farrell and Shapiro (1988), Beggs and Klemperer (1992), Padilla (1992, 1995). Klemperer (1995) provides an excellent survey of the literature
[5] Von Weizsacker, C. C. " The Costs of Substitiution" Econometrics, Vol. 52(1984), pp 1085-1116
[6] Klemperer P. "The Competitiveness of markets with switching costs" *Rand Journal of Economics.* Vol. 18 (1987a) pp 137-150
[7] Chen, Y. " Paying Customers to Switch", *Journal of Economics and Management Strategies,* vol. 6(1997) pp 877-897

Klemperer's case to allow firms to price discriminate between existing customers and new customers and showed in a two-period homogeneous good duopoly model that firms are worse off engaging in this practice of price-discrimination (or poaching) and results in excessive switching in equilibrium. In his model however, switching is always inefficient because net of the switching costs consumers are identical and goods are homogeneous. Taylor[8] (2003) looked at the case where there are more than two firms and showed that the market becomes fully competitive only when there are more than two firms. Each firm earns economic rent on its customer base but zero economics profit. The fully competitive equilibrium leads to higher (inefficient) switching.

The above papers miss one important feature that is common in the US cell phone service industry. Service providers commonly require new customers to sign fixed length contracts specifying early termination charges (breach penalty) if they switch providers before the end of the contract. This provides an instrument to the firms to counter consumer poaching by rivals. Introduction of this new feature changes the structure of the price competition in two important ways, (1) switching costs become endogenous through contractual provisions and (2) firms are able to commit to second period prices through the contract.

I examine a two-period duopoly model where firms are homogeneous in the first period but in the second period, firm specific tastes (in the manner of Hotelling) and switching costs emerge and where one or both firms offer a two period pricing contract along with a breach penalty. Note that despite ex ante homogeneity, firms earn positive profits because there is ex post differentiation in the second period. I show that, when

[8] Taylor, C " Supplier Surfing: Competition and Consumer Behavior in Subscription Markets" *RAND Journal of Economics,* Vol. 34, no. 2 Summer 2003, pp 223-246.

contracts are feasible, not using contracts does not survive iterative elimination of dominated strategies. Offering a contract with breach penalty (CWP) is an optimal response. If the rival firm is not locking in customers, the other firm wants to. However in equilibrium when all firms use CWP first period competition yields lower firm profits than would occur if contracts were not feasible. Also compared to the previous literature, in the equilibrium with CWP there is less switching than is socially efficient. Contracts prevent some efficient switching. The result is quite interesting because it has been often commented upon that this practice disadvantage customers by locking them in and conversely, firms profit by using this practice. In fact, we find that the opposite is true.

1.2 Motivation and Introduction to Chapter 3:

Chapter 3 looks at Price Competition in markets with strategic complements. The industry I study is the wholesale markets of gasoline in the United States where branded and unbranded gasoline are considered strategic complements. In a seminal paper, Bulow, Geanakoplos and Klemperer[9] (1985) introduced the concept of strategic complements and substitutes. In oligopolistic markets the distinction between strategic complements and substitutes is determined by whether a more "aggressive" strategy by one firm raises or lowers the other's marginal profit from an increase in its own strategy. In short, two products are defined as strategic complements in price if an increase in price of one product increases the marginal profitability of raising the price of the other product. The converse is true for strategic substitutes. We examine the pricing decision of a firm that sells more than one product in markets where products are strategic complements and the firms have some market power. In a simple theoretical model I

[9] Bulow, J., Geanakoplos, J., Klemperer, P. " Multimarket Oligopolies: Strategic Substitutes and Complements", *Journal of Political Economy,* 1985, vol. 93, no. 3

show that a firm that sells two products that are strategic complements internalizes these complementarities when optimally choosing the prices. It results in higher prices compared to a firm that sells only one product.

In the empirical part of the chapter, I find evidence of the above in the wholesale market for unbranded gasoline in the United States. There has been some amount of previous empirical literature on the wholesale gasoline industry in the United States (see Kapoor (2003), Hastings[10] (2004), etc). Borenstein and Shepard[11] (2002) find that wholesale prices of gasoline respond with a lag to crude oil cost shocks due to the presence of adjustment cost in production and inventory. They also find that refiners have market power in the wholesale markets and that those with more market power adjust more slowly. Pinske, Slade and Brett[12](2003) finds that competition is highly localized in the wholesale market for unbranded gasoline. The empirical part of chapter 3 is closest to Gilbert and Hastings[13] (2005) who examined the relationship between vertical integration and wholesale prices of gasoline. They looked at the 1997 acquisition by Tosco of Unocal's west coast refining and retailing assets and find evidence consistent with the strategic incentive to raise rivals' cost. They concluded that, in the presence of upstream market power, changes in vertical market structure can have substantial impact on upstream firm conduct and on equilibrium prices.

In the United States wholesale market for gasoline, the sellers are the refiners who may be either Majors, like BP, Shell, Chevron, etc. or Independent refiners who do not

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10 Hastings, J. " Vertical Relationships and Competition in Retail Gasoline Markets: Empirical Evidence from Contract Changes in Southern California" *American Economic Review*, March 2004

11 Borenstein, S. and Shepard, A. " Sticky Prices, Inventories, Market Power in Wholesale Gasoline Market" *Rand Journal of Economics* vol. 33 no. 1 Spring 2002 pp 116-139

12 Pinske, J., Slade, M.E., Brett, C. "Spatial Price Competition: A Semi Parametric Approach" *Econometrica* Vol. 70 , No. 3 (May 2002) pp 1111-1153.

13 Gilbert, R. and Hastings, J." Market Power, Vertical Integration and the Wholesale Price of Gasoline", *Journal of Industrial Economics,* vol. 53, no. 4 (December 2005) pp 469-492

have a brand name at retail. Majors sell both branded and unbranded gasoline at many wholesale markets whereas Independent refiners sell only unbranded gasoline. So majors that sell both types of gasoline at a market have a strategic incentive to internalize the complementarities when optimally choosing price. In our empirical section we looked at the price of unbranded gasoline charged by refiners that sell both branded and unbranded gasoline at the wholesale markets compared to price charged by refiners selling only unbranded gasoline. We perform two types of empirical exercises depending on the scope of the data available. The first exercise is for the whole set of refiners (firms) selling wholesale unbranded gasoline in the United States and for all city terminals located in the United States in the time period of our analysis. For this dataset we only have information on whether a refiner sells only unbranded gasoline (one product) or both unbranded and branded gasoline (two products) but no additional information on the market shares of the refiners. The main result of this exercise is that refiners that sell both unbranded and branded gasoline at a city terminal charge a higher price for unbranded gasoline compared to refiners that sell only unbranded gasoline.

The second empirical exercise is done for a major refiner, Marathon Petroleum, which operates in 99 city terminals (wholesale markets). The wholesale dataset is augmented with the share[14] of Marathon brand retail stations. This share is a proxy for the market share of Marathon's branded gasoline. Marathon has retail brand presence in a little more than half of the 99 markets (city terminals) where it sells wholesale unbranded gasoline. The main results of this empirical exercise are the following. First, we find that Marathon charges a significantly higher price for unbranded gasoline in those markets

[14] By share here, we mean the share retail stations selling Marathon Brand gasoline to the total number of retail stations in the market. This is a proxy measure for the market share of Marathon Brand Gasoline at the wholesale level.

where it also sells branded gasoline (i.e., has retail brand presence). This results in similar to the result obtained from first exercise. Second, the share of Marathon brand retail stations has a positive and significant impact on the price Marathon charges for unbranded gasoline. This suggests that the gain from internalizing the strategic complementarities is increasing in the market share of the second product. Third, in a non-linear specification of the reduced form estimation, we find that the price of unbranded gasoline charged by marathon is concave in the share of its branded retail stations. Finally, we find that the number of refiners selling unbranded gasoline in the wholesale market has a negative and significant impact on the price of unbranded gasoline charged by Marathon. This result confirms the accepted view that competition at the wholesale level is important for keeping prices low.

Chapter 2.

Countering Consumer Poaching: The case of Contracts with Breach Penalty.

2.1 Introduction

In many business settings firms are able to identify between their own customers and new (rival firm's) customers. In such settings firms often practice pricing policies where they offer discounts to new (rival firm's) customers in markets with switching costs. An example of a market where such a pricing policy is commonly observed is the market for long distance telephone services in the United States where rival firms routinely offer discounts (monetary or in the form of free long distance minutes of comparable monetary value) to rival firm's customers to switch. Others examples are the market for credit cards and the market for high-speed internet service. This type of competition where firms offer consumers enticement to switch suppliers is common in subscription markets for homogeneous goods [Taylor 2003]. In a two period homogeneous good duopoly model, Chen [97] showed that in equilibrium firms are worse off engaging in this practice of poaching on rival firm's customers than if they can't discriminate between customers. Furthermore consumers need not necessarily benefit from it. There is excessive switching in equilibrium. Since switching is never efficient in a homogeneous goods model with switching cost the dead weight loss to society of switching is higher. Taylor [2003] extended Chen's results for the case where there are more than two firms in the market and showed that the market becomes fully competitive only when there are more than two firms. Each firm earns economic rent on its customer base but zero economics profit. An interesting result that he showed was that the fully competitive equilibrium leads to higher (inefficient) switching.

It is interesting to note that the above papers have focused on only one part of the business practice by the firms, viz. trying to poach on rival firms customers. However firms also develop strategies that make it harder for rival firms to entice their present customers to switch or in the event they actually switch, the firm can extract some rent from their rivals. For example it is common practice in the US Cellular phone industry for customers to sign contracts (one year or two years) with the service provider. Such a contract specifies price for the length of the contract and an early termination fee (breach penalty) if the customer switches to a different provider before the contract expires. This is an instrument, which increases the switching cost of the consumers. In the light of the results of the above papers my research questions are the following.

Could the practice of contracts with breach penalties be used by firms as an instrument to mitigate excessive poaching by rival firms?

How does the equilibrium with contracts and penalties compare to the one when firms can't use this practice? In particular how do firms profits compare when they can use contracts with penalties?

I look at a model where firms are homogeneous in the first period but in the second period switching costs and possibly, firm specific tastes emerge. I examine two cases. The "Base Case" is like Klemperer (1987 a) and Chen (1999), where firms compete in each period. Firms can identify incumbent customers and charge them different prices. In the "Contract with Breach Penalty" (CWP) case, one or both firms offer a two period pricing contract along with a breach penalty in the first period .

Note that despite ex ante homogeneity, firms earn positive profits because there is ex post differentiation in period 2. In the base case, firms price below marginal cost in the first period, and compete vigorously in the second period for rival customers. Compared to the efficient outcome, there is excessive switching. In CWP, I show that offering a contract with breach penalty is privately optimal. If the rival firm is not locking in customers, the other firm wants to. In CWP, there is less switching than is socially efficient. Contracts prevent some efficient switches. Also I find that in CWP, first period competition yields lower firm profits than would occur if contracts were not feasible.

2.2 The Homogeneous product model

2.2.1 The Base Model

Consider the two period homogeneous good duopoly model. There are two firms A and B selling a homogeneous good. Both firms produce the good at a constant marginal cost c. There is a continuum of consumers with mass normalized to one. There are two periods and each consumer demands a unit of the good in each of the two periods. Consumers have high enough reservation value for the good that all consumers buy one unit of the good in each period. In the second period if a consumer switches firms, she incurs a switching cost (exogenous), s, which she learns privately at the beginning of the second period. We assume that s is distributed uniformly over the interval [0,1]. Firms have a discount factor δ_F and consumer have a discount factor, δ_C. We assume that $0 \le \delta_C \le \delta_F \le 1$. In the second period firm can tell whether a consumer is its first period consumer or that of the rival. So the firm can poach (price discriminate) on the consumers of the rival firm in the second period. As a benchmark case, let us consider the case where long term contract with breach penalty is not available as an instrument to the firms.

2.2.1a Second Period Competition

In the second period each firm has an established market share from the first period, α for A and $1-\alpha$ for firm B. Firm i chooses two prices in the second period: a price p_{ii} that it charges to its previous period customers and another price, p_{ij} to the firm j's previous period customers who switch to i in the second period (i, j = A or B). Now consider the marginal consumer of firm A who is indifferent between switching to B or staying with A. Her realization of switching costs, s is such that the following is true.

$$p_{AA} = p_{BA} + s$$

$$\Rightarrow s = p_{AA} - p_{BA}$$

Let q_{ij} be the mass of consumers who bought from j in the first period and from i in the second period.

Then,

$$q_{AA} = \alpha[1 - F(s)] = \alpha[1 - p_{AA} - p_{BA}]$$

and,

$$q_{BA} = \alpha F(s) = \alpha[p_{AA} - p_{BA}]$$

Similarly, consider the marginal first period consumer of firm B who is indifferent between switching to A or staying with B. She has an s such that the following is true,

$$\begin{aligned} & p_{BB} = p_{AB} + s \\ \Rightarrow \quad & s = p_{BB} - p_{AB} \end{aligned}$$

Then,

$$q_{BB} = (1-\alpha)[1 - F(s)] = (1-\alpha)[1 - p_{BB} + p_{AB}]$$

and,

$$q_{AB} = (1-\alpha)F(s) = (1-\alpha)[p_{BB} - p_{AB}]$$

The second period profit of firm A can then be written as:

$$\begin{aligned} \pi_{A2} &= (p_{AA} - c)q_{AA} + (p_{AB} - c)q_{AB} \\ &= (p_{AA} - c)\alpha[1 - p_{AA} - p_{BA}] + (p_{AB} - c)(1-\alpha)[p_{BB} - p_{AB}] \end{aligned}$$

The first term is the profit from first period customers who choose to stay with A in the second period and the second term is profit from the rival firm's first period customers who switch to firm A in the second period.

Similarly, B's second period profit is given by:

$$\begin{aligned} \pi_{B2} &= (p_{BB} - c)q_{BB} + (p_{BA} - c)q_{BA} \\ &= (p_{BB} - c)(1-\alpha)[1 - p_{BB} - p_{AB}] + (p_{BA} - c)\alpha[p_{AA} - p_{BA}] \end{aligned}$$

Firm A chooses p_{AA} and p_{AB} to maximize π_{A2} taking second period prices of firm B as given and firm B chooses p_{BB} and p_{BA} to maximize π_{B2} taking second period prices of firm A as given. The first order conditions yields the following best response functions of firm A and B:

$$p_{AA}=\frac{1}{2}(1+c+p_{BA})$$
$$p_{AB}=\frac{1}{2}(c+p_{BB})$$
$$p_{BB}=\frac{1}{2}(1+c+p_{AB})$$
$$p_{BA}=\frac{1}{2}(c+p_{AA})$$

The second order sufficient conditions are satisfied. Solving the above equations simultaneously yields the unique Nash equilibrium prices of the second period stage game.

$$p^*_{AA} = p^*_{BB} = c+\frac{2}{3}$$
$$and \;\; p^*_{AB} = p^*_{BA} = c+\frac{1}{3}$$

Note that in the equilibrium firms charge a lower price to rival’s first period customers to induce them to switch. There is second period switching in the equilibrium. In fact, one-third of the total customer population switch firms in the second period. Given that the product is homogeneous and switching is costly this is clearly inefficient

Substituting the second period equilibrium prices in the firms’ second period profit we can derive the following second period equilibrium profits of the firms:

$$\pi^*_{A2} = \frac{1}{9} + \frac{1}{3}\alpha$$
$$\pi^*_{B2} = \frac{1}{9} + \frac{1}{3}(1-\alpha)$$

Note that, the second period profits of each firm is increasing in its first period market share. Firms compete for market shares in the first period.

2.2.1b First Period Competition

Consider consumer's choice of firms in the first period. Since both firms charge the same price in equilibrium in the second period, consumer's choice of firms in the first period depends solely on the first period prices. Since consumers are ex-ante identical, all consumers will choose A, $(i.e., \alpha = 1)$ if the first period price of A is less than that of B, i.e., $p_{A1} < p_{B1}$. Conversely all consumers will choose B, $(i.e., \alpha = 0)$ if $p_{A1} > p_{B1}$. If $p_{A1} = p_{B1}$, we assume that consumers choose A and B with equal probability. So $\alpha = \frac{1}{2}$ if $p_{A1} = p_{B1}$.

Proposition 1.

There exists a unique subgame perfect equilibrium of the game. The subgame perfect equilibrium is characterized as follows. In the first period both firms charge the same price:

$$p^*_{A1} = p^*_{B1} = c - \frac{\delta_F}{3}$$

and in the second period each firm chooses prices p_{ii} *and* p_{ij} *optimally as described in the previous section.*

The formal proof is given in the appendix. The intuition is simple. Because of the presence of switching cost in the second period, firms can charge a higher price to its customers in the second period. Firms earn positive profits in the second period which are increasing in first period market shares. So firms compete for market share in the first period. This leads to intense price competition in the first period yielding first period prices less than marginal cost. The firms earn the same two-period equilibrium discounted profits given by:

$$\pi_A^* = \pi_B^* = \frac{1}{2}\left(c - \frac{\delta_F}{3} - c\right) + \delta_F\left(\frac{1}{9} + \frac{1}{6}\right) = \frac{\delta_F}{9} > 0$$

Note that firms earn positive profits. This is because each firm can guarantee itself of at least the equilibrium profit by not competing in the first period and poaching on its rival firm's customers in the second period. So equilibrium profits are not driven down to zero. This equilibrium profit is however known to be lower[15] than that if firms were not able to poach on rival firm's customers in the second period.

The expected surplus of a consumer who bought from firm i in the first period can be expressed as:

$$EU^i = (v - p_{i1}) + \delta_c[(v - p_{ii})q_{ii} + (v - p_{ji} + E[s \mid switch])q_{ji}]$$

The first term is first period surplus and the second term is discounted second-period expected surplus. The first term of which is surplus if the consumer stays with the same firm in the second period times the probability that she will stay and the second term is expected surplus of switching in the second period times probability of switching. In

[15] Chen [97] has shown this to hold true. CHEN, Y. " Paying Customers to Switch " Journal of Economics and Management Strategies, Vol. 6(1997), pp 877-897

equilibrium the expected consumer surplus of buying from firm A is the same as that buying from firm B and is given by:

$$EU^{i*} = (v-c)(1+\delta_c) + \frac{1}{3} - \frac{5}{18}\delta_c$$

2.2.2 Contracts with Breach Penalty (CWP)

Definition 1:

A contract with breach penalty (CWP) is a 3-tuple (p_{i1}, p_{ii}, τ_i) *where* p_{i1} *and* p_{ii} *are defined as before and* τ_i *is a breach penalty to be paid by the first period customer if she switches to firm j in the second period.*

Consumer's first period choice:

We assume that consumers are rational and they have a discount factor, δ_c. A rational consumer will choose A over B if her expected consumer surplus from choosing A in the first period is greater than that from choosing B., i.e.,

$EU^A > EU^B$

where,

$EU^i = (v - p_{i1}) + \delta_c[(v - p_{ii})q_{ii} + (v - p_{ji} + E[s \mid switch])q_{ji}]$

Assume that consumers discount future more than firms do, i.e., $0 \le \delta_c \le \delta_F \le 1$

Proposition 2:

If Contact with Breach Penalty (CWP) is available as an instrument then no strategies that involve not using CWP survive iterative elimination of weakly dominated strategies.

In other words if CWP is feasible then any strategy that involve not using CWP is not optimal. Conversely firms will always choose a strategy that involves using CWP. We show that if firm B doesn't use CWP and it chooses prices optimally then firm A can do better by using CWP which stops its first period customers from switching to firm B in the second period. See appendix for the formal proof.

Proposition 2 states that in the game where contracts are feasible both firms will use contracts. The equilibrium outcome of the game turns out to be unique. Both firms use CWP and split the market in the first period. The first period price charged by both firms is $p_{i1} = c - \delta_F(v - c)$ and the second period contract price and poaching price are v *and* c respectively. The outcome however can be supported by multiple equilibrium strategies as shown in proposition 3 below. These strategies differ only in one aspect, the penalty level. The prices remain the same. Any penalty, $\tau_i \geq v - c$, completely stops switching and hence any penalty level greater than that threshold are economically equivalent as it pertains to the outcome of the game.

