ABSTRACT

Title of dissertation: IS IT MORE PROFITABLE TO POST PRICES? – MARKET STRUCTURE WITH ENDOGENOUS SEARCH COSTS

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This dissertation contains three chapters. It analyzes a market where firms can choose whether or not to publicly post their prices. Price posting rewards a firm by reducing search costs for customers and thus attracting more demand, at the risk of triggering more direct price competition.

In the first two chapters, I use a continuous model and a discrete model to discuss possible market equilibria, respectively. In a non-cooperative and dynamic environment, I find that when the supporting information technology becomes available to all firms, a firm wants to post prices only when it has appropriate cost advantage over its competitors. A lower cost of posting prices encourages firms to post their prices. Price posting improves market efficiency unless one firm has too much cost advantage. When a more efficient entrant replaces the incumbent price-posting firm, the incumbent wants to hide its prices again. These results explain why in some markets firms or individual traders hesitate to publicly post their prices and some even impose search costs on their prices.

In the third chapter, I use a laboratory experiment to show how a market evolves when firms or individual traders endogenously determine the search costs on their prices. In the experiment, human subjects play sellers and the computer calculates demands and profits, assuming consumers behave optimally. I assign costs and demand parameters to subjects and let them choose both their prices and whether or not to publicly post them. I alter the production costs, the fixed cost of posting prices, and the possibility of communication among subjects across treatments to show the effect of these factors on market structure. Experimental results show that one is more likely to post prices when he or she has lower unit cost and when the fixed cost of posting prices becomes lower. Price posting lowers effective prices when communication among subjects is not allowed but raises prices when subjects can communicate with each other.

IS IT MORE PROFITABLE TO POST PRICES?
– MARKET STRUCTURE WITH ENDOGENOUS SEARCH COSTS

by

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Dissertation submitted to the Faculty of the Graduate School of the
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Preface

With the rapid development of information technology, the costs of exchanging information are getting lower. This directly affects the pattern of the market structures as well as our everyday life. An obvious example is that some firms are using the Internet to publicly post their prices and other product information. This dramatically cuts customer search costs and at the same time, could result in more direct price competition among firms.

However, we do not see all the firms posting their prices, although they have the option to do so. Some firms even try to make it harder to obtain their price information. In the U.S. bond market and the steel wholesale market, dealers/middlemen choose not to publicly post their prices. In the car retail market, a big company called Carmax entered in 1993 with a new concept of car buying-they publicly post their "no haggle" price. But most car dealerships nowadays still "haggle" with their customers for hours before giving them a final price quote. Although consumers can easily find the market suggested retail price (MSRP) and invoice price of any particular car on various websites, there is usually a gap of thousands of dollars between these two prices. So, this information does not help the consumers much.

When firms or individual sellers can choose whether or not to post their prices, which factors lead them to make different decisions? How will the improvement of information technology affect their price posting decisions and thus change the market structures? Is price posting always good for market efficiency? Will it and