Proposition 3:
There exists a unique family of subgame perfect equilibria of the game (one equilibrium for each penalty level) in which both firms use CWP and the equilibrium strategies are as below:

In the first period firm i offers the contract:

$$p_{i1} = c - \delta_F(v - c)$$
$$p_{ii} = v$$
$$\tau_i \geq v - c$$

and in the second period,

$$p_{ij} = \frac{1}{2}\left(p_{jj} + c - \tau_j\right) \; if \;\; \tau_j \leq p_{jj} - c$$
$$p_{ij} = c \; if \;\; \tau_j > p_{jj} - c$$

The proof is given in the appendix.

The second period profit of firm A can be expressed as:

$$\pi_{A2} = \alpha(p_{AA} - c) - \alpha(p_{AA} - c - \tau_A)q_{BA} + (1-\alpha)(p_{AB} - c)q_{AB}$$

The second term is firm A's "net" loss arising from firm B's poaching on its customers. We say "net" because A loses sales revenue from consumer leaving it but receives rent in the form of penalties from the consumers who do leave. This net loss can be non-positive only if $\tau_A \geq p_{AA} - c$. But then $q_{AB} = 0$. The intuition is simple. Along the relevant range of price where B will profitably poach, it is never profitable for A to let B poach, i.e., its rent from penalties is always less than its loss from poaching. A can assure itself of a non-positive loss by choosing a penalty, $\tau_A \geq p_{AA} - c$, which stops switching completely.

At the proposed equilibrium, the second period poaching price is, $p_{ij}^* = c$. There is no switching in equilibrium and since switching is costly, this is efficient.

The second period equilibrium profit for firm A reduces to $\pi_{A2}^* = \alpha(p_{AA} - c)$. This is increasing in the first period market share, α. The two period discounted profit for firm A can be expressed as:

$$\pi_A = \alpha[(p_{A1} - c) + \delta_F(v - c)]$$

The same argument is true for firm B too. So firms compete for market share in the first period in the Bertrand fashion. This drives down the first period price and profit until equilibrium discounted profit is zero. So firms are worse off when CWP is feasible than when it is not.

In equilibrium, the expected two-period discounted consumer surplus is

$$\overline{EU^{i}} = (v-c)(1+\delta_F)$$

Comparing with the expected discounted consumer surplus from the model with no CWP, we find that $\overline{EU^{i}} > EU^{i*}$ *if and only if* $\delta_F - \frac{13}{18}\delta_c > \frac{1}{3}$. So, in this range of firm's and consumer's discount factor, consumers are better off when firms use CWP. However firms are worse off.

In the above model when products are completely homogeneous, the equilibrium penalty is not unique. This is because equilibrium penalty so high that it stops switching completely and so in the equilibrium, penalties do not affect switching at the margin.

2.3 Ex-ante Homogeneous Ex-post Product Differentiation Model.

We enrich the previous model by allowing for horizontal product differentiation in the second period. The motivation is the following. Consumers are inherently heterogeneous in their preferences for the product. In the first period when a customer is considering purchasing the product from some firm, she does not have enough information to differentiate between the various products offered and hence view them as homogeneous products. However in the second period when she has experienced one product for sometime, the true characteristics are revealed and she knows exactly how close the product is to her "ideal" product characteristics.

Assumption 1: Second period location of consumer, x is uniformly distributed over [0,1]

Assumption 2: Firm A located at 0 and Firm B is located at 1.

Assumption 3: Second period switching cost is distributed over the unit interval, [0,1].

2.3.1. No CWP case.

Let us now look at the case when CWP is not available as an instrument to the firm.

2.3.1a: Second Period Competition.

The marginal first period customer of firm A realizes a 2-tuple (x, s) such that the following holds:

$$p_{AA} + x = p_{BA} + (1 - x) + s$$

Competition in Firm A's first period customers' market segment yields the following demands. Figure 2.1 shows the demand regions for a typical set of prices.

$$q_{BA} = prob(2x - s > p_{BA} - p_{AA} + 1) \quad \textit{for } 0 \le s \le 1,\ 0 \le x \le 1$$
$$q_{AA} = 1 - q_{BA}$$

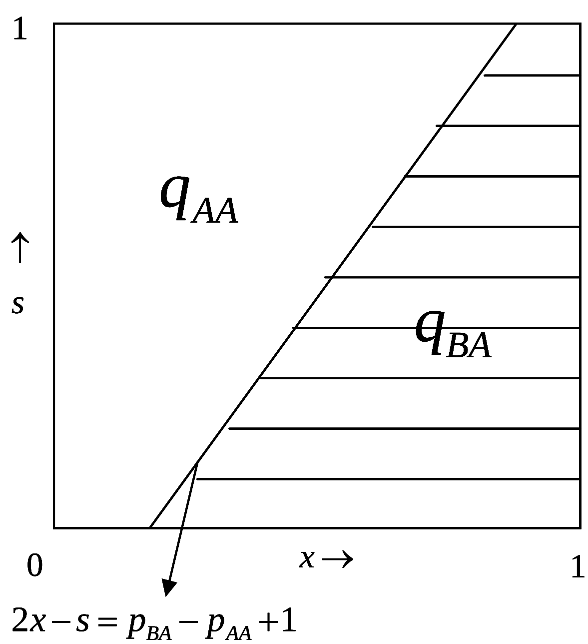

Figure 2.1. Competition in A's first period customers market segment.

The above shaded region represents the A's first period customers who switches to firm B in the second period, for a given the set of prices, (p_{AA}, p_{BA}). In other words, B's “poaching” in firm A’s first period customers market segment which is given below for different ranges of p_{AA} *and* p_{BA}.

$$q_{BA} = \begin{cases} 0 & if \;\; p_{AA} - p_{BA} < -1 \\ \frac{1}{4}\left(p_{AA} - p_{BA} + 1\right)^2 & if \;\; -1 \le p_{AA} - p_{BA} \le 0 \\ \frac{1}{4}\left[1 - 2(p_{BA} - p_{AA})\right] & if \;\; 0 \le p_{AA} - p_{BA} \le 1 \\ 1 - \frac{1}{4}(p_{BA} - p_{AA})^2 & if \;\; 1 \le p_{AA} - p_{BA} \le 2 \\ 1 & if \;\; p_{AA} - p_{BA} > 2 \end{cases}$$

Note that, the first two ranges represent cases where the “poaching” price by firm B is greater than the second-period price to own-customer by firm A. Here, firm B is not actively poaching, and switching may occur only due to extremely “bad” realization of the location random variable, x combined with a realization of a low enough switching cost, s. The last two ranges shows cases where the “poaching” price by firm B is too low compared to the second-period price to own-customer by firm A. It is shown in the appendix that it is never profitable for firm B to poach in these ranges.

The relevant poaching region is given by the third range, i.e., $0 \le p_{AA} - p_{BA} \le 1$. We will describe the equilibrium in this poaching range.

Similarly for marginal first period customer of firm B:

$$p_{BB} + (1 - x) = p_{AB} + x + s$$

And competition in B’s first period customers market segment yields the following demands:

$$q_{AB} = prob(2x + s > p_{BB} - p_{AB} + 1) \quad for \;\; 0 \le s \le 1,\; 0 \le x \le 1$$
$$q_{BB} = 1 - q_{AB}$$

Figure 2.2 shows the corresponding demand region for a typical set of prices, (p_{BB}, p_{AB}).

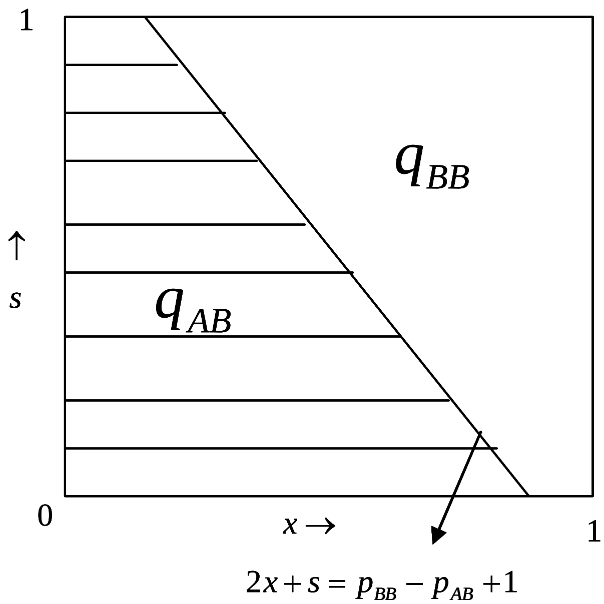

Figure 2.2. Competition in Firm B's first period customers market segment.

Analogously, the shaded region represents firm A's "poaching" of firm B's first period customers for a given set of prices, (p_{BB}, p_{AB}) and this is given below for all range of the prices, (p_{BB}, p_{AB}).

$$q_{AB} = \begin{cases} 0 & \text{if } \; p_{BB} - p_{AB} < -1 \\ \frac{1}{4}(p_{BB} - p_{AB} + 1)^2 & \text{if } \; -1 \le p_{BB} - p_{AB} \le 0 \\ \frac{1}{4}[1 - 2(p_{AB} - p_{BB})] & \text{if } \; 0 \le p_{BB} - p_{AB} \le 1 \\ 1 - \frac{1}{4}(p_{AB} - p_{BB})^2 & \text{if } \; 1 \le p_{BB} - p_{AB} \le 2 \\ 1 & \text{if } \; p_{BB} - p_{AB} > 2 \end{cases}$$

As before, Firms A and B maximize their second period profit by choosing a set of two prices, one for its own first period customers and another a poaching price. The problem is symmetric for both firms. Let us look at firm A's maximization problem. Firm A's second period profit is:

$$\pi_{A2} = \alpha(p_{AA} - c)(1 - q_{BA}) + (1 - \alpha)(p_{AB} - c)q_{AB}$$

The first term is profit from A's first period customers who stay with it in the second period and the second term is profit from poaching on B's first period customers. Let us focus on the relevant poaching region where $0 \le p_{AA} - p_{BA} \le 1$ and $0 \le p_{BB} - p_{AB} \le 1$. Plugging in the demands for the above regions, the second period profit for firm A is then given by:

$$\pi_{A2} = \frac{1}{4}\{\alpha(p_{AA} - c)[3 + 2(p_{BA} - p_{AA})] + (1 - \alpha)(p_{AB} - c)[1 - 2(p_{AB} - p_{BB})]\}$$

Firm A chooses p_{AA} *and* p_{AB} to maximize π_{A2} which yields the following best response functions:

$$p_{AA} = R_{AA}(p_{BA}) = \frac{1}{2}\left(c + p_{BA} + \frac{3}{2}\right)$$

$$p_{AB} = R_{AB}(p_{BB}) = \frac{1}{2}\left(c + p_{BB} + \frac{1}{2}\right)$$

Similarly, B's best response functions are:

$$p_{BB} = R_{BB}(p_{AB}) = \frac{1}{2}\left(c + p_{AB} + \frac{3}{2}\right)$$

$$p_{BA} = R_{BA}(p_{AA}) = \frac{1}{2}\left(c + p_{AA} + \frac{1}{2}\right)$$

Solving the above best response functions yields the unique Nash equilibrium prices of the second period sub-game.

$$p^*_{AA} = p^*_{BB} = c + \frac{7}{6} \ and \ p^*_{AB} = p^*_{BA} = c + \frac{5}{6}$$

The second period equilibrium profits are:

$$\pi^*_{A2} = \frac{25}{72} + \frac{1}{3}\alpha \ and \ \pi^*_{B2} = \frac{25}{72} + \frac{1}{3}(1-\alpha).$$

It is easy to check that the above set of equilibrium prices are indeed in the relevant poaching regions discussed earlier and that there is switching in the equilibrium. In particular the proportions of first period customers who switch firms in the second period for both firms are the same given by:

$$q^*_{AB} = q^*_{BA} = \frac{5}{12}$$

So in equilibrium a little less than half of the customers switch firms. Compared to the case with no second period product differentiation, equilibrium switching is higher. This is not surprising. In the first case, since the products are homogeneous, switching by a customer is solely motivated by the difference in the second period offered by its first period firm and the second period poaching price of the rival firm. With product differentiation there is another incentive for consumers to switch that arises due to the realization of their true preferences in the second period.

Socially Efficient Amount of Switching.

In this model switching is not altogether inefficient as was the case with the first model when any switching is socially inefficient. This is because for consumers with realizations of low enough switching cost, s and strong preference for the rival firm, it is efficient to switch. However we will show that there is excessive switching in equilibrium.

Efficient switching arises when switching is solely motivated by the relative trade-offs between the switching cost, s and the second period preference parameter, x and not due to difference in second period prices. This implies that socially efficient switching occurs when $p^*_{AA} = p^*_{BA}$ and $p^*_{BB} = p^*_{AB}$. Plugging these values in the demands we get the socially efficient amount of switching, $q^*_{AB} = q^*_{BA} = \frac{1}{4}$, i.e., social efficiency entails that one-fourth of the market switches firms in the second period. See figure 2.3. So there is excessive switching in equilibrium.

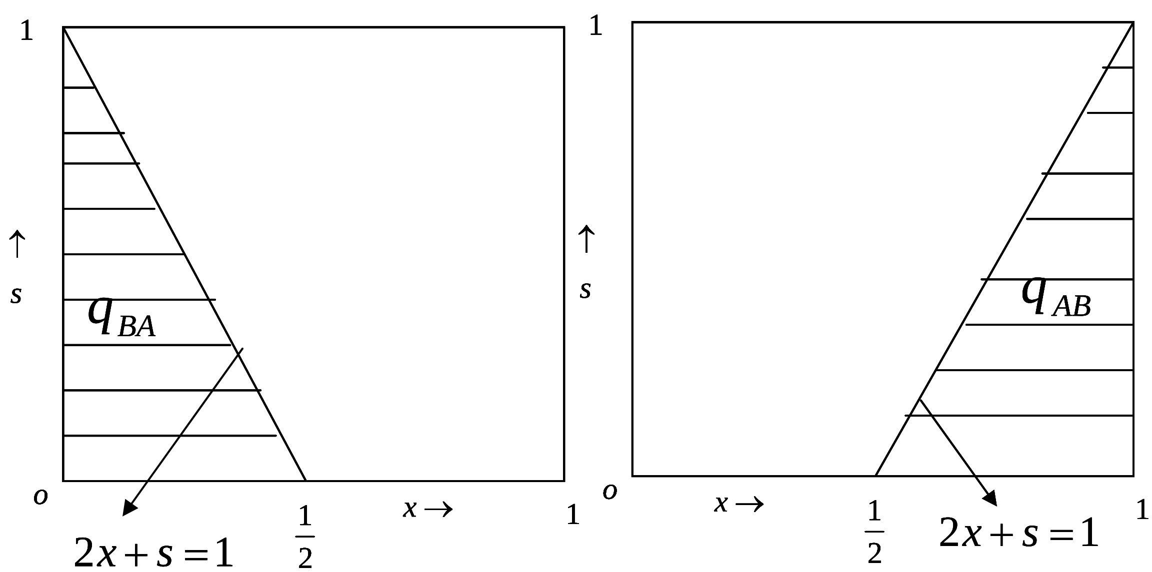

Figure 2.3. Socially efficient switching.

Note that, similar to the first model, the second period profit is increasing in first period market share. This will have implications for first period prices as firms compete for market share in the first period.

2.3.1b: First Period Competition.

We assume that consumers are rational in the following sense. A consumer will choose the firm that gives the highest expected consumer surplus for the two period given first period prices. Since the second period prices for the two firms are the same in equilibrium consumers will choose firms solely on the basis of the first period prices. And since all consumers are ex-ante identical all consumers will choose A over B if the first period price of A is lower than that of B and vice versa, i.e., $\alpha = 1$ if $p_{A1} < p_{B1}$ and $\alpha = 0$ if $p_{A1} > p_{B1}$. As before we assume that consumers choose A and B with equal probability if they charge the same first period price, i.e., $\alpha = \frac{1}{2}$ if $p_{A1} = p_{B1}$.

Proposition 4:

There exists a unique symmetric sub-game perfect equilibrium of the game in which contracts(CWP) are not feasible. The strategies are as follows:

In the first period firm i chooses $p_i = c - \frac{\delta_F}{3}$ *and in the second period it chooses* p_{ii} *and* p_{ij} *optimally as described in the last section.*

The firms split the market in the first period, i.e., $\alpha = \frac{1}{2}$. The equilibrium two-period discounted profit of the firms is:

$$\pi_A^* = \pi_B^* = \frac{25}{72}\delta_F$$

The formal proof is similar to that of proposition 1 and is given in the appendix. A heuristic explanation follows. The two-period discounted profit for firm A and B can be written as:

$$\pi_A^* = (p_{A1} - c)\alpha + \delta_F \pi_{A2}^* = \frac{25}{72}\delta_F + \left[(p_{A1} - c) + \frac{1}{3}\delta_F\right]\alpha$$

$$\pi_B^* = (p_{B1} - c)(1-\alpha) + \delta_F \pi_{B2}^* = \frac{25}{72}\delta_F + \left[(p_{B1} - c) + \frac{1}{3}\delta_F\right](1-\alpha)$$

Notice that the profits are increasing in the respective first period market shares. So firms compete for market shares in the first period by cutting first period prices in the Bertrand fashion. Note also, that firm i can assure itself of a positive profit equal to $\frac{25}{72}\delta_F$ by choosing not to compete in the first period and then poaching on its rival firm's market in the second period. For any first period price above the proposed equilibrium price, Bertrand competition in the first period prices drives down equilibrium profit to this reservation value. If firm i chooses a first period price below the equilibrium price, it captures the entire market but its profit is less than $\frac{25}{72}\delta_F$. So the proposed equilibrium prices indeed constitute equilibrium.

Compared to the equilibrium of the model with no ex-post product differentiation in the second period, the firms earn a higher equilibrium profit. First period prices and market shares are the same however second period prices are higher. This is intuitive. Product differentiation in the second period imparts some market power to the firms. Firms exploit this power by charging a higher price in equilibrium. A more subtle point is that the amount of switching in equilibrium is also higher. This is because now switching is driven by two factors. First, as before, by the second period poaching by rival firms and secondly, by the realization of consumers' relative preference between the firms.

2.3.2. Contract with Breach Penalty model:

Assume that contracts of the following form are available to the firms. In the first period, firm i can offer a contract which specifies a first period price, p_{i1}; a second period price, p_{ii}; and a breach penalty, τ_i which is to be paid by its first period customer if she leaves the firm in the second period. In the second period firm i can offer a new price, p_{ij}, to the first period customers of the rival firm, j who switch to firm i.

Proposition 5:

If Contact with Breach Penalty (CWP) is available as an instrument then no strategies that involve not using CWP survive iterative elimination of weakly dominated strategies.

The proof is similar to that of proposition 2 given in the appendix.

Proposition 6:

There exists a unique sub-game perfect equilibrium of the game where both firms use CWP and the strategies of each firm involves:

In the first period firm i offers the following contract,

$$p_{i1} = c - \delta_F (v - c) - \frac{4}{729}\delta_F$$
$$p_{ii} = v$$
$$\tau_i = v - c + \frac{1}{3}$$

And in the second period firm i chooses,

$$p_{ij} = \frac{1}{3}(p_{jj} + 2c - \tau_j + 1) \quad if \;\; -1 \leq p_{jj} - p_{ij} - \tau_j \leq 0$$
$$p_{ij} = \frac{1}{2}(p_{jj} + c - \tau_j + \frac{1}{2}) \quad if \;\; 0 \leq p_{jj} - p_{ij} - \tau_j \leq 1$$

To illustrate the above proposition let us solve the game by backward induction. First consider second-period stage game.

2.3.2a Second Period Competition.

The marginal first-period customer of firm A gets a realization of s and x such that,

$$p_{AA} + x = p_{BA} + (1 - x) + s + \tau_A$$

Competition in Firm A's first-period market segment yields the following demand:

$$q_{BA} = prob(2x - s > p_{BA} + \tau_A - p_{AA} + 1) \quad \textit{for} \;\; 0 \le s \le 1,\, 0 \le x \le 1$$
$$q_{AA} = 1 - q_{BA}$$

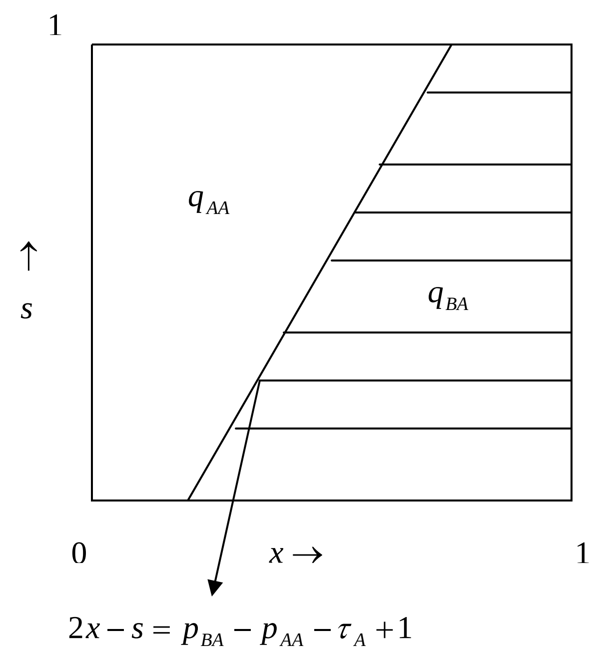

Figure 2.4. Competition in A's first-period customers segment.

The above shaded region represents the A’s first period customers who switches to firm B in the second period, for a given the set of prices and penalty, (p_{AA}, p_{BA}, τ_A). Firm B’s “poaching” demand in firm A’s first period customers market segment:

$$
q_{BA} = \begin{cases} 0 & \text{if} \quad p_{AA} - p_{BA} - \tau_A < -1 \\ \frac{1}{4}(p_{AA} - p_{BA} - \tau_A + 1)^2 & \text{if} \quad -1 \le p_{AA} - p_{BA} - \tau_A \le 0 \\ \frac{1}{4}\left[1 - 2(p_{BA} + \tau_A - p_{AA})\right] & \text{if} \quad 0 \le p_{AA} - p_{BA} - \tau_A \le 1 \\ 1 - \frac{1}{4}(p_{BA} + \tau_A - p_{AA})^2 & \text{if} \quad 1 \le p_{AA} - p_{BA} - \tau_A \le 2 \\ 1 & \text{if} \quad p_{AA} - p_{BA} - \tau_A > 2 \end{cases}
$$

Similarly for firm B, the marginal first-period customer realizes, s and x such that,

$$p_{BB} + (1 - x) = p_{AB} + x + s + \tau_B$$

Competition in its first period customers market segment yields

$$
\begin{aligned}
q_{AB} &= prob(2x + s > p_{BB} - p_{AB} - \tau_B + 1) \quad \text{for} \;\; 0 \le s \le 1,\ 0 \le x \le 1 \\
q_{BB} &= 1 - q_{AB}
\end{aligned}
$$

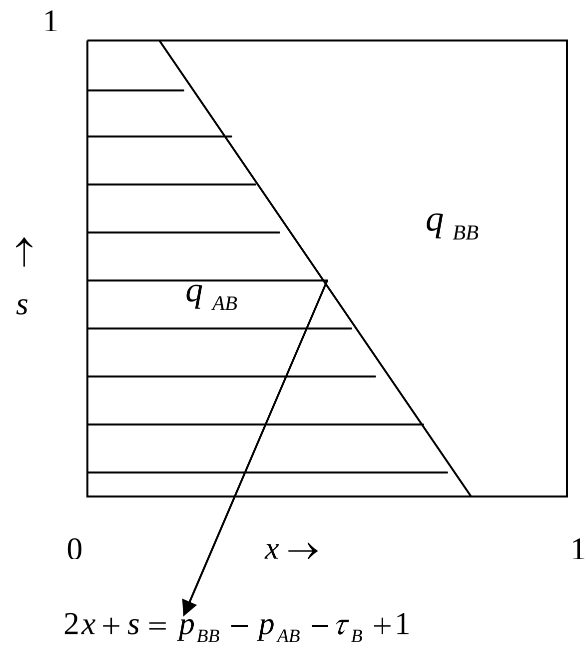

Figure 2.5. Competition in B's first period customers market segment.

Figure 2.5 shows the demand region for a typical set of prices and penalties, (p_{BB}, p_{AB}, τ_B). The shaded region represents customers, who switch to firm A in the second period. Generally, firm A's "poaching" in B's first-period market segment is given by:

$$q_{AB} = \begin{cases} 0 & if \quad p_{BB} - p_{AB} - \tau_B < -1 \\ \frac{1}{4}(p_{BB} - p_{AB} - \tau_B + 1)^2 & if \quad -1 \leq p_{BB} - p_{AB} - \tau_B \leq 0 \\ \frac{1}{4}\left[1 - 2(p_{AB} + \tau_B - p_{BB})\right] & if \quad 0 \leq p_{BB} - p_{AB} - \tau_B \leq 1 \\ 1 - \frac{1}{4}(p_{AB} + \tau_B - p_{BB})^2 & if \quad 1 \leq p_{BB} - p_{AB} - \tau_B \leq 2 \\ 1 & if \quad p_{BB} - p_{AB} - \tau_B > 2 \end{cases}$$

Now let us look at the second period maximization exercise of the two firms. Since the problem is symmetric we can look at firm A's problem. A's second period is given by:

$$\pi_{A2} = \alpha\left[(p_{AA} - c)(1 - q_{BA}) + \tau_A q_{BA}\right] + (1-\alpha)(p_{AB} - c)q_{AB}$$

Firm A chooses p_{AB} to maximize it second period profit. Note that the first term comprises of profit from firm A's first period customers who stay and rent (penalties) from those who leave A in the second period. This does not depend on its second period choice, p_{AB}. A's second period optimization can therefore be written as:

$$\max(p_{AB} - c)q_{AB} \quad w.r.t \;\; p_{AB}$$

The best response in the relevant poaching region is

$$p_{AB} = \begin{cases} \frac{1}{3}\left(p_{BB} + 2c - \tau_B + 1\right) & if \ -1 \le p_{BB} - p_{AB} - \tau_B \le 0 \\ \frac{1}{2}\left(p_{BB} + c - \tau_B + \frac{1}{2}\right) & if \ 0 \le p_{BB} - p_{AB} - \tau_B \le 1 \end{cases}$$

At the proposed equilibrium, the optimal second period poaching price for firm A is $p^*_{AB} = c + \frac{2}{9}$. It is easy to verify that this (given optimal penalty and optimal second period contract price of firm B) satisfies the first range above. In fact at the proposed equilibrium $p^*_{BB} - p^*_{AB} = \tau^*_{B}{}_B - \frac{5}{9}$. This means that firm A finds it optimal not to completely subsidize the consumer of the switching penalty. Combined with the existence of the consumer specific inherent switching cost, s this in turn means that only consumers with very strong enough "dislike" of firm B and low enough switching cost will find it better-off to switch.

Equilibrium Switching Outcome:

At the proposed equilibrium we obtain positive switching as an equilibrium outcome. At the proposed equilibrium $q^*_{AB} = \frac{4}{81}$, i.e., close to one-twentieth of the first period customers of firm B switch to firm A in the second period. Since the equilibrium is symmetric the same amount switches from firm A to B. i.e., at the proposed equilibrium 4/81 of the total market switches firms in the second period. So compared to the socially efficient switching amount there is too little switching in the equilibrium. The intuition is simple. When there is a second motivation for consumers to switch (other than just the price differential) it is no longer optimal to stop switching completely. Some consumers are willing to pay high enough penalties and switch to the other firm even though the penalty of breach is not completely compensated by the price differential. At the margin, the firm finds it more profitable to let such consumers switch and earn the rent from the penalties rather than stop switching all together by charging a very high penalty.

2.3.2b First Period Competition and optimal choice of contract:

First let us look at consumer's choice of firms in the first period. A consumer will choose firm A over B if her expected surplus from choosing A in the first period is greater than that of choosing B. Expected surplus from choosing firm A in the first period is given by:

$$EU^A = (v - p_{A1}) + \delta_c \left[prob(stay)(v - p_{AA}) - E(x \mid stay) + prob(switch)\{(v - p_{BA}) - \tau_A - E[1 - x + s \mid switch]\}\right]$$

And that of choosing B is

$$EU^B = (v - p_{B1}) + \delta_c \left[prob(stay)(v - p_{BB}) - E(1 - x \mid stay) + prob(switch)\{(v - p_{AB}) - \tau_B - E[x + s \mid switch]\}\right]$$

Since all consumers are ex-ante identical A's first period market share, $\alpha = 1$ if $EU^A > EU^B$ and $\alpha = 0$ if $EU^A < EU^B$. As before we make the assumption that all consumers choose A and B with equal probability if they get the same expected surplus from both firms, i.e., $\alpha = \frac{1}{2}$ if $EU^A = EU^B$.

Now let us derive firm's optimal choice.

The two-period discounted profit for firm A can be written as:

$$\begin{aligned}\pi_A &= (p_{A1} - c)\alpha + \delta_F \pi_{A2} \\ &= (p_{A1} - c)\alpha + \delta_F \left[\alpha(p_{AA} - c) - \alpha\{(p_{AA} - c) - \tau_A\}q_{BA} + (1 - \alpha)(p_{AB} - c)q_{AB}\right]\end{aligned}$$

The first term is the first period profit and the second term is the discounted second period profit. Consider the second term. The first term within the square brackets is second period profit from its first period customers' base. The middle term is loss of profit less rent from penalties due to customers switching from A in the second period. This represents A's net "loss" from B's poaching on its first period customers. The last term represent A's profit from poaching on B's first-period customers.

The proposed equilibrium strategy for firm A involves choosing $p_{A1} = c - \delta_F(v-c) - \frac{4}{729}\delta_F$, $p_{AA} = v$ and $\tau_A = v - c + \frac{1}{3}$ in the first period. The explanation is as follows.

Firm A's optimal penalty is chosen so as to maximize its second-period profit for any second period contract price p_{AA} and given that B's second-period poaching price in A's customer segment, p_{BA} is optimally chosen This results in the optimal penalty, $\tau_A^* = p_{AA} - c + \frac{1}{3}$. The derivation of the optimal penalty is given in the appendix. As long as firm A discounts the future less than consumers, $\delta_F < \delta_c$, it would find it profitable to cross subsidize first period price, p_{A1} with second period price, p_{AA}. So firm A charges the highest possible second period price, v. Since the problem is symmetric the same is true for firm B. Now consider the optimal choice of first period price by A. At the proposed equilibrium the two period discounted profit for firm A shown above can be expressed just as a function of first period price, p_{A1} and its market share, α :

$$\pi_A = (p_{A1} - c)\alpha + \delta_F \left[\alpha \left(v - c + \frac{4}{243} \right) + (1-\alpha)\frac{8}{729} \right]$$

Note that the second term which represents second-period profit is increasing in first period market share. Firms compete for market share in the first period. This competition drives down first period price. Note however that firm can assure itself of a positive profit at least equal to $\frac{8}{729}\delta_F$ by not competing in the first period and then poaching on B's first period customers in the second period. So, competition in the first period prices drives down profit until equilibrium profit equals $\frac{8}{729}\delta_F$. The corresponding equilibrium first period price for firm A is, $p_{A1} = c - \delta_F(v-c) - \frac{4}{729}\delta_F$. Firm B charges the same price in equilibrium and the firms split the market in the first period.

To sum up, the equilibrium outcome of CWP for firm i (i=A, B) is given below:

$$p_{i1}^* = c - \delta_F\left(v - c - \frac{4}{729}\right)$$
$$p_{ii}^* = v$$
$$\tau_i^* = v - c + \frac{1}{3}$$
$$p_{ij}^* = c + \frac{2}{9}$$
$$\textit{Equilibrium } 2-\textit{period profit}, \ \pi_i^* = \frac{8}{729}\delta_F$$
$$\textit{Equilibrium switching}, \ q_{ij}^* = \frac{4}{81}$$

Compared to the No CWP game, firms earn less profit in equilibrium. This is a classic prisoners' dilemma. When CWP is available, firms find it privately optimal to use. But when all firms use it they are worse off than when no firms used it. Equilibrium switching is much lower with CWP than with no CWP. In fact it is even lower than the socially efficient amount of switching.

2.4. Conclusions:

Consumer poaching is a commonly observed business practice in subscription market with switching costs. Switching costs lock in firm's customers and makes profit increasing in market share. Firms recognize this value of market share and compete vigorously in the first period. The consumer recognizes that once she is locked in, prices will be higher if she stays while the rival firm will offer inducements to switch (poaching). This makes first period demand very elastic and firms price below marginal costs in the first period. There is excessive switching in equilibrium. In certain industry firms use instruments to mitigate poaching by rivals. We examine the common practice in the US cell phone service industry of requiring customers to sign contracts for a specified length of time and early termination fees. Contracts with breach penalty has been used an instrument to mitigate consumer poaching by rival firms and has been seen by many as being disadvantageous to consumers by locking them in and that firms profit from using it. The above analysis finds that it is not the case. Contracts alter the structure of the game in two main ways. First they make the switching cost endogenous through the provisions of early termination penalties. Second, they enable firms to commit to second period prices through the contracts. Firms can use the first feature to lock in customers by choosing high enough penalties. Consumers recognize this and demand even higher compensation in the first period to enter into the contract. Uncertainty of switching cost and product characteristics however restrict consumers from dissipating away all benefits of the lock-in from the firm. As a result, offering a contract becomes an optimal response for a firm. If rival firms are not using a contract, then other firm finds it better to use one. However first period competition in the market share yields lower profits for the firms than what would occur if contracts were not feasible.

Areas for future research:

In the above analysis we look at a two-period structure of the game where the length of the contract is exogenously given to the firms. This assumption, although a very useful one to answer our research question of how firms behave strategically when contracts are feasible, is a simplification. One possible extension of the research would be to allow for endogenous contract length to study the choice of optimal length of contracts. This is particularly an interesting topic, which relates directly to the number portability issue. Beginning late 2003, the cell-phone industry allowed number portability where customers can take their old numbers when they switch service providers. Prior to that, customers have to get a new number if they switch providers. The act was resisted by service providers for some time because it imposed additional costs to them. When finally, portability was introduced most providers simultaneously increased the length of the contracts (from usually one year to two years). Two things happened. Number portability shifted the distribution of the exogenous random switching costs faced by consumers. It also increased the marginal costs of the providers. It would be very interesting to see how firms choose the optimal length of the contract and how this length is affected by a shift in exogenous switching costs.

Chapter 3.

Strategic Complementarities and the Incentive to Raise Prices: Evidence from the US Wholesale Gasoline Market.

3.1 Introduction.

The US wholesale market for unbranded[16] gasoline exhibits considerable price dispersion both across different regional wholesale markets known as city terminals[17] and also within a typical regional wholesale market (i.e., within a city-terminal). This price dispersion is observed at two apparently different levels.

First, there is considerable variation in the wholesale price of unbranded gasoline charged by different refiners in the same city-terminal. For instance, in the third week of August 1999, the average spread of the wholesale price of unbranded gasoline in a city terminal was 6.1 cents for regular unleaded gasoline. On average this amounts to around 8% of the mean terminal prices.

[16] Unbranded gasoline is generic gasoline that does not carry any major brand name, like Shell or BP. Chemically and physically, unbranded gasoline sold by different refiners is a homogeneous product.
[17] A city terminal is a storage and distribution facility that serves as the local wholesale market for gasoline for the region around the city. More description follows.

Second, there is also significant variation in the price of unbranded gasoline charged by the same refiner in different city-terminals. For example, the price of unbranded regular unleaded gasoline charged by Marathon Petroleum, a major refiner that operates in nearly a hundred city-terminals during our sample period, at the Convent/Garyville city terminal in Louisiana was 54.65 cents per gallon. At the Columbus city-terminal in Ohio the price charged by Marathon was 71.84 cents per gallon, around 15 cents higher! The average price charged by Marathon during the period was 63.2 cents with a standard deviation of 4.4.

Unbranded gasoline is physically a homogeneous product. Transportation cost imparts product differentiation to unbranded gasoline sold by refiners at different terminals. But the prices of unbranded gasoline charged by the same refiner at different terminals vary by much more than that could be attributable to transportation cost[18].

In this paper we analyze the price dispersion in the wholesale market for unbranded gasoline and attempt to provide an explanation based on the pricing decision of two different types of firms in the market, viz. refiners that sell only unbranded gasoline at a terminal and refiners that also sell branded gasoline at the terminal. The economic motivation derives from internalizing strategic complementarities of prices by a firm that sells more than one product in the market. Products are said to be strategic complements[19] in prices if an increase in price of one increases the marginal profitability of an increase in price of the other product . Unbranded gasoline and branded gasoline are strategic complements in prices. A refiner that sells both branded and unbranded gasoline

[18] Gasoline can be transported over large distances for a cost of 1-2 cents per gallon by pipelines or barges. Gilbert and Hastings (2005)

[19] J. Bulow, J. Geanakoplos, and P. Klemperer, “ Multimarket Oligopoly: Strategic Substitutes and Complements”, Journal of Political Economy 93 (1985)

internalizes these strategic complementarities when optimally choosing its prices. This result in higher price for unbranded gasoline by a refiner that sells both the products compared to that of a refiner that sells only unbranded gasoline.

The chapter is organized in the following sections. Section 3.2 develops a simple model to describe how a firm that sells more than one product in a market where the products are strategic complements, internalizes the complementarities in choosing its optimal prices which leads it to choose a higher price for its product compared to a similar firm which sells only one product. Section 3.3 provides a brief description of the US wholesale market for gasoline and outlines the hypotheses that we aim to test for the wholesale market for unbranded gasoline. The detailed description of the data and the results of the empirical exercises are given in section 3.4. Section 3.5 concludes.

We perform two types of empirical exercises depending on the scope of the data available. The first exercise is for the whole set of refiners (firms) selling wholesale unbranded gasoline in the United States and for all city terminals located in the United States in the time period of our analysis. For this dataset we only have information on whether a refiner sells only unbranded gasoline (one product) or both unbranded and branded gasoline (two products) but no additional information on the market shares of the refiners.. The main result of this exercise is that refiners that sell both unbranded and branded gasoline at a city terminal charge a higher price for unbranded gasoline compared to refiners that sell only unbranded gasoline.

The second empirical exercise is done for a major refiner, Marathon Petroleum, which operates in 99 city terminals (wholesale markets). The wholesale dataset is augmented with the share[20] of Marathon brand retail stations. This share is a proxy for the market share of Marathon's branded gasoline. Marathon has retail brand presence in a little more than half of the 99 markets (city terminals) where it sells wholesale unbranded gasoline. The main results of this empirical exercise are the following. First, we find that Marathon charges a significantly higher price for unbranded gasoline in those markets where it also sells branded gasoline (i.e., has retail brand presence). This result is similar to the result obtained from first exercise. Second, the share of Marathon brand retail stations has a positive and significant impact on the price Marathon charges for unbranded gasoline. This suggests that the gain from internalizing the strategic complementarities is higher the higher is the market share of the second product. Third, in a non-linear specification of the reduced form estimation, we find that the price of unbranded gasoline charged by Marathon is concave in the share of its branded retail stations. Finally, we find that the number of refiners selling unbranded gasoline in the wholesale market has a negative and significant impact on the price of unbranded gasoline charged by Marathon. This result is expected and confirms the commonly held view that competition at the wholesale level is important for keeping prices low.

The conclusions and possible extensions are given in section 5.

3.2. The Model.

Let us look at a simple model to motivate the analysis

3.2.1 Case I.

[20] By share here, we mean the share retail stations selling Marathon Brand gasoline to the total number of retail stations in the market. This is a proxy measure for the market share of Marathon Brand Gasoline at the wholesale level.

First, as a benchmark case, consider three firms A_1, A_2 *and* B located at the corners of the unit square as shown in the figure 1. With a slight abuse of notation let A_1, A_2 *and* B respectively denote the products of the three firms as well. A_1 *and* B are horizontally differentiated products while A_2 is vertically differentiated from the other two products while co-locating with A_1 along the horizontal dimension. The assumption of vertical differentiation is not necessary for our analysis. Horizontal differentiation suffices. This assumption, however, apart from simplifying our modeling exercise is a natural fit to the industry that we analyze in the empirical section, viz., the gasoline industry where there is a natural vertical differentiation in the form of branded and unbranded gasoline.

Suppose that buyers' preferences are distributed uniformly over the unit square. Each buyer receives a common indirect utility, v from consuming one unit of any of the three products. Furthermore a buyer located at (x, y) receives an additional utility of y if she buys the high quality product, A_2. She also incurs a transportation cost of x if she buys either A_1 *or* A_2 and a cost of (1-x) if she buys B. Assume that the common indirect utility, v is high enough that everyone buys at least one unit in the equilibrium.

Let the prices of A_1, A_2 *and* B be p_{A_1}, p_{A_2} *and* p_B respectively. We can now derive the demands for each of the products. There are three margins to consider: the marginal buyers between A_1 *and* A_2, those between A_1 *and* B and those between A_2 *and* B. It is easy to verify that the marginal buyers with realization y^* are indifferent between A_1 *and* A_2 where $y^* = p_{A_2} - p_{A_1}$. Similarly the marginal buyers with realization x^* are indifferent between A_1 *and* B where

$$x^* = \frac{1}{2}\left(1 + p_B - p_{A_1}\right)$$

Now consider the marginal buyers between A_2 *and* B. Consider a buyer with realization (x,y). If she purchases A_2 she derives a net indirect utility of $v + y - p_{A_2} - x$ and if she purchases B, a net utility of $v - p_B - (1 - x)$. The marginal buyers between A_2 *and* B have realization $(\tilde{x}, \tilde{y})$ such that

$$v + \tilde{y} - p_{A_2} - \tilde{x} = v - p_B - (1 - \tilde{x})$$

i.e., $$2\tilde{x} - \tilde{y} = 1 + p_B - p_{A_2}$$

The demands regions for the products are shown below in Figure 3.1,

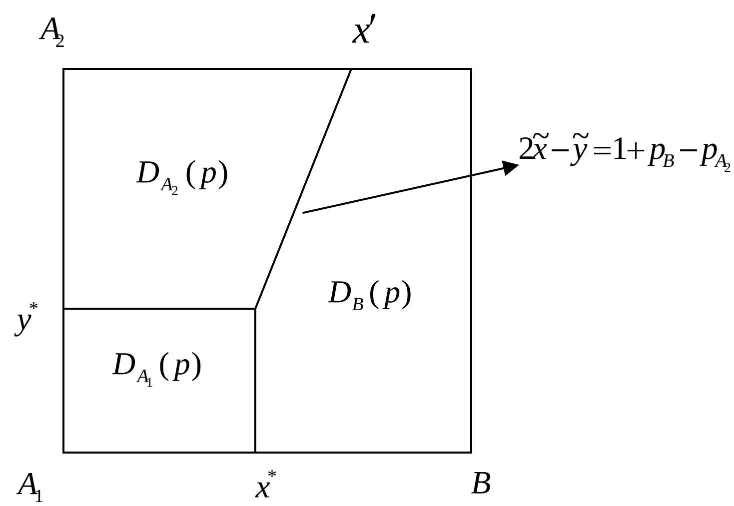

Figure 3.1. Product locations and Demand regions.

where $x' = \frac{1}{2}\left(2 + p_B - p_{A_2}\right)$.

Profit Maximization:

Assume that the marginal cost of A_1 *and* B is zero and that of A_2 is $c \geq 0$. For the purpose of our analysis of strategic complementarities of prices we do not need for c to be strictly greater than zero.

Each firm chooses its price to maximize profit taking other firms' prices and cost as given. Firm A_1's profit is given by:

$$\begin{aligned}\pi_{A_1} &= p_{A_1} * D_{A_1}(p) = p_{A_1} x^* y^* \\ &= p_{A_1}\left(\frac{1+p_B-p_{A_1}}{2}\right)\left(p_{A_2}-p_{A_1}\right)\end{aligned} \tag{1}$$

Maximizing equation (1) with respect to p_{A_1} yields the following first order condition:

$$3p_{A_1}^{\ 2} - 2p_{A_1}\left(1+p_{A_2}+p_B\right) + p_{A_2}(1+p_B) = 0 \tag{2}$$

The second order sufficient condition for a maximum is satisfied if the following holds at the candidate equilibrium solution.

$$6p_{A_1} - 2\left(1+p_{A_2}+p_B\right) < 0 \tag{3}$$

Similarly, Firm A_2's profit is given by:

$$\begin{aligned}\pi_{A2} &= \left(p_{A2}-c\right) * D_{A2}(p) = \left(p_{A2}-c\right)\frac{1}{2}(1-y^*)(x^*+x') \\ &= \left(p_{A2}-c\right)\frac{1}{2}\left(1+p_{A1}-p_{A2}\right)\left(\frac{1+p_B-p_{A1}}{2}+\frac{2+p_B-p_{A2}}{2}\right)\end{aligned} \tag{4}$$

Differentiating equation (4) with respect to p_{A2} yields the first order condition given below:

$$3p_{A2}^{\ 2} - p_{A1}^{\ 2} - 4p_{A2}\left(p_B+2\right) + 2p_{A1}\left(p_B+1\right) + 2p_B + 3 + c\left(4+2p_B-2p_{A2}\right) = 0 \tag{5}$$

and the second order sufficient condition at the candidate solution is given below:

$$6p_{A2} - 4(p_B + 2 + 2c) < 0 \tag{6}$$

Firm B's profit is given by:

$$\begin{aligned}\pi_B &= p_B * D_B(p)\\ &= p_B\left[\frac{1}{2}(1 + p_{A1} - p_B)(p_{A2} - p_{A1}) + \frac{1}{4}(1 - p_{A2} + p_{A1})(1 - 2p_B + p_{A1} + p_{A2})\right]\end{aligned} \tag{7}$$

The first order condition is found by differentiating above with respect to p_B.

$$p_B = \frac{1}{4}\left[1 + p_{A2}(2 + p_{A1}) - p_{A1}{}^2 - p_{A2}{}^2\right] \tag{8}$$

The second order sufficient condition is always satisfied[21].

Now the three first order conditions, i.e., equations (2), (5) and (8) can be solved simultaneously to get the equilibrium prices. Note that the first order conditions are quadratic equations (the third equation is linear in p_B) and cannot be solved by hand. We solve these equations using MATLAB's symbolic math tool. The codes and the set of resulting candidate solutions are shown in the appendix. For each value of c small enough, we obtain a unique solution that satisfies the second order conditions after eliminating complex and negative roots. For example if c equals zero, then the unique solution that maximizes the firms' profits is given by:

$$\{p^*_{A1} = 0.250,\quad p^*_{A2} = 0.563,\quad p^*_B = 0.472\} \tag{9a}$$

Similarly for $c = 0.1$ the unique solution is

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[21] The second order condition is $\dfrac{\partial^2 \pi_B}{\partial p_B{}^2} = -1 < 0$

$$\left\{p_{A1}^* = 0.276, \quad p_{A2}^* = 0.632, \quad p_B^* = 0.491\right\} \tag{9b}$$

It is easy to verify that the above solutions indeed satisfy the second order conditions.

3.2.2 Case II:

Now let us consider the case where the products A_1 *and* A_2 are both sold by the same firm, say A. The motivation of this exercise is the central part of the paper. Firm A now chooses two prices, p_{A1} *and* p_{A2} to maximize its joint profit from the two market segments (i.e., its two products). Note that prices are strategic complements. When optimally choosing a price of one of its product, Firm A internalizes this strategic effect from the other product resulting in higher equilibrium prices. In particular, relevant to the empirical exercise that follows, we expect to find that the equilibrium price of A_1 is higher when both A_1 *and* A_2 are sold by the same firm than when they are sold by separate firms.

Assume that there is no change in the preferences and cost. Then the demands for the products remain unchanged. See Figure 1 above. Firm B's maximization exercise given other prices, p_{A1} *and* p_{A2} also remains unchanged. Firm A maximizes its joint profit by choosing p_{A1} *and* p_{A2} optimally. The joint profit for firm A is given by:

$$\begin{aligned}
\pi_A &= \pi_{A1} + \pi_{A2} = p_{A1} * D_{A1}(p) + \left(p_{A2} - c\right) * D_{A2}(p) \\
&= p_{A1} x^* y^* + \left(p_{A2} - c\right)\frac{1}{2}\left(1 - y^*\right)\left(x^* + x'\right) \\
&= p_{A1}\left(\frac{1 + p_B - p_{A1}}{2}\right)\left(p_{A2} - p_{A1}\right) + \left(p_{A2} - c\right)\frac{1}{2}\left(1 + p_{A1} - p_{A2}\right)\left(\frac{1 + p_B - p_{A1}}{2} + \frac{2 + p_B - p_{A2}}{2}\right)
\end{aligned} \tag{10}$$

Partially differentiating equation (10) with respect to p_{A1} and p_{A2} respectively yields the following first order conditions:

$$p_{A1} : 3p_{A1}{}^2 - p_{A1}(2 + 2p_B + 3p_{A2}) + 2p_{A2}(1 + p_B) - c(1 + p_B - p_{A1}) = 0 \qquad (11)$$

and

$$p_{A2} : 3p_{A2}{}^2 - 3p_{A1}{}^2 - 4p_{A2}(2 + p_B) + 4p_{A1}(1 + p_B) + 2p_B + 3 + c(2 + p_B - p_{A2}) = 0 \qquad (12)$$

The second order conditions are satisfied if the following holds at the candidate equilibrium solution:

$$\begin{gathered}
6p_{A1} - (2 + 2p_B + 3p_{A2} + c) < 0 \\
6p_{A2} - 4(2 + p_B + c) < 0 \\
\begin{vmatrix} 6p_{A1} - (2 + 2p_B + 3p_{A2} + c) & 2(1 + p_B) - 3p_{A1} \\ 4(1 + p_B) - 6p_{A1} & 6p_{A2} - 4(2 + p_B + c) \end{vmatrix} > 0
\end{gathered}$$

For firm B the maximization exercise remains unchanged and consequently we have the same first order condition, i.e., equation (8)

$$p_B = \frac{1}{4}\left[1 + p_{A2}(2 + p_{A1}) - p_{A1}{}^2 - p_{A2}{}^2\right] \qquad (8)$$

We can now get the equilibrium prices by solving the first order conditions simultaneously. We solve equations (11), (12) and (8) using MATLAB. Here again we obtain unique interior solutions satisfying second order conditions for c close to zero after eliminating complex and negative roots. For example, the unique solutions for $c = 0$ *and for* $c = 0.1$ are given below. See Appendix for the set of candidate solutions.

$$\left\{ p_{A1}^{*} = 1, \quad p_{A2}^{*} = 1, \quad p_{B}^{*} = \frac{1}{2} \right\} \tag{13a}$$

$$\left\{ p_{A1}^{*} = 0.884, \quad p_{A2}^{*} = 1.04, \quad p_{B}^{*} = 0.534 \right\} \tag{13b}$$

We can easily verify that the second order conditions are satisfied[22].

We are now ready to compare the equilibrium prices in the two cases analyzed above. Compare the equilibrium prices given in (9a) and (9b) to the ones found in (13a) and (13b). Note that the equilibrium prices are higher in the second case when firm A sells both A_1 *and* A_2 than when they were sold by separate firms. This result will likely hold for all values of c close to zero. It does hold for all values of c that we checked numerically. Table B.0 shows the equilibrium prices of the two cases for some values of c close to zero. The intuition is simple. Prices are strategic complements. An increase in price of A_1 has the effect of increasing the demand for A_2 and marginal profitability from raising the price of A_2, which in turn raises the price of A_2 and vice versa. When a single firm sells both A_1 *and* A_2, it internalizes this strategic complementarities effect resulting in higher equilibrium prices.

3.3. A brief description of the US Gasoline Wholesale Market.

A stylized illustration of the production and distribution of gasoline in the United States is shown in Figure 1. Gasoline consumed in the United States is either produced by domestic refiners or imported. Domestic production accounts for 65 % of the total

[22] For $c = 0$ the second order conditions are weakly satisfied. We can find unique solution satisfying the second order conditions for any c arbitrarily close to zero

gasoline consumption of the United States. Refiners may be classified into two types: Majors and Independent refiners.

Majors are large companies such as BP, Exxon, Chevron and Marathon, who, among other things, are integrated in the distribution and marketing of gasoline and have a brand presence in the retail markets in many cities. Independent refiners, such as Western Refining, Navajo, etc. specialize only in the refining aspect and are not involved in marketing. After production (or on arrival in case of imports) gasoline is transported from the refineries and coastal areas to distribution and storage facilities called “Terminals” which are located near large cities in metropolitan areas. The city terminal serves as the wholesale market for the supply of gasoline to retail stations located in and around the city within the metropolitan area, the sellers being the refiners and the buyers, the retail gas stations. There are two types of gasoline sold in the terminals: “Branded” and “Unbranded”. Branded gasoline refers to gasoline sold by a major refiner such as Exxon, BP or Chevron under its brand name and resold at branded retail stations under the same brand name. Unbranded gasoline is generic gasoline that does not carry any major brand name and are sold at the terminals by both Independent refiners and Majors. Many Majors sell part of their gasoline as unbranded gasoline without permission to use the refiners’ brand name at retail. In fact there is quite a few number of city terminals where a Major sells only unbranded gasoline. These terminals correspond to metropolitan areas where a Major has no brand presence at retail.

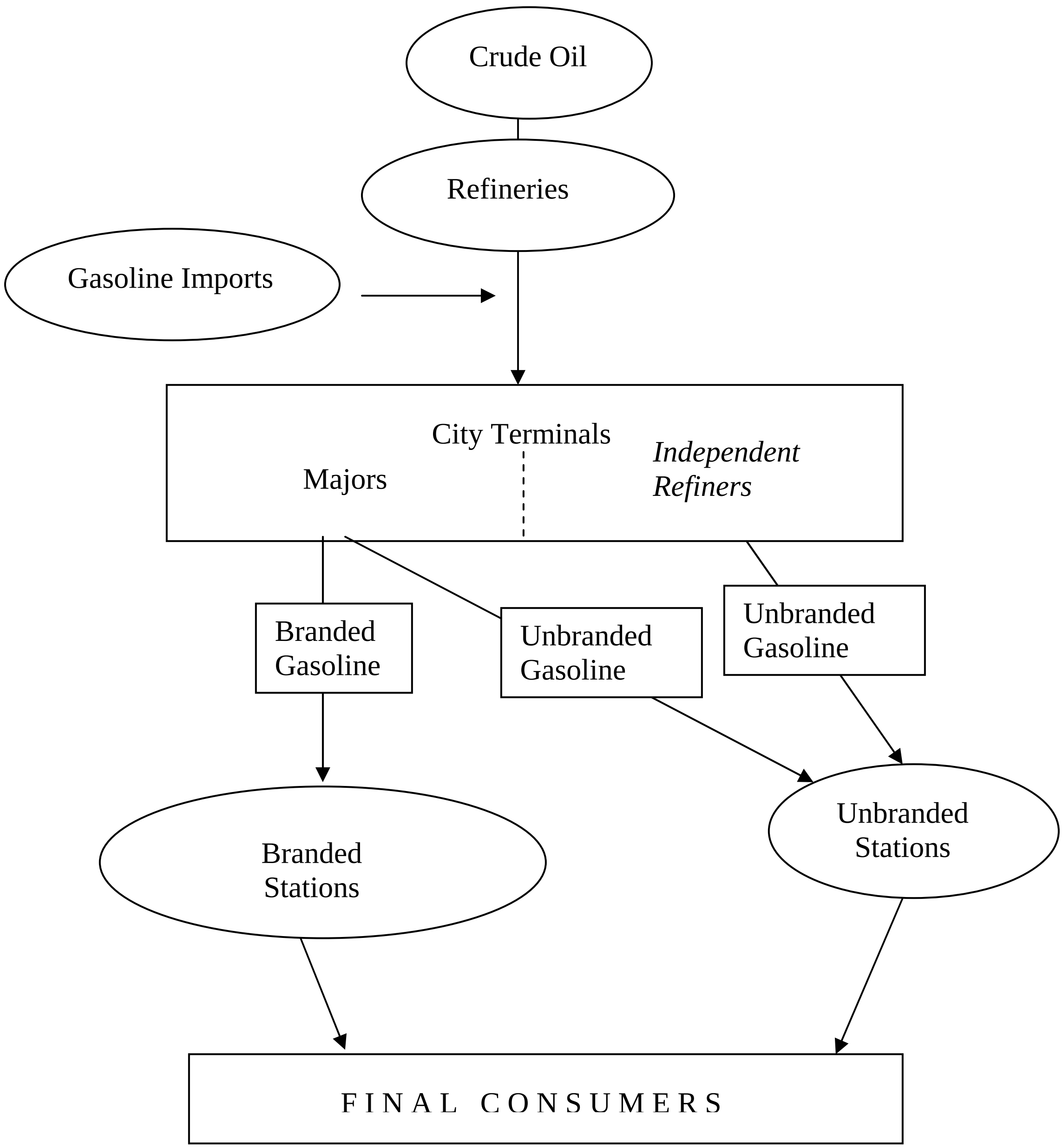

Figure 3.2. US Gasoline Industry Structure[23]

[23] Adapted from Borenstein, Cameron and Gilbert (1997)

On the demand side of the wholesale market we have the retail gas stations. They can be classified into two broad types corresponding to the two types of gasoline discussed above. They are the branded retail stations and the unbranded stations. Branded retail stations can only sell its brand of gasoline and cannot sell other brands or unbranded gasoline. This means, for example, a Shell retail station can only purchase the Shell brand gasoline from the city terminal. Even though in the long run a retail gas station can change the brand of gasoline it carries or even change to an unbranded gasoline station, there is a significant sunk cost to do so in the short run, e.g. it is usual for branded retail stations to sign a contract with the major refiner whose brand for a pre-specified period of time. For this reason, in the short run there is little competition among the refiners in the upstream wholesale market (Terminal) in the branded segment. Furthermore a typical branded retail station can be one of three types, wholly owned by the major refiner, a lessee-dealer or an independent dealer. However regardless of the ownership type, they are contractually bound to sell the refiner's brand gasoline.

On the other hand unbranded retail stations sell unbranded gasoline purchased from either the independent refiners or the majors in the city terminals. This market is very competitive as unbranded gasoline is a homogeneous product and there are no contractual restrictions on the retail stations to purchase it from a particular refiner. We therefore focus our empirical analysis on the price competition in the wholesale market for unbranded gasoline. The sellers in this market can be classified into two functional categories: those who sell only unbranded gasoline in the terminal and those who sell both branded and unbranded gasoline. Note that, while the second type comprises only of major refiners, the first type comprises of independent refiners and also those majors who only sell unbranded gasoline in that terminal (corresponding to those majors that do not have a brand presence at retail in the area).

Branded and unbranded gasoline are strategic complements in prices at the retail market. The seller type who sells both branded and unbranded internalizes these strategic complementarities. Thus all else equal we would expect that refiners that sell both branded and unbranded gasoline in a terminal would want to charge a higher price for unbranded gasoline than those that sell only unbranded.

However there are factors that work to weaken or strengthen this effect. First, the extent to which an increase in the price of unbranded gasoline increases profit in the branded segment depends on the demand for the refiner’s branded gasoline, hence on market share of the refiner’s branded gasoline at retail. The higher is the market share the greater is its gain from this strategic effect. Conversely, if the market share of its branded gasoline is small the refiner will have less incentive to raise the price in the unbranded market because the loss in profit in the unbranded segment would be offset by a smaller gain in profit in the branded segment.

Secondly, whether the refiner will be able to raise the price of unbranded gasoline in the wholesale market depends on its market power and the competition in the unbranded wholesale market. If there are a large number of refiners in the market then we should expect that competition would dominate the strategic effect. Conversely we should expect to see a stronger effect on price due to strategic complementarities when there are only a small number of refiners in the market.

3.4. Evidence from US wholesale Market for Unbranded Gasoline: Data and Empirical Estimation

Data of unbranded wholesale gasoline prices was obtained from Oil Price Information Service (OPIS). The price data is the weekly average terminal rack prices of unbranded regular unleaded gasoline posted by the refiners at a terminal at two time periods, a high demand period (third week of August 1999) and a low demand period (third week of January 2000) for all the terminals located in the 50 states of United States. Prices are in cents per gallon. Apart from prices the data also include the unique refiner names, the location of terminals where the refiners operate (city and State) and an identifier whether the refiner also sells branded gasoline in that particular terminal. There were 78 refiners[24] in 300 terminals[25] selling unbranded wholesale gasoline during that time period. Out of these 78 refiners selling unbranded gasoline 19 sell branded gasoline as well in at least one terminal while the remaining refiners sell only unbranded gasoline in all the terminals they operate. Many of these refiners, mainly the major refiners, sell in more than one terminal and there may exist some competition across terminals. But since the terminals are far apart from one another and because of the presence of significant transportation costs, we expect the inter-terminal competition to be of a second order. We therefore treat a terminal as a single independent market and as a consequence we treat a refiner who operates in two terminals as different firms for the purpose of their profit maximization in each terminal.

We perform two types of empirical exercises based on the scope of the data available. The first exercise is for the whole set of refiners selling unbranded gasoline in

[24] See table B.2 in the appendix for a complete list of refiners selling unbranded gasoline.
[25] See table B.1 in the appendix for a complete list of the city terminals in the sample.

the United States and for all city terminals located in the United States in the time period of our analysis. For all refiners that sell unbranded gasoline in any terminal we can identify whether they also sell branded gasoline in that particular terminal. We can therefore identify which refiners have a strategic incentive to raise the price of their unbranded gasoline. However we do not have information on the number or market share of retail stations selling that refiner's brand gasoline.

In our analysis we make the assumption that in the short run a refiner chooses prices only and does not choose whether to sell both types of gasoline or just one type in a terminal. In other words, we take the type and the distribution of the types of refiners as given. This choice may be endogenous to the refiners. There may be factors unique to some terminals or markets that facilitate a refiner to sell both types of gasoline. The same factors may also affect price choice. If that were the case then we would have endogeneity problems in our estimation and we would have to find good instruments. However for our case our assumption that this choice is exogenous in the short run seems to be a reasonable one. As mentioned before a refiner that sells branded gasoline at a terminal has brand presence at retail in the local markets served by the terminal. This means there has to exist retail gas stations, either company owned, franchises or independent dealers selling the refiners brand gasoline. This involves either buying and operating the stations in the case of company owned, or making initial investments in business format and infrastructure for the case of franchises or signing contracts with the independent dealers. There has to be a network for distribution of branded gasoline to the station as well. So even though in the long run refiners do make the choice of whether to enter the branded market segment or not these involve considerable upfront investment which is a sunk cost in the short run. Therefore in the short run analysis of price choice in our case it is reasonable to assume that the market structure is exogenous to the choice of price.

We create a dummy variable that equals one if a refiner also sells branded gasoline in that terminal. We regress the price of unbranded gasoline on the dummy after controlling for various factors including competition factors within a terminal as measured by the number of sellers in the terminal for unbranded as well as branded gasoline, city-terminal fixed effects and dummies for major brand refiners that sell unbranded gasoline.

The US petroleum industry is divided into five broad regions called the Petroleum Administration for Defense Districts[26] (PADDs). These are PADD1 (East Coast), PADD2 (Midwest), PADD3 (Gulf Coast), PADD4 (Rocky Mountain), PADD5 (West Coast). Each of these regions is different in terms of production and consumption of gasoline[27]. To control for these regional effects we include dummies for PADDs in our regression.

In order to control for changes in demand and supply of gasoline within each of the PADD, changes in stocks of gasoline are computed for each region and included in the regression. The data on stock is available from EIA for each of the PADDs. The % change in gasoline stock for both periods is computed as the difference in stock between the third and second week divided by the stock in the second week times 100.

[26] See figure B.1 in the appendix for the detailed map of PADDs. Source: Energy Information Administration
[27] Kapoor (2003)

The results of the regression are shown in Table 3.1. The dependent variable is price of unbranded gasoline of regular-unleaded grade[28] posted by refiners at the city-terminals. Note that the coefficient on the dummy for a refiner selling branded gasoline as well at that terminal is positive and highly significant at both time periods. For example, in the high demand period (August 1999), all else equal, a refiner who also sells branded gasoline charges 2.3 cents more for its unbranded gasoline than one that sells only unbranded gasoline. With an average price of unbranded gasoline around 70 cents, this amounts to a 3.3 % higher price due to the strategic effect. The corresponding figure for the low demand period (January 2000) is around 3.1%.

The results lend support to our prediction of the incentive to raise price due to strategic complementarities that exist for a firm that sell both unbranded and branded gasoline. The intuition is simple. A higher price in the unbranded market segment increases demand for the branded product. A refiner that sells both branded and unbranded gasoline internalizes this strategic effect when optimally choosing the price.

[28] We also ran regressions on the price of Premium grade of unbranded gasoline and the results are similar.

Table 3.1.

Dependent Variable is Price of Unbranded Regular Unleaded Gasoline. Controls for major brands selling unbranded gasoline included in the regression.Terminal(city) Fixed effects included.Dummies for PADDs included

	Aug-99	Jan-00
Dummy for a seller who sells both branded and unbranded (in a terminal)	2.318***	2.630**
	[0.733]	[1.134]
# of unbranded Sellers (in a terminal)	-0.42	-1.186
	[0.632]	[1.204]
# of Branded Sellers (in a terminal)	0.032	1.165
	[0.473]	[1.103]
% Change in gasoline stocks (in PADDs)	0.956	11.716**
	[0.941]	[5.380]
Amoco	-1.882*	-4.471***
	[1.011]	[1.294]
BP	-1.022	1.077
	[0.714]	[1.096]
Exxon	-1.912***	-2.807***
	[0.726]	[1.001]
Shell	7.346	5.643
	[7.094]	[6.174]
Total	-1.433	-3.646
	[1.259]	[2.472]
Citgo	-1.501*	-4.023***
	[0.799]	[1.392]
Phillips	-3.368***	-5.888***
	[0.817]	[1.249]
Chevron	0.093	-3.351***
	[0.888]	[1.122]
Marathon	-1.368**	-3.531***
	[0.589]	[1.273]
Tosco	-2.107***	-2.061***
	[0.597]	[0.560]
Constant	73.002***	71.444***
	[5.379]	[9.756]
Observations	2090	1984
R-squared	0.46	0.34

Robust standard errors in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

However the incentive to raise price by a refiner selling both unbranded and unbranded gasoline will depend on the payoff from doing so. The strategic incentive to raise the price of its unbranded gasoline therefore will depend on how much of the loss of demand from its unbranded segment due to the higher price is absorbed by it branded segment. This would in turn depend on the market share of its branded gasoline. All else equal a higher market share of its branded gasoline would mean a bigger gain from a unit increase in the price of its unbranded gasoline. To analyze that, we turn to the next empirical exercise.

The second empirical exercise is done for a major refiner, Marathon Petroleum, which sells unbranded gasoline in 99 city terminals located in 23 states concentrated in the Midwest, Upper Great Plains, Gulf Coast and Southeast regions of the United States. The company ranks as the fifth-largest[29] crude oil refiner in the United States and the largest in the Midwest.

First, Marathon has brand presence in the retail market, either in the form of company owned stations, franchises or independent dealers selling the Marathon brand gasoline, in over half of the cities where the terminals are located. Marathon Petroleum sells both branded and unbranded gasoline in these terminals (and in the remaining city terminals Marathon sells only unbranded gasoline). In these markets Marathon has a strategic incentive to raise its prices for unbranded gasoline. So we expect Marathon to charge a higher price for unbranded gasoline in these terminals.

Second, in the markets where Marathon has brand presence there is considerable variance in the market share of Marathon retail stations, the highest being close to 41% of

[29] Source: Company website of Marathon Petroleum http://www.marathonpetroleum.com/

total retail stations. We expect the strategic incentive to charge a higher price to be stronger in markets where Marathon has a bigger market share in retail.

Third, the share of company owned stations also vary across the markets. If company owned stations are strategically different from franchises and independent stations, then we would observe a significant effect on price due to share of company owned stations. On the other hand if the two types of stations are strategically similar from Marathon's perspective we should not observe any additional effect due to the share of company owned stations. We can exploit this variance to test for the effect of the share of company owned stations on wholesale prices unbranded gasoline.

Fourth, even when the strategic incentive to raise price is present, the ability and the extent to which Marathon can do so depends on the level of competition in the terminal. If there are a large number of refiners selling unbranded gasoline in a terminal, the demand for Marathon's unbranded gasoline will be quite elastic. So we expect to observe a negative effect of the number of sellers on the price Marathon charges.

Data on the prices of unbranded gasoline charged by Marathon at the wholesale terminals were obtained from Oil Price Information Service (OPIS). The price data is the weekly average terminal rack prices of two grades of unbranded gasoline; regular unleaded and Premium gasoline, posted by Marathon in the terminals it operates during the period of August 1999. Prices are in cents per gallon. Apart from the data on prices, the OPIS dataset also has information on the unique location of the terminals[30] (city and state) and the number of refiners in a terminal selling unbranded gasoline.

[30] See Tables B.3 and B.4 in the appendix for a list of city-terminals where Marathon sells unbranded gasoline

The data on the number of retail stations selling Marathon brand gasoline was obtained from Marathon Petroleum Company. These retail stations are wholly owned by Marathon, franchised or owned by independent dealers selling marathon brand gasoline. The wholly company owned stations are marketed under the chain names Speedway and Super America. There are around 1500 Speedway and Super America stores, almost all in the Midwest states. The locations of these stations are found in the Speedway website. In addition to the company owned stations there are around 3000 retail stations comprising of both franchises and independent dealers selling Marathon brand gasoline selling. The location of these remaining stations, were obtained from the Marathon Petroleum website. The addresses contain city, state and zip. We identify the Metropolitan Statistical Areas (MSA) where the retail stations are located. This is done by first identifying the county locations of all the retail stations and then matching them up with the MSA county definition of the Census Bureau. We obtain the market share of Marathon brand at retail as the percentage of Marathon retail stations to the total number of gas stations in the MSA. The data on total number of gas stations in MSAs are obtained from the economic census published by the Census Bureau. We then match the data on the number of Marathon retail stations with the wholesale price data by the common MSA where the wholesale terminal and the retail stations are located.

Demand, cost and market factors vary from one city terminal to the other. We need to control for these factors in order to sensibly perform cross terminal analysis. We use population (log), per capita personal income (demand factors), average wage (cost factor), number of competitors, % change in stocks of gasoline and dummies for

PADD[31]s (market factors) as controls. Data on population, per capita personal income and average wages were obtained from the Bureau of Economic Analysis (BEA). BEA's Regional Economic Information Service (REIS) has detailed data at the MSA level of the above variables. In order to control for changes in demand and supply of gasoline within each of the PADD, changes in stocks of gasoline are computed for each region and included in the regression. The data on stock is available from EIA for each of the PADDs. The % change in gasoline stock is computed as the difference in stock between the third and second week of August 1999 divided by the stock in the second week times 100.

We regress the price of unbranded gasoline charged by Marathon at the terminals on a dummy for whether Marathon has brand presence at retail (i.e., sells branded gasoline as well), the share of Marathon retail stations to total retail stations, the share of wholly company-owned Marathon Stations after controlling for the demand, cost and competition factors discussed above. The results of the regressions are shown in Table 3.2. The dependent variables in the two columns are prices of two grades of unbranded gasoline; regular unleaded gasoline and premium gasoline respectively, that were posted by Marathon at the terminals during the third week of August 1999[32].

[31]The US petroleum industry is divided into five broad regions called the Petroleum Administration for Defense Districts (PADDs). These are PADD1 (East Coast), PADD2 (Midwest), PADD3 (Gulf Coast), PADD4 (Rocky Mountain), PADD5 (West Coast). See appendix for a map of the PADDs. Each of these regions are different in terms of production and consumption of gasoline. Marathon terminal are located only in the first three PADDs: PADD1, PADD2 and PADD3. To control for these regional effects we include dummies for PADDs in our regression.

[32]We also performed the regressions for the second period in our sample, January 2000. The results are similar.

Table 3. 2.

	Regular Unleaded (1)	Premium (1)
D1:Dummy=1 if Marathon Brand Retail Stations present	2.039***	2.113***
	[0.758]	[0.730]
Percentage of Marathon Stations to Total retail Stations interacted with dummy, D1	0.440***	0.450***
	[0.064]	[0.061]
# of unbranded Sellers (in a city terminal)	-0.225***	-0.204***
	[0.077]	[0.074]
Percentage of company-owned Marathon stations to total retail stations Interacted with Dummy, D1	0.027	0.016
	[0.116]	[0.111]
Log(population)	-0.282	-0.374
	[0.366]	[0.348]
Average Wage	-0.000*	-0.000**
	[0.000]	[0.000]
Per capita personal Income	0	0.000*
	[0.000]	[0.000]
% Change in gasoline stocks (in PADDs)	0.550*	0.755*
	[0.328]	[0.403]
PADD2	-0.616	-0.911
	[0.800]	[0.815]
Constant	66.562***	70.788***
	[2.813]	[2.750]
Observations	99	99
R-squared	0.9	0.9

Robust standard errors in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%

Note that the coefficient on the dummy for brand presence is positive and significant. This result is similar to that obtained in the first exercise. For instance at the margin the price of unbranded gasoline charged by Marathon for regular-unleaded gasoline is around 2 cents higher in terminals where it has brand presence at retail. The corresponding figure is just above 2 cents for premium unbranded gasoline. Further, the share of Marathon brand retail stations has a positive and significant impact on the price of unbranded gasoline charged by Marathon.. It supports our hypothesis that the strategic incentive to raise price of one product is higher the higher is the market share of the second product. Note however that after controlling for the share of Marathon brand retail stations, the share of company owned stations does not have a significant impact on the price of unbranded gasoline. This is quite an interesting result. It supports the hypothesis that the company-owned stations are not strategically different from other retail stations selling Marathon brand gasoline from the perspective of Marathon's incentive to raise price due to the strategic complementarities. Finally, the number of refiners selling unbranded gasoline in a terminal has a negative and significant impact on the price charged by Marathon. This is expected. It underscores the importance of competition for keeping prices low.

In the above specification we assumed a linear relationship between the price of marathon's unbranded gasoline and the share of retail stations its brand gasoline. In the following estimation we relax that assumption and allow for a non-linear relationship. We consider two specifications. The first is a quadratic specification, where we include the squared share as an additional regressor. In the second specification, we include indicator variables for consecutive non-overlapping intervals of the shares. The results are shown in Table 3.3.

The results are qualitatively similar to the last set of results. We find that the price of unbranded gasoline charged by Marathon is increasing and concave in the share of its brand retail stations. That the price is increasing in the market share is similar to the result found in Table 3.2. The concavity result is interesting because it suggest that although the effect of internalizing strategic complementarities is increasing in the market share of branded gasoline, it is increasing at a diminishing rate. However compared to Table 3.2 we find that the coefficient of the dummy for markets where Marathon has brand presence at retail is smaller in magnitude and less significant or insignificant at the 10% level and that of the dummy for share of Marathon stations is larger.

Table 3.3

	Regular Unleaded		Premium	
	(1)	(2)	(1)	(2)
D1:Dummy=1 if Marathon Brand Retail Stations present	1.009+		1.121*	
	[0.690]		[0.674]	
Percentage of Marathon Stations to Total retail Stations interacted with dummy, D1	0.747***		0.746***	
	[0.102]		[0.100]	
Square of Percentage of Marathon Stations to Total retail Stations interacted with dummy, D1	-0.010***		-0.010***	
	[0.003]		[0.003]	
Dummy=1 if % of Marathon Brand stations 0<x<=10		3.000***		3.106***
		[0.935]		[0.913]
Dummy=1 if % of Marathon Brand stations 10<x<=20		7.465***		7.596***
		[0.977]		[0.954]
Dummy=1 if % of Marathon Brand stations more than 20		8.011***		8.369***
		[1.474]		[1.453]
# of unbranded Sellers (in a city terminal)	-0.192***	-0.204**	-0.172***	-0.183*
	[0.067]	[0.096]	[0.064]	[0.092]
Percentage of company-owned Marathon stations to total retail stations Interacted with Dummy, D1	0.117	0.523***	0.103	0.514***
	[0.101]	[0.102]	[0.099]	[0.103]
Log(population)	-0.293	-0.332	-0.384	-0.432
	[0.315]	[0.412]	[0.298]	[0.397]
Average Wage	-0.000**	0	-0.000**	0
	[0.000]	[0.000]	[0.000]	[0.000]
Per capita personal Income	0.000*	0	0.000**	0
	[0.000]	[0.000]	[0.000]	[0.000]
% Change in gasoline stocks (in PADDs)	0.545*	0.605*	0.751*	0.811**
	[0.308]	[0.325]	[0.385]	[0.399]
PADD2	-0.659	-0.607	-0.952	-0.925
	[0.693]	[0.970]	[0.721]	[0.983]
Constant	66.389***	67.044***	70.621***	71.377***
	[2.491]	[3.421]	[2.423]	[3.381]
Observations	99	99	99	99
R-squared	0.92	0.85	0.92	0.85

Robust standard errors in brackets
+ significant at 15%; * significant at 10%; ** significant at 5%; *** significant at 1%

This is not inconsistent with earlier results. The difference is due to the linear approximation of the quadratic specification which turns out to be concave. The first dummy is significant at the 10% level for premium grade and at 15% for regular unleaded grade. In theory a specification test (for example the likelihood ratio test) of the linear model against the quadratic model could possibly allow us to choose the model of best fit. However the small number of observations in our case severely limits the accuracy of such a test and it would be dangerous to infer from one. Interestingly, the result from the quadratic specification implies that at very low market share the effect of internalizing strategic complementarities is small, which is not unreasonable to expect.

3.5. Conclusions.

We looked at the incentive for a firm to raise prices when it sells more than one product and when there exist strategic complementarities in prices among the products. We empirically examine whether this incentive indeed leads to higher wholesale prices for unbranded gasoline in the US by those refiners that sells also sell branded gasoline in the same market. The empirical analysis lends support to the hypothesis that firms that sells products that are strategic complements internalizes this effect when optimally choosing prices and may lead to higher prices.

We then focus on a major refiner, Marathon Petroleum that sells unbranded gasoline in ninety-nine wholesale markets allowing us to control for refiner specific idiosyncrasies. It is particularly interesting because Marathon's market share of its branded product varies across the markets. We empirically exploit this variation and confirm that the incentive to raise price of one product increases with the market share of the second product.

The empirical evidence of the proposed theory of internalizing strategic complementarities is quite strong. However there may be other alternative theories that may in part explain the price dispersion observed for unbranded gasoline. First, there may be intangible differences in the quality of services offered by the majors and independent refiners that gets reflected in the observed price variation. Brand dummies included in the estimation should control for this effect. Moreover the second analysis precludes this effect since we look at just one refiner.

Secondly, it could be that refiners that also sell branded gasoline at a terminal have big market shares and the other refiners are fringe firms. So the former are the price leaders and the other refiners follow the prices set by them. Or alternatively, refiners that post high prices at a terminal do not sell any or sell very little unbranded gasoline. If the price of branded gasoline is indexed directly to the price of unbranded gasoline sold by the same refiner then the refiner has the incentive to post a higher price for its unbranded gasoline even if it does not sell any or sell very little unbranded gasoline. Then we may observe the systematic price variation even without the effect of strategic complementarities at retail. However, this doesn't seem the likely explanation for two reasons. First, there seem to be little evidence that refiners tie their branded price to the price of their unbranded gasoline. In fact the pricing of branded gasoline follows complex rules and guidelines known as zoning and redlining which has very little to do with unbranded wholesale price but rather with the prices of branded gasoline the refiner charges to different retail stations at different zones. Secondly, the analysis for Marathon shows that this price variation correlates positively with the share of branded gasoline. This supports the strategic complementarities explanation rather than the above explanation.

Finally, the data is limited by the lack of information on sales volume of the refiners at the wholesale markets. This precluded direct tests of whether the refiners posting higher prices are indeed market leaders in the unbranded segment or alternatively are those that sell very little of none at all. It would be interesting to test for further evidence in the gasoline industry with a more comprehensive dataset.

Alternatively, it would be very interesting to see if we can find similar evidence in other markets with similar structure, for example, the pharmaceutical industry where producers often sell both a branded and a generic version of the same drug.

Appendix A

Appendix to Chapter 2.

Proofs of Propositions

A.1 Proof of Proposition 1.

Proposition 1.

There exists a unique subgame perfect equilibrium of the game. The subgame perfect equilibrium is characterized as follows. In the first period both firms charge the same price:

$$p_{A1}^{*} = p_{B1}^{*} = c - \frac{\delta_F}{3}$$

and in the second period each firm chooses prices p_{ii} *and* p_{ij} *optimally as described in the previous section.*

Proof:

We have shown the optimal second period prices for each firm, given the rival firm's prices and hence the proposed strategies constitute a Nash equilibrium in the second stage subgame. We need only check for possible profitable deviations in the first period subgame. We have also shown that the equilibrium two-period discounted profit of firm i at the proposed equilibrium is given by,

$$\pi_{i}^{*} = \alpha_i^{*}\left(p_{i1}^{*} - c\right) + \delta_F\left(\frac{1}{9} + \frac{1}{3}\alpha_i^{*}\right) = \frac{\delta_F}{9},$$

Where $p_{i1}^{*} = c - \frac{\delta_F}{3}$ *and* $\alpha_i^{*} = \frac{1}{2}$

If a firm deviates to any first period price higher than $c-\frac{\delta_F}{3}$, it does not sell any in the first period and therefore poaching its customers in the second period is not possible. It only engages in poaching the rival firm's customers. And its two-period discounted profit is $\frac{\delta_F}{9}$. Hence it can not do better by deviating to a price higher than $c-\frac{\delta_F}{3}$.

Now suppose it deviates to any price lower than $c-\frac{\delta_F}{3}$, say $c-\frac{\delta_F}{3}-\varepsilon,\ \ \varepsilon>0$. It sells to all customers in the first period, i.e., its first period market share is 1 and its two-period discounted profit is given by

$$\tilde{\pi}_i=\left(c-\frac{\delta_F}{3}-\varepsilon-c\right)+\delta_F\left(\frac{1}{9}+\frac{1}{3}\right)=\frac{\delta_F}{9}-\varepsilon<\frac{\delta_F}{9}.$$

Hence the proposed strategies indeed consitute a subgame perfect equilibrium.

Uniqueness of symmetric equilibrium:

Suppose there exist another symmetric equilibrium pair of first period prices, (p_{A1},p_{B1}). They can either be higher than or lower than $c-\frac{\delta_F}{3}$. First suppose $p_{A1}=p_{B1}=c-\frac{\delta_F}{3}+\varepsilon,\ \ \varepsilon>0$. The two-period discounted profit would then be $\frac{\delta_F}{9}+\frac{\varepsilon}{2}$. This cannot be an equilibrium because A can lower its first period price by just a little, (by less than $\frac{\varepsilon}{2}$), say to $c-\frac{\delta_F}{3}+\frac{2}{3}\varepsilon$ and capture the entire market in the first period. Its profit will be $\frac{\delta_F}{9}+\frac{2}{3}\varepsilon>\frac{\delta_F}{9}+\frac{\varepsilon}{2}$.

Now suppose $p_{A1} = p_{B1} = c - \frac{\delta_F}{3} - \varepsilon, \quad \varepsilon > 0$. The two-period discounted profit will be, $\frac{\delta_F}{9} - \frac{\varepsilon}{2}$. This cannot be an equilibrium either because A can deviate to a slightly higher price and earn profit, $\frac{\delta_F}{9}$

Q.E.D.

A.2 Proof of Proposition 2

Proposition 2:

If Contact with Breach Penalty (CWP) is available as an instrument then no strategies that involve not using CWP survives iterative elimination of weakly dominated strategies.

Proof:

Since the problem is symmetric we need only show for one firm, say A. First let us suppose firm B does not use CWP. We show that firm A can do better by using CWP than any strategies that involve not using CWP when firm B chooses prices optimally.

2^{nd} –Period Subgame:

The marginal first period customer of firm A who is indifferent between staying with A or switching to B gets a second period realization of the random switching cost, s yielding the following demands in A first period customers segment.

$$q_{BA} = s_A = p_{AA} - \tau_A - p_{BA}$$

And ,

$$q_{AA} = 1 - q_{BA} = 1 - p_{AA} + \tau_A + p_{BA}$$

Since B doesn't use CWP we have as before,

$$q_{AB} = s_B = p_{BB} - p_{AB}$$

And,

$$q_{BB} = 1 - q_{AB} = 1 - p_{BB} + p_{AB}$$

A's program in the second period is

$$\max_{p_{AB}} (p_{AB} - c)(1-\alpha)q_{AB}$$

where 1-α is B's first period market share, which yields the following best response function,

$$p_{AB} = \frac{1}{2}(p_{BB} + c) \qquad (1)$$

Firm B's second period program is

$$\max_{p_{BB}, p_{BA}} (p_{BB} - c)(1-\alpha)q_{BB} + (p_{BA} - c)\alpha * q_{BA}$$

where α is A's first period market share. It yields the following best response functions,

$$p_{BB} = \frac{1}{2}(1 + p_{AB} + c) \qquad (2)$$

$$\begin{aligned} p_{BA} &= \frac{1}{2}(p_{AA} + c - \tau_A) && if\ q_{BA} \geq 0 \\ &= c && if\ q_{BA} < 0 \end{aligned} \qquad (3)$$

Solving (1) and (2) we get the optimal second period prices in B's first period customers market segment, (which is the same as in the case with no CWP).

$$p^*_{BB} = c + \frac{2}{3} \ \ and \ \ p^*_{AB} = c + \frac{1}{3}$$

And hence,

$$q_{AB} = \frac{1}{3} \quad \& \quad q_{BB} = \frac{2}{3}$$

The second period profits are,

$$\pi_{A2} = \alpha\{(p_{AA} - c)q_{AA} + \tau_A q_{BA}\} + (1-\alpha)(p_{AB} - c)q_{AB}$$

$$\pi_{B2} = (1-\alpha)(p_{BB} - c)q_{BB} + \alpha(p_{BA} - c)q_{BA}$$

Now suppose A chooses τ_A such that it completely stops customers switching from A. The lowest τ_A that stops switching completely is $\tau_A = p_{AA} - c$. Then $q_{BA} = 0$ & $q_{AA} = 1$.

The second-period profits reduces to,

$$\pi_{A2} = \alpha\left(p_{AA} - c - \frac{1}{9}\right) + \frac{1}{9}$$

$$\pi_{B2} = \frac{4}{9}(1-\alpha)$$

The two-period discounted profits for first period market shares, $(\alpha, 1-\alpha)$ are then

$$\pi_A = (p_{A1} - c)\alpha + \delta_F\left\{\alpha\left(p_{AA} - c - \frac{1}{9}\right) + \frac{1}{9}\right\}$$

$$\pi_B = (p_{B1} - c)(1-\alpha) + \delta_F\left\{\frac{4}{9}(1-\alpha)\right\}$$

Note that the profits are increasing in first period market shares. In particular, B's profit is zero if its first period market share is zero.

Consumers' choice of firms in the first period:

The two-period discounted expected consumer surplus from choosing B is,

$$EU^B = (v - p_{B1}) + \delta_C\left[\Pr ob(stay\,with\,B)(v - p_{BB}) + \Pr ob(switch\,to\,A)\{v - p_{AB} - E(s \mid switch\,to\,A)\}\right]$$
$$EU^B = (v - p_{B1}) + \delta_C(v - c) - \frac{11}{18}\delta_C$$

Since A chooses τ_A to stop switching completely, a consumer that chooses A in the first period gets a certain two-period discounted consumer surplus given by,

$$EU^A = (v - p_{AA}) + \delta_C (v - p_{AA})$$

And since τ_A stops switching completely, A will choose the highest possible second period price, i.e., $p_{AA} = v$

Suppose A & B choose first period prices so that they split the market in the first period, i.e., $\alpha = \frac{1}{2}$. This implies,

$$EU^A = EU^B \Rightarrow p_{A1} = p_{B1} - \delta_C (v - c) + \frac{11}{18}\delta_C \tag{4}$$

First period competition for market share will drive π_B to zero [bc of no switching? yes],

$$\pi_B = \frac{1}{2}\left[(p_{B1} - c) + \delta_F \frac{4}{9}\right] = 0$$

$$p_{B1} = c - \delta_F \frac{4}{9}$$

Plugging in (4) we get,

$$p_{A1} = c - \delta_F \frac{4}{9} - \delta_C (v - c) + \frac{11}{18}\delta_C$$

Then A's two-period discounted profit is given by,

$$\pi_A = (p_{A1} - c)\alpha + \delta_F \left\{\left(p_{AA} - c - \frac{1}{9}\right)\alpha + \frac{1}{9}\right\}$$

$$\pi_A = \frac{1}{2}\left[(v - c)(\delta_F - \delta_C) + \frac{11}{36}\delta_C - \frac{3}{18}\delta_F\right]$$

For $\delta_F = \delta_C$ it can be easily verified that, $\pi_A = \frac{5}{36}\delta_F > \frac{1}{9}\delta_F$. Also it can be easily shown that π_A is greater than $\frac{1}{9}\delta_F$ for all $0 \le \delta_C < \delta_F \le 1$ if $(v - c) > \frac{8\delta_F - 11\delta_C}{18(\delta_F - \delta_C)}$. The upper constraint is $(v - c) > \frac{4}{9}$ for the extreme case where $\delta_C = 0$ and $\delta_F = 1$. The constraint on $(v-c)$ becomes considerably less stringent when the two discount factors are close.

We had shown earlier that if both firms do not use CWP the equilibrium profit is $\frac{1}{9}\delta_F$.

This means no strategies of A involving not using CWP can achieve a profit higher than $\frac{1}{9}\delta_F$ when B does not use CWP and chooses optimally. So A does better by using CWP than any strategy that involves not using CWP when B does not use CWP and chooses optimally.

Now suppose firm B uses CWP. We have shown above that if A uses CWP and B doesn't, B's profit is zero. Since the problem is symmetric, A's profit will be driven down to zero if B uses CWP and A doesn't. Suppose A also uses CWP then there is no switching in the second period. A's two-period discounted profit can be reduced to,

$$\pi_A = [(p_{A1} - c) + \delta_F (v - c)]\alpha$$

The game reduces to a pure Bertrand Price competition in the first period with profits increasing in market share. Competition for the first period market share drives profit down to zero.

Hence no strategy involving not using CWP survives iterative elimination of weakly dominated strategies.

Q.E.D.

A.3 Proof of Proposition 3.

Proposition 3:

There exists a unique family of subgame perfect equilibria of the game (one equilibrium for each penalty level) in which both firms use CWP and the equilibrium strategies are as below:

In the first period firm i offers the contract:

$$p_{i1} = c - \delta_F (v - c)$$
$$p_{ii} = v$$
$$\tau_i \geq v - c$$

and in the second period,

$$p_{ij} = \frac{1}{2}\left(p_{jj} + c - \tau_j\right) \text{ if } \tau_j \leq p_{jj} - c$$
$$p_{ij} = c \text{ if } \tau_j > p_{jj} - c$$

Proof:

By proposition 2 both firm will use CWP if available.

Second period subgame:

We have shown in the last proof that if firm j uses CWP as defined, firm i's second period optimal price choice (best response) is given by,

$$p_{ij} = \frac{1}{2}\left(p_{jj} + c - \tau_j\right) \text{ if } \tau_j \leq p_{jj} - c$$
$$p_{ij} = c \text{ if } \tau_j > p_{jj} - c$$

and that $\tau_j \geq p_{jj} - c$ completely stops switching in the second period. So the proposed strategies constitute a Nash equilibrium in the second period subgame. Let us check for possible first period profitable deviations. At the proposed equilibrium, each firm earns zero profit and $\alpha = \frac{1}{2},\ q_{BA} = q_{AB} = 0,\ q_{AA} = q_{BB} = 1$. Since the problem is symmetric let us look at firm A. The two-period discounted profit can be written as,

$$\pi_A = (p_{A1} - c)\alpha + \delta_F\left[(p_{AA} - c)q_{AA}\alpha + (1-\alpha)(p_{AB} - c)q_{AB} + \tau_A q_{BA}\alpha\right]$$

Suppose A deviates to a lower penalty, say $\tau_A = v - c - 2\varepsilon$, $\varepsilon > 0$. Then

$\alpha = 1,\ q_{BA} = \varepsilon,\ q_{AA} = 1-\varepsilon,\ p_{BA} = c + \varepsilon$. Then,

$$\pi_A = (c - \delta_F(v-c) - c) + \delta_F\left[(v-c)(1-\varepsilon) + (v-c-2\varepsilon)\varepsilon\right]$$
$$\pi_A = -\delta_F 2\varepsilon^2 < 0$$

Now suppose A deviates to a lower penalty and simultaneously raises first period price, p_{A1}, so that market share α remains one half. This implies,

$$EU^A = EU^B$$
$$(v - p_{A1}) + \delta_C\left[q_{AA}(v - p_{AA}) + q_{BA}(v - p_{BA} - \tau_A - E(s \mid switch))\right] = (v - p_{B1})(1+\delta_F)$$
$$p_{A1} = v - (v-c)(1+\delta_F) + \delta_C \frac{\varepsilon^2}{2}$$

A can charge a first period price just below the above p_{A1} and get the entire market in the first period, i.e., $\alpha = 1$. Then its profit is,

$$\pi_A = \left(v - (v-c)(1+\delta_F) + \delta_C\frac{\varepsilon^2}{2}\right) + \delta_F\left[(v-c)(1-\varepsilon) + (v-c-2\varepsilon)\varepsilon\right]$$
$$\pi_A = -\varepsilon^2\left(2\delta_F - \frac{\delta_C}{2}\right) < 0$$

Hence deviating to a lower penalty is not a profitable deviation.

We assume that the highest per period price that can be charged is v, the consumer's valuation of the product.

Suppose A deviates to a lower second period contract price, $p_{AA} = v - \varepsilon,\ \ \varepsilon > 0$. Then

$\alpha = 1,\ q_{BA} = \varepsilon,\ q_{AA} = 1$

$$\pi_A = (c - \delta_F(v-c) - c) + \delta_F\left[(v - \varepsilon - c)\right]$$
$$\pi_A = -\delta_F\varepsilon < 0$$

Hence this is not a profitable deviation either.

Suppose A deviates to a higher first period price, say $p_{A1} = c - \delta_F(v-c) + \varepsilon,\ \varepsilon > 0$. Then $\alpha = 0$ and $\pi_A = 0$. Now suppose A deviates to a lower first period price, say $p_{A1} = c - \delta_F(v-c) - \varepsilon,\ \varepsilon > 0$. Then $\alpha = 1$ and

$$\pi_A = (c - \delta_F(v-c) - \varepsilon - c) + \delta_F[(v-c)]$$
$$\pi_A = -\varepsilon < 0$$

Hence this is not a profitable deviation.

Finally, suppose A deviates to a higher first period price, $p_{A1} = c - \delta_F(v-c) + \varepsilon,\ \varepsilon > 0$ and simultaneously lowers second period contract price so that α remains one-half. It can be shown by comparing the consumer surpluses that second period contract price needs to be lowered to $v - \dfrac{\varepsilon}{\delta_C}$. Then,

$$\pi_A = (c - \delta_F(v-c) + \varepsilon - c) + \delta_F\left[\left(v - \frac{\varepsilon}{\delta_C} c\right)\right]$$
$$\pi_A = \varepsilon\left(1 - \frac{\delta_F}{\delta_C}\right) \le 0,\ for\ \delta_C \le \delta_F$$

Hence this is not a profitable deviation either.

So, the proposed strategies indeed constitute a subgame perfect equilibrium. Note that the equilibrium outcome is unique. The penalty level is not unique but the optimal prices and market shares are unique for each penalty greater than v-c, and thus the equilibrium is unique for each penalty level, $\tau_i \ge v - c$

Proof of Proposition 4.

Proposition 4:

There exists a unique symmetric sub-game perfect equilibrium of the game in which contracts (CWP) are not feasible and the strategies are as follows:

In the first period firm i chooses $p_i = c - \frac{\delta_F}{3}$ *and in the second period it chooses* p_{ii} *and* p_{ij} *optimally as described in the last section.*

Proof:

We have shown earlier that in the second period sub-game, each firm chooses optimally given rival firm's prices, i.e.,

$$p_{ii} = \frac{1}{2}\left(c + p_{ji} + \frac{3}{2}\right),$$
$$p_{ij} = \frac{1}{2}\left(c + p_{jj} + \frac{1}{2}\right)$$
$$for\ i, j = A, B$$

So the proposed strategies constitute Nash equilibrium in the second period sub-game. It is also the unique Nash Equilibrium. Let us now check for possible first period profitable deviations. Since the problem is symmetric we shall look at firm A. The two-period discounted profit of firm A at the proposed equilibrium can be written as,

$$\pi_A^* = (p_{A1} - c)\alpha + \delta_F\left(\frac{1}{3}\alpha + \frac{25}{72}\right)$$

Suppose A deviates to any higher first period price, say $p_{A1} = c - \frac{1}{3}\delta_F + \varepsilon,\ \ \varepsilon > 0$, then it sells zero in the first period and its two-period discounted profit is, $\frac{25}{72}\delta_F$. Now suppose A deviates to any lower first period price, say $p_{A1} = c - \frac{1}{3}\delta_F - \varepsilon,\ \ \varepsilon > 0$, then it captures the whole market in the first period. Its two-period discounted profit is then given by,

$$\pi_A = \left(c - \frac{1}{3}\delta_F - \varepsilon - c\right) + \delta_F\left(\frac{1}{3} + \frac{25}{72}\right)$$

$$\pi_A = \frac{25}{72}\delta_F - \varepsilon$$

Hence the proposed strategies indeed constitute a sub-game perfect equilibrium.

Uniqueness of symmetric equilibrium:

Suppose there is another symmetric equilibrium pair of first period prices (p_{A1}, p_{B1}). It can either be higher or lower than the proposed equilibrium prices. Suppose first, $p_{A1} = p_{B1} = c - \frac{1}{3}\delta_F + \varepsilon,\ \varepsilon > 0$. Then the two-period discounted profit is, $\frac{25}{72}\delta_F + \frac{\varepsilon}{2}$. This cannot be an equilibrium because A can lower its price by just a little (by less than $\frac{\varepsilon}{2}$) and capture the entire market. For example it can deviate to $p_{A1} = c - \frac{\delta_F}{3} + \frac{2}{3}\varepsilon$. Then its profit would be $\frac{25}{72}\delta_F + \frac{2}{3}\varepsilon > \frac{25}{72}\delta_F + \frac{1}{2}\varepsilon$. Now suppose $p_{A1} = p_{B1} = c - \frac{1}{3}\delta_F - \varepsilon,\ \varepsilon > 0$ Then the two-period discounted profit is, $\frac{25}{72}\delta_F - \frac{\varepsilon}{2}$. This cannot be an equilibrium either because A can deviate to a slightly higher price and earn profit, $\frac{25}{72}\delta_F$.

Q.E.D.

Proof of Proposition 5.

Proposition5.

If Contact with Breach Penalty (CWP) is feasible then no strategies that involve not using CWP survives iterative elimination of weakly dominated strategies.

Proof:

Suppose firm B doesn't use CWP. Firm A uses it. The marginal first period customer of A gets a realization of s and x such that,

$$p_{AA} + x = p_{BA} + (1 - x) + s + \tau_A,$$

It yields,

$$q_{BA} = \Pr ob[2x - s > p_{BA} + \tau_A - p_{AA} + 1] \qquad for \ 0 \le s \le 1, \ 0 \le x \le 1$$
$$q_{BA} = 1 - q_{BA}$$

Since B doesn't use CWP we have as before,

$$p_{BB} + (1 - x) = p_{AB} + x + s$$

and,
$$q_{AB} = \Pr ob[2x + s > p_{BB} - p_{AB} + 1] \quad for \ 0 \le s \le 1, \ 0 \le x \le 1$$
$$q_{BB} = 1 - q_{AB}$$

Firm A's second period program is

$$\max_{p_{AB}} \pi_{A2} = \alpha[(p_{AA} - c)q_{AA} + \tau_A q_{BA}] + (1 - \alpha)(p_{AB} - c)q_{AB}$$
$$\Leftrightarrow \max_{p_{AB}}(p_{AB} - c)q_{AB}$$

The best response is given by,

$$p_{AB} = \frac{1}{2}\left(c + p_{BB} + \frac{1}{2}\right) \tag{1}$$

Firm B's second period program is ,

$$\max_{p_{BB}, p_{BA}} \pi_{B2} = (1 - \alpha)(p_{BB} - c)q_{BB} + \alpha(p_{BA} - c)q_{BA}$$

The best responses are,

$$p_{BB} = \frac{1}{2}\left(c + p_{AB} + \frac{3}{2}\right) \tag{2}$$

$$p_{BA} = \begin{cases} \frac{1}{3}\left(p_{AA} + 2c - \tau_A + 1\right) & if \; -1 \le p_{AA} - p_{BA} - \tau_A \le 0 \\ \frac{1}{2}\left(p_{AA} + c - \tau_A + \frac{1}{2}\right) & if \; 0 \le p_{AA} - p_{BA} - \tau_A \le 1 \end{cases} \qquad (3)$$

Solving (1) & (2) we get the optimal second period prices in B's first period market segment, (which is the same as in the case with no CWP).

$$p^*_{BB} = c + \frac{7}{6}, \quad p^*_{AB} = c + \frac{5}{6}. \text{ Then, } \quad q_{AB} = \frac{5}{12}, \, q_{BB} = \frac{7}{12}$$

The second period profits are,

$$\pi_{A2} = \alpha\{(p_{AA} - c)q_{AA} + \tau_A q_{BA}\} + (1-\alpha)(p_{AB} - c)q_{AB}$$

$$\pi_{B2} = (1-\alpha)(p_{BB} - c)q_{BB} + \alpha(p_{BA} - c)q_{BA}$$

Suppose A chooses τ_A to completely stop its first period customers from switching. The lowest τ_A which does that is, $\bar{\tau}_A = 1 + p_{AA} - c$. Then we have, $q_{BA} = 0, \, q_{AA} = 1$. Then the second period profits reduces to,

$$\pi_{A2} = \alpha\left(p_{AA} - c - \frac{25}{72}\right) + \frac{25}{72}$$

$$\pi_{B2} = (1-\alpha)\frac{49}{72}$$

The two-period discounted profits for first period market shares, $(\alpha, 1-\alpha)$ are then

$$\pi_A = (p_{A1} - c)\alpha + \delta_F\left\{\alpha\left(p_{AA} - c - \frac{25}{72}\right) + \frac{25}{72}\right\}$$

$$\pi_B = (p_{B1} - c)(1-\alpha) + \delta_F\left\{\frac{49}{72}(1-\alpha)\right\}$$

Consumers' choice of firms in the first period:

The two-period discounted expected consumer surplus from choosing B is,

$$EU^B = (v - p_{B1}) + \delta_C [\Pr ob(stay)(v - p_{BB}) - E(1 - x \mid stay) + \Pr ob(switch)\{v - p_{AB} - E(x + s \mid switch)\}]$$

It is easy to show that,

$$E(x + s \mid switch\ to\ A) = E\left(x + s \mid x < \frac{2}{3} - \frac{s}{2}\right) = \frac{1}{prob(switch)} \int_0^1 \int_0^{2/3 - s/2} (x + s) dx ds$$

and, $E(1 - x \mid stay\ with\ B) = E\left(1 - x \mid x > \frac{2}{3} - \frac{s}{2}\right) = \frac{1}{prob(stay)} \int_0^1 \int_{2/3 - s/2}^1 (1 - x) dx ds$

Solving for the integrals and plugging in we get,

$$EU^B = (v - p_{B1}) + \delta_C (v - c) - \frac{59}{36} \delta_C$$

Since A chooses τ_A to stop switching completely, a consumer that chooses A in the first period has an expected two-period discounted surplus,

$$EU^A = (v - p_{AA}) + \delta_C (v - p_{AA} - E(x)) = (v - p_{AA}) + \delta_C \left(v - p_{AA} - \frac{1}{2}\right)$$

And since τ_A stops switching completely, A would choose the highest possible second period price, i.e., $p_{AA} = v$

Suppose A & B chooses first period prices so that they split the market in the first period, i.e., $\alpha = \frac{1}{2}$. This implies,

$$EU^A = EU^B \Rightarrow p_{A1} = p_{B1} - \delta_C (v - c) + \frac{41}{36} \delta_C \tag{4}$$

First period competition for market share will drive π_B to zero,

$$\pi_B = \frac{1}{2}\left[(p_{B1} - c) + \delta_F \frac{49}{72}\right] = 0$$

$$p_{B1} = c - \delta_F \frac{4}{9}$$

Plugging in (4) we get,

$$p_{A1} = c - \delta_F \frac{49}{72} - \delta_C (v - c) + \frac{41}{36}\delta_C$$

Then A's two-period discounted profit is given by,

$$\pi_A = (p_{A1} - c)\alpha + \delta_F \left\{ \left(p_{AA} - c - \frac{25}{72} \right)\alpha + \frac{25}{72} \right\}$$

$$\pi_A = \frac{1}{2}\left[(v - c)(\delta_F - \delta_C) + \frac{41}{36}\delta_C - \frac{24}{72}\delta_F \right]$$

For $\delta_F = \delta_C$ it can be easily verified that, $\pi_A = \frac{29}{72}\delta_F > \frac{25}{72}\delta_F$. Also it can be easily shown that π_A is greater than $\frac{25}{72}\delta_F$ for all $0 \le \delta_C < \delta_F \le 1$ if $(v - c) > \frac{49\delta_F - 82\delta_C}{72(\delta_F - \delta_C)}$.

The upper constraint is $(v - c) > \frac{49}{72}$ for the extreme case where $\delta_C = 0$ and $\delta_F = 1$. The constraint on $(v - c)$ becomes considerably less stringent when the two discount factors are close.

We had shown earlier that if both firms do not use CWP the equilibrium profit is $\frac{25}{72}\delta_F$. This means no strategies of A involving not using CWP can achieve a profit higher than $\frac{25}{72}\delta_F$ when B also chooses optimally. So A does better by using CWP than any strategy that involves not using CWP when B does not use CWP and chooses optimally.

Suppose B uses CWP. If A doesn't use CWP it gets zero. If she chooses CWP, the worst she can do is get zero.

Hence proved.

A.6. Derivation of Optimal Penalty.

The optimal penalty $\tau_A^* = p_{AA} - c + \frac{1}{3}$, maximizes the second period optimal profit of firm A for a given p_{AA}.

Derivation:

$$\max_{\tau_A} \pi_{A2}(p_{AA}, \tau_A) \Leftrightarrow \max_{\tau_A} \{\tau_A - (p_{AA} - c)\} q_{BA}$$

It is easy to show that if $\tau_A = p_{AA} - c + \frac{1}{3}$, then, $q_{BA} = \frac{1}{4}\left(p_{AA} - p_{BA}^* - \tau_A + 1\right)$ and optimal

$p_{BA}^* = \frac{1}{3}(p_{AA} + 2c - \tau_A + 1)$. Plugging in we get,

$q_{BA} = \frac{1}{9}[p_{AA} - \tau_A - c + 1]^2$. Hence the maximization program is,

$\max_{\tau_A} (\tau_A - p_{AA} + c)(p_{AA} - \tau_A - c + 1)^2$ and the first order condition is given by,

$$(p_{AA} - \tau_A - c + 1)(3p_{AA} - 3c + 1 - 3\tau_A) = 0$$

Solving for τ_A, $\tau_A = \left\{(p_{AA} - c + 1), \left(p_{AA} - c + \frac{1}{3}\right)\right\}$

The second order condition for a maximum is,

$$-6p_{AA} + 6c - 4 + 6\tau_A < 0$$

Plugging the roots we find that the SOC is satisfied only for the second root.

Hence, $\tau_A^* = p_{AA} - c + \frac{1}{3}$ maximizes π_{A2}^*.

Appendix B

Appendix to Chapter 3.

B.1 Matlab Codes and results.

Let x, y and z denote p_{A_1} , p_{A_2} *and* p_B respectively. Equilibrium solutions satisfying second order conditions are shown in bold.

B.1.a Case 1: Three firms case

c=0

```
>> syms  x y z , eq1='3*x^2-2*x*(1+y+z)+y*(1+z)=0', eq2='-x^2+3*y^2-y*(8+4*z)+x*(2+2*z)+2*z+3=0',eq3='4*z=1+y*(2+x)-x^2-y^2'

eq1 =3*x^2-2*x*(1+y+z)+y*(1+z)=0

eq2 =-x^2+3*y^2-y*(8+4*z)+x*(2+2*z)+2*z+3=0

eq3 =4*z=1+y*(2+x)-x^2-y^2

>> [x, y, z]= solve(eq1, eq2, eq3, x,y,z)

x =

[  -1.4241308876958787024016976498 3]
```

[-1.42413088769587870240169764983]
[-4.28623001241677811227538082357]
[-7.19324075650379114140023635057 8]
[.249518062714681426833683914343 89]

z =

[-5.323522326362843734355736211816]
[-5.744864702319461858245679456498]
[-11.000078719438354368247572663978]
[.47182300872712834088353874742998]
[.39108236041543823972298528493081]
[.2657627478780817678689362134437]
[.2682576700863663882019881254736]

a) c=0.1

```
>> syms  x y z , eq1='3*x^2-2*x*(1+y+z)+y*(1+z)=0',
eq2='x^2+3*y^2y*(8+4*z)+x*(2+2*z)+2*z+3+0.1*(4+2*z-2*y)=0', eq3='4*z=1+y*(2+x)-x^2-y^2'

eq1 =3*x^2-2*x*(1+y+z)+y*(1+z)=0

eq2 =-x^2+3*y^2-y*(8+4*z)+x*(2+2*z)+2*z+3+0.1*(4+2*z-2*y)=0

eq3 =4*z=1+y*(2+x)-x^2-y^2

>> [x, y, z]= solve(eq1, eq2, eq3, x,y,z)
```

x =

[-1.4290153814328697758599205379379]
[-4.2867548725599171610922733120485]
[-7.2066874684073907097519804341871]
[.27562417367146416344235697180483]
[1.1627639022737402534048806871419]
[1.8827735492071808798030112550421]
[.52819668204311398748082595498000]

y =

[-4.2326642477509299685259472732057]
[-3.7727915312267077691498081980796]
[-2.5353788923356628674067946556128]
[.63211081917582159494174470600854]
[.85584661658016357746227829977045]
[2.3481030618253065574586003641320]
[2.3831367468314240798982893300865]

z =

[-5.3435794438963675241051050895119]
[-5.7456934645816732583904803043144]
[-11.040891222153157980860281784652]
[.49072847193114141406373237369906]
[.40558686531507150549439240016506]
[.26468205818002745681060480866585]

[.26667648179365234410214734253683]

B.1.b Case II: Two firms case, one firm selling two products

a) c=0

syms x y z , eq1='3*x^2-x*(2+2*z+3*y)+y*(2+2*z)=0', eq2='-3*x^2+3*y^2-y*(8+4*z)+x*(4+4*z)+2*z+3=0',eq3='4*z=1+y*(2+x)-x^2-y^2'

eq1 =3*x^2-x*(2+2*z+3*y)+y*(2+2*z)=0

eq2 =-3*x^2+3*y^2-y*(8+4*z)+x*(4+4*z)+2*z+3=0

eq3 =4*z=1+y*(2+x)-x^2-y^2

>> [x, y, z]= solve(eq1, eq2, eq3, x,y,z)

x =

[-7]
[1]
[10/9*(11663+45*113^(1/2))^(1/3)+5140/9/(11663+45*113^(1/2))^(1/3)-583/9+3*(1/9*(11663+45*113^(1/2))^(1/3)+514/9/(11663+45*113^(1/2))^(1/3)-25/9)^2]
[-5/9*(11663+45*113^(1/2))^(1/3)-2570/9/(11663+45*113^(1/2))^(1/3)-583/9+5*i*3^(1/2)*(1/9*(11663+45*113^(1/2))^(1/3)-514/9/(11663+45*113^(1/2))^(1/3))+3*(-1/18*(11663+45*113^(1/2))^(1/3)-257/9/(11663+45*113^(1/2))^(1/3)-25/9+1/2*i*3^(1/2)*(1/9*(11663+45*113^(1/2))^(1/3)-514/9/(11663+45*113^(1/2))^(1/3)))^2]
[-5/9*(11663+45*113^(1/2))^(1/3)-2570/9/(11663+45*113^(1/2))^(1/3)-583/9-5*i*3^(1/2)*(1/9*(11663+45*113^(1/2))^(1/3)-514/9/(11663+45*113^(1/2))^(1/3))+3*(-1/18*(11663+45*113^(1/2))^(1/3)-257/9/(11663+45*113^(1/2))^(1/3)-25/9-1/2*i*3^(1/2)*(1/9*(11663+45*113^(1/2))^(1/3)-514/9/(11663+45*113^(1/2))^(1/3)))^2]

y =

[-7]
[1]
[1/9*(11663+45*113^(1/2))^(1/3)+514/9/(11663+45*113^(1/2))^(1/3)-25/9]
[-1/18*(11663+45*113^(1/2))^(1/3)-257/9/(11663+45*113^(1/2))^(1/3)-25/9+1/2*i*3^(1/2)*(1/9*(11663+45*113^(1/2))^(1/3)-514/9/(11663+45*113^(1/2))^(1/3))]
[-1/18*(11663+45*113^(1/2))^(1/3)-257/9/(11663+45*113^(1/2))^(1/3)-25/9-1/2*i*3^(1/2)*(1/9*(11663+45*113^(1/2))^(1/3)-514/9/(11663+45*113^(1/2))^(1/3))]

z =

[-31/2]
[1/2]
[-
589/6+5/3*(11663+45*113^(1/2))^(1/3)+2570/3/(11663+45*113^(1/2))^(1/3)+9/2*(1/9*(11663+45*113^(1/2))^(1/3)+514/9/(11663+45*113^(1/2))^(1/3)-25/9)^2]
[-589/6-5/6*(11663+45*113^(1/2))^(1/3)-1285/3/(11663+45*113^(1/2))^(1/3)+15/2*i*3^(1/2)*(1/9*(11663+45*113^(1/2))^(1/3)-514/9/(11663+45*113^(1/2))^(1/3))+9/2*(-1/18*(11663+45*113^(1/2))^(1/3)-257/9/(11663+45*113^(1/2))^(1/3)-25/9+1/2*i*3^(1/2)*(1/9*(11663+45*113^(1/2))^(1/3)-514/9/(11663+45*113^(1/2))^(1/3)))^2]
[-589/6-5/6*(11663+45*113^(1/2))^(1/3)-1285/3/(11663+45*113^(1/2))^(1/3)-15/2*i*3^(1/2)*(1/9*(11663+45*113^(1/2))^(1/3)-514/9/(11663+45*113^(1/2))^(1/3))+9/2*(-1/18*(11663+45*113^(1/2))^(1/3)-257/9/(11663+45*113^(1/2))^(1/3)-25/9-1/2*i*3^(1/2)*(1/9*(11663+45*113^(1/2))^(1/3)-514/9/(11663+45*113^(1/2))^(1/3)))^2]

b) c=0.1

```
>> syms  x y z , eq1='3*x^2-x*(2+2*z+3*y)+y*(2+2*z)-(1+z-x)*0.1=0', eq2='-3*x^2+3*y^2-y*(8+4*z)+x*(4+4*z)+2*z+3+(2+z-y)*0.1=0',eq3='4*z=1+y*(2+x)-x^2-y^2'

eq1 =3*x^2-x*(2+2*z+3*y)+y*(2+2*z)-(1+z-x)*0.1=0

eq2 =-3*x^2+3*y^2-y*(8+4*z)+x*(4+4*z)+2*z+3+(2+z-y)*0.1=0

eq3 =4*z=1+y*(2+x)-x^2-y^2

>> [x, y, z]= solve(eq1, eq2, eq3, x,y,z)

x =

[-7.2353571433432438139691071661108]
[ -5.8321613582352887333261506509362-1.2789442704487282533372656246017*i]
[ -5.8321613582352887333261506509362+1.2789442704487282533372656246017*i]
[.88400322518224722120911546214626]
[.93017025616893669490374179884731]
[1.1083133960064970136313582245335]


y =

[-7.1441894062987758557466735524156]
[ -5.3294601897947434314097020334010+.11424606872713433907944398697935*i]
[ -5.3294601897947434314097020334010-.11424606872713433907944398697935*i]
[1.0401973350469430171914493688682]
[2.2571683370628476376154651901116]
[1.0118844646556650462153034111150]


z =
```

[-16.246863055784084216575984853035]
[-9.7997589143405229842669194390457-1.8305014380587989507342172333093*i]
[-9.7997589143405229842669194390457+1.8305014380587989507342172333093*i]
[.53411506778249628660157069229280]
[.41346547928185270780460368262944]
[.47324632078028257574520060274205]

Table B.0: Equilibrium prices comparison of the two cases for different values of c.

		p_{A1}	p_{A2}	p_B
$c = 0$	Three sellers case	0.250	0.563	0.472
	Two sellers case	1.000	1.000	0.500
$c = 0.01$	Three sellers case	0.252	0.570	0.474
	Two sellers case	0.965	1.008	0.510
$c = 0.05$	Three sellers case	0.263	0.598	0.482
	Two sellers case	0.919	1.024	0.524
$c = 0.1$	Three sellers case	0.276	0.632	0.491
	Two sellers case	0.884	1.040	0.534
$c = 0.2$	Three sellers case	0.300	0.700	0.508
	Two sellers case	0.831	1.069	0.548

Table B.1. List of City Terminals selling wholesale unbranded Gasoline during August 1999

City		state	city		state	City		state	city		state
1	Anchorage	AK	76	Kankakee	IL	151	Springfield	MO	226	Northumberland	PA
2	Fairbanks	AK	77	Peoria	IL	152	St. Louis	MO	227	Philadelphia	PA
3	Anniston/Oxford	AL	78	Robinson	IL	153	Biloxi	MS	228	Pittsburgh	PA
4	Birmingham	AL	79	Rockford	IL	154	Collins	MS	229	Scranton	PA
5	Mobile	AL	80	Wood River	IL	155	Greenville	MS	230	Sinking Springs	PA
6	Montgomery	AL	81	Evansville	IN	156	Meridian	MS	231	Warren	PA
7	El Dorado	AR	82	Hammond	IN	157	Pascagoula	MS	232	Williamsport	PA
8	Ft.Smith	AR	83	Huntington	IN	158	Vicksburg	MS	233	Providence	RI
9	Little Rock	AR	84	Indianapolis	IN	159	Bozeman	MT	234	Belton	SC
10	Rogers	AR	85	Muncie	IN	160	Missoula	MT	235	Charleston	SC
11	West Memphis	AR	86	Princeton	IN	161	Charlotte	NC	236	North Augusta	SC
12	Flagstaff	AZ	87	Coffeyville	KS	162	Fayetteville	NC	237	Spartanburg	SC
13	Phoenix	AZ	88	Concordia	KS	163	Greensboro	NC	238	Aberdeen	SD
14	Tucson	AZ	89	El Dorado	KS	164	Raleigh/Apex	NC	239	Mitchell	SD
15	Bakersfield	CA	90	Great Bend	KS	165	Selma	NC	240	Rapid City	SD
16	Barstow	CA	91	Hutchinson	KS	166	Wilmington	NC	241	Sioux Falls	SD
17	Brisbane	CA	92	Kansas City	KS	167	Fargo	ND	242	Watertown	SD
18	Chico	CA	93	McPherson	KS	168	Grand Forks	ND	243	Wolsey	SD
19	Colton	CA	94	Olathe	KS	169	Jamestown	ND	244	Yankton	SD
20	Eureka	CA	95	Phillipsburg	KS	170	Columbus	NE	245	Chattanooga	TN
21	Fresno	CA	96	Salina	KS	171	Doniphan	NE	246	Knoxville	TN
22	Imperial	CA	97	Scott City	KS	172	Geneva	NE	247	Memphis	TN
23	Los Angeles	CA	98	Topeka	KS	173	Lincoln	NE	248	Nashville	TN
24	Sacramento	CA	99	Wathena	KS	174	Norfolk	NE	249	Abilene	TX
25	San Diego	CA	100	Wichita	KS	175	North Platte	NE	250	Amarillo	TX
26	San Francisco	CA	101	Ashland	KY	176	Omaha	NE	251	Austin	TX

27	San Jose	CA	102	Covington	KY	177	Osceola	NE	252	Beaumont	TX
28	Stockton	CA	103	Lexington	KY	178	Sidney	NE	253	Big Spring	TX
29	Colorado Springs	CO	104	Louisville	KY	179	Newington	NH	254	Brownsville	TX
30	Denver	CO	105	Owensboro	KY	180	Newark	NJ	255	Bryan	TX
31	Fountain	CO	106	Paducah	KY	181	Paulsboro	NJ	256	Caddo Mills	TX
32	La Junta	CO	107	Arcadia	LA	182	Albuquerque	NM	257	Center	TX
33	Hartford/Rocky Hill	CT	108	Archie	LA	183	Artesia	NM	258	Corpus Christi	TX
34	New Haven	CT	109	Baton Rouge	LA	184	Bloomfield	NM	259	Dallas Metro	TX
35	Wilmington	DE	110	Chalmette	LA	185	Ciniza	NM	260	Edinburg	TX
36	Jacksonville	FL	111	Convent/Garyville	LA	186	Las Vegas	NV	261	El Paso	TX
37	Miami	FL	112	Lake Charles	LA	187	Sparks/Reno	NV	262	Gulf Coast	TX
38	Niceville	FL	113	Monroe	LA	188	Albany	NY	263	Harlingen	TX
39	Orlando	FL	114	New Orleans	LA	189	Binghamton/Vestal	NY	264	Hearne	TX
40	Panama City	FL	115	Shreveport	LA	190	Buffalo	NY	265	Hidalgo	TX
41	Pensacola	FL	116	Boston	MA	191	Long Island	NY	266	Houston	TX
42	St.Marks	FL	117	Springfield	MA	192	New York	NY	267	Laredo	TX
43	Tampa	FL	118	Baltimore	MD	193	Newburgh	NY	268	Lubbock	TX
44	Albany	GA	119	Salisbury	MD	194	Rochester	NY	269	Midland/Odessa	TX
45	Americus	GA	120	Bangor	ME	195	Syracuse	NY	270	Mt. Pleasant	TX
46	Athens	GA	121	Portland	ME	196	Utica	NY	271	San Angelo	TX
47	Atlanta	GA	122	Bay City	MI	197	Akron/Canton	OH	272	San Antonio	TX
48	Bainbridge	GA	123	Cheboygan	MI	198	Cincinnati	OH	273	Sherrin	TX
49	Chattahooche	GA	124	Detroit	MI	199	Cleveland	OH	274	Three Rivers	TX
50	Columbus	GA	125	Ferrysburg	MI	200	Columbus	OH	275	Tyler	TX
51	Griffin	GA	126	Flint	MI	201	Dayton	OH	276	Victoria/Placedo	TX
52	Macon	GA	127	Jackson	MI	202	Heath	OH	277	Waco	TX
53	Rome	GA	128	Lansing	MI	203	Lebanon	OH	278	Wichita Falls	TX
54	Savannah	GA	129	Muskegon	MI	204	Lima	OH	279	Salt Lake City	UT

55 Bettendorf	IA	130 Niles	MI	205 Lorain	OH	280 Fairfax	VA
56 Council Bluffs	IA	131 Traverse City	MI	206 Marietta	OH	281 Norfolk	VA
57 Des Moines	IA	132 Alexandria	MN	207 Sciotoville	OH	282 Richmond	VA
58 Dubuque	IA	133 Duluth	MN	208 Tiffin	OH	283 Roanoke	VA
59 Ft. Dodge	IA	134 Duluth	MN	209 Toledo	OH	284 Anacortes	WA
60 Ft. Madison	IA	135 Mankato	MN	210 Youngstown	OH	285 Moses Lake	WA
61 Iowa City	IA	136 Marshall	MN	211 Ardmore	OK	286 Pasco	WA
62 Lemars	IA	137 Minneapolis	MN	212 Enid	OK	287 Seattle	WA
63 Mason Cty/Clr.Lk	IA	138 Rochester	MN	213 Laverne	OK	288 Spokane	WA
64 Milford	IA	139 Roseville	MN	214 Oklahoma City	OK	289 Tacoma	WA
65 Ottumwa	IA	140 Sauk Centre	MN	215 Ponca City	OK	290 Wilma	WA
66 Rock Rapids	IA	141 St.Paul	MN	216 Shawnee	OK	291 Chippewa Falls	WI
67 Sioux City	IA	142 Belle	MO	217 Tulsa	OK	292 Green Bay	WI
68 Waterloo	IA	143 Cape Girardeau	MO	218 Turpin	OK	293 Junction City	WI
69 Boise	ID	144 Carrollton	MO	219 Wynnewood	OK	294 Madison	WI
70 Burley	ID	145 Carthage	MO	220 Eugene	OR	295 Milwaukee	WI
71 Pocatello	ID	146 Columbia	MO	221 Portland	OR	296 Superior	WI
72 Amboy	IL	147 Jefferson City	MO	222 Altoona	PA	297 Waupun	WI
73 Champaign	IL	148 Mt.Vernon	MO	223 Harrisburg	PA	298 Wausau	WI
74 Chicago	IL	149 Palmyra	MO	224 Macungie	PA	299 Charleston	WV
75 Decatur/Forsythe	IL	150 Riverside	MO	225 Midland	PA	300 Cheyenne	WY

Table B.2. Refiners selling unbranded gasoline during August 1999

1	Aectra	21	Ergon	41	Minn.Solv	60	Rio
2	Agway	22	Exxon	42	MinnIowa	61	Shamrock
3	Amoco	23	Farm & H	43	Murphy	62	Shell
4	Apex	24	Fina	44	Navajo	63	So.States
5	BP	25	Flying J	45	New West	64	Sprague
6	Berry-Hnk	26	Frontier	46	Noco	65	Streett
7	Buckeye	27	Gary Ener	47	Northeast	66	TAC
8	Catamount	28	Giant	48	Northrdge	67	Tesoro
9	Center	29	Global	49	Oil Prod.	68	Texaco
10	Chevron	30	Hartford	50	Pal	69	Tosco
11	Chief Eth	31	Hess	51	Parker	70	Total
12	Citgo	32	Hunt	52	Pennzoil	71	TransMont
13	Clark	33	Inland	53	Pet Produ	72	U.S. Oil
14	Coast	34	Irving	54	Petro.Ser	73	Ultramar
15	Colonial	35	Kern	55	Petron	74	United Re
16	CountryEn	36	Koch	56	Phillips	75	Valero
17	Crandall	37	Leffler	57	Placid	76	Wesco
18	Crown	38	Lion	58	Pride	77	Western Refining
19	Dale	39	Marathon	59	Primary	78	Westside
20	EOTT	40	Martin				

Table B.3 and B.4 list the city-terminals where Marathon sells wholesale unbranded gasoline .

Table B.3. City-Terminals where Marathon sells both unbranded and branded gasoline.

	city	**state**		**city**	**state**		**City**	**state**		**city**	**state**
1	Miami	FL	12	Covington	KY	23	Roseville	MN	34	Lebanon	OH
2	Tampa	FL	13	Lexington	KY	24	St.Paul	MN	35	Lima	OH
3	Athens	GA	14	Bay City	MI	25	St.Louis	MO	36	Toledo	OH
4	Atlanta	GA	15	Detroit	MI	26	Charlotte	NC	37	Youngstown	OH
5	Columbus	GA	16	Flint	MI	27	Greensboro	NC	38	Midland	PA
6	Macon	GA	17	Jackson	MI	28	Akron/Canton	OH	39	Pittsburgh	PA
7	Chicago	IL	18	Muskegon	MI	29	Cincinnati	OH	40	Belton	SC
8	Kankakee	IL	19	Niles	MI	30	Cleveland	OH	41	Knoxville	TN
9	Rockford	IL	20	Duluth	MN	31	Columbus	OH	42	Green Bay	WI
10	Evansville	IN	21	Minneapolis	MN	32	Dayton	OH	43	Milwaukee	WI
11	Ashland	KY	22	Rochester	MN	33	Heath	OH	44	Superior	WI
									45	Charleston	WV

Table B.4. City terminals where Marathon sells only unbranded gasoline.

	City	state		city	state		city	state		city	state
1	Birmingham	AL	14	Milford	IA	27	Selma	NC	41	North Augusta	SC
2	Montgomery	AL	15	Sioux City	IA	28	Wilmington	NC	42	Spartanburg	SC
3	Jacksonville	FL	16	Waterloo	IA	29	Fargo	ND	43	Aberdeen	SD
4	Orlando	FL	17	Huntington	IN	30	Grand Forks	ND	44	Mitchell	SD
5	Albany	GA	18	Indianapolis	IN	31	Jamestown	ND	45	Sioux Falls	SD
6	Bainbridge	GA	19	Louisville	KY	32	Columbus	NE	46	Watertown	SD
7	Savannah	GA	20	Paducah	KY	33	Doniphan	NE	47	Wolsey	SD
8	Council Bluffs	IA	21	Convent/Garyville	LA	34	Geneva	NE	48	Yankton	SD
9	Des Moines	IA	22	Baltimore	MD	35	Lincoln	NE	49	Chattanooga	TN
10	Dubuque	IA	23	Cheboygan	MI	36	Norfolk	NE	50	Nashville	TN
11	Ft. Dodge	IA	24	Alexandria	MN	37	North Platte	NE	51	Norfolk	VA
12	Iowa City	IA	25	Mankato	MN	38	Omaha	NE	52	Richmond	VA
13	Mason Cty/Clr.Lk.	IA	26	Marshall	MN	39	Marietta	OH	53	Roanoke	VA
						40	Charleston	SC	54	Chippewa Falls	WI

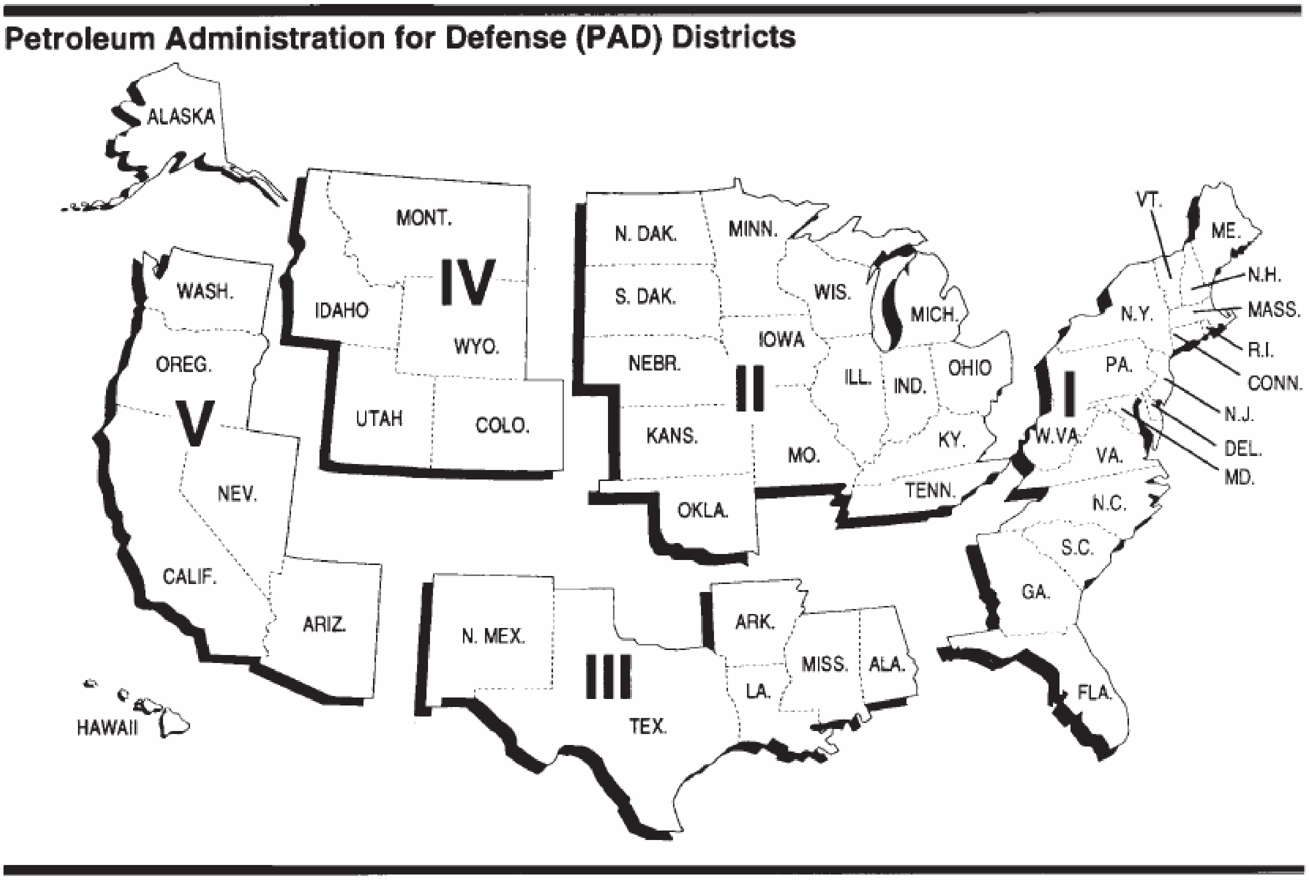

Figure B.1 PADD Map

Source: Energy Information Administration

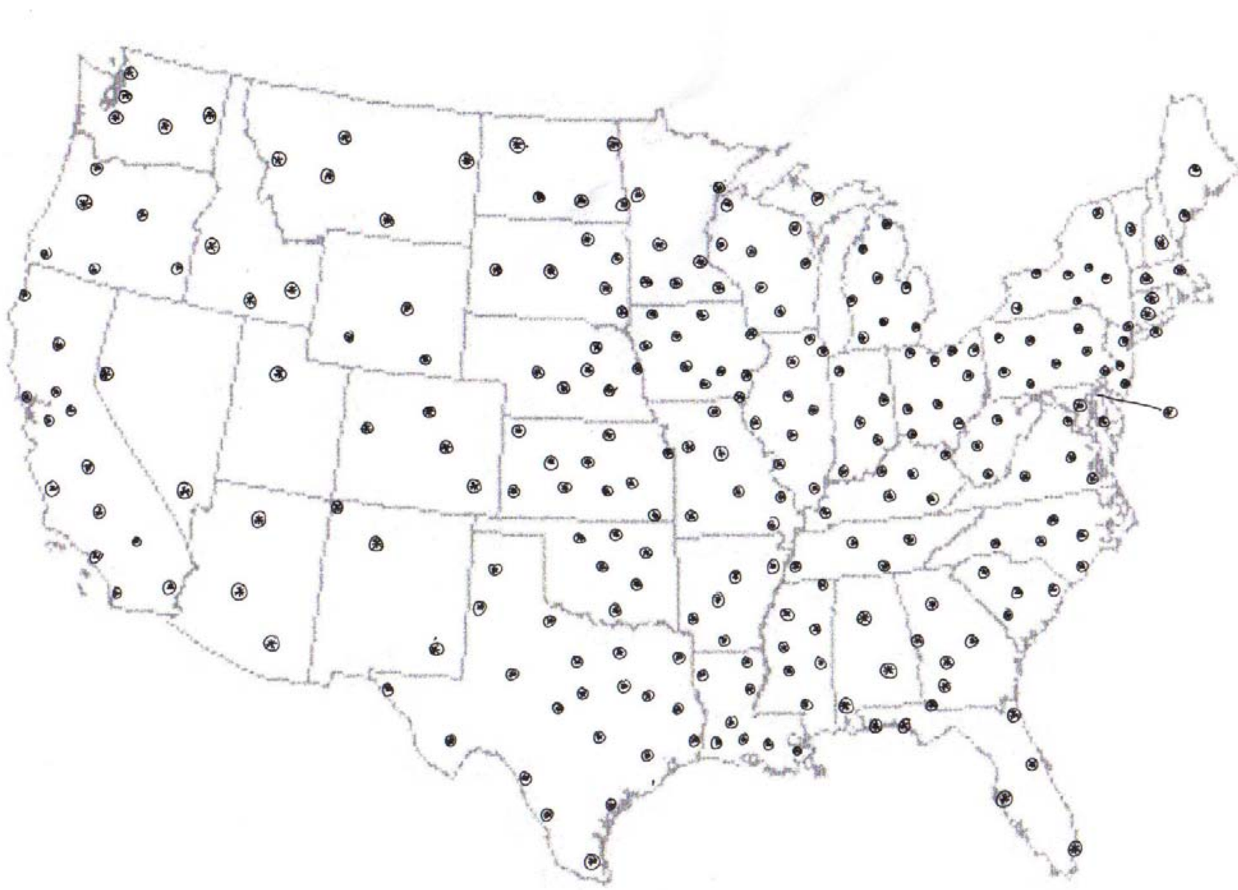

Figure B.2 Map of City Terminals in the United States.

Source: Terminal Location information from OPIS

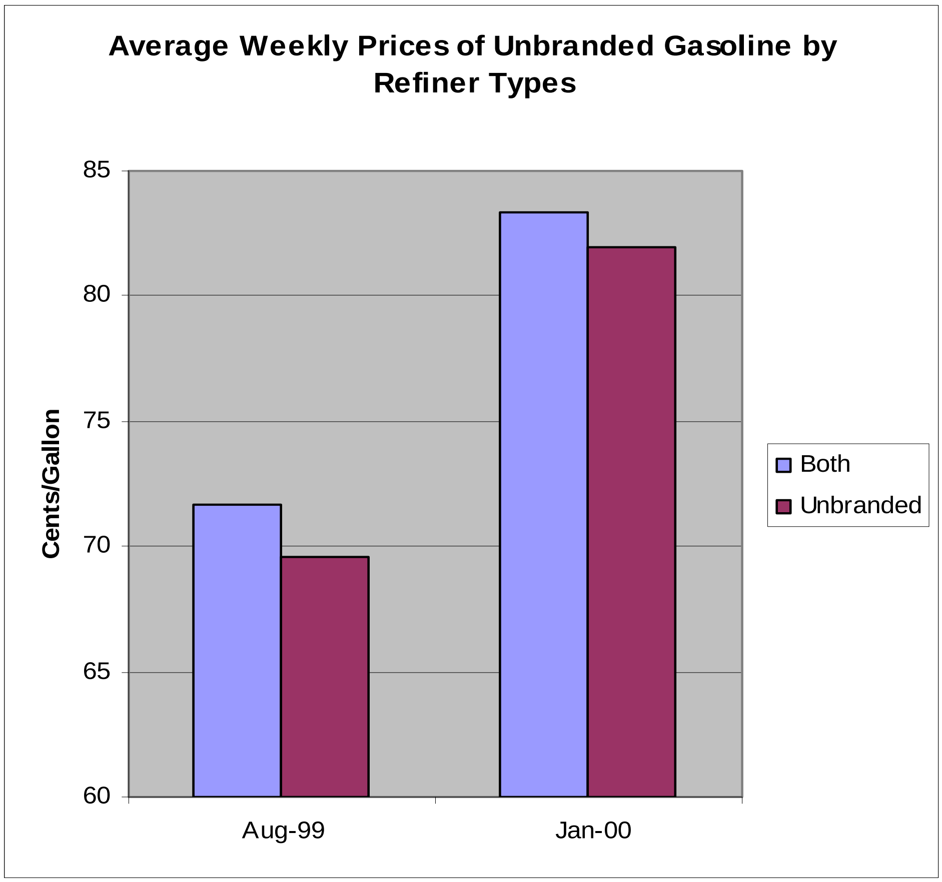

Figure B.3 Average weekly price of unbranded regular unleaded gasoline by refiner types.

Refiner Types:

Both:	Sell both branded and unbranded gasoline
Unbranded:	Sell only unbranded gasoline

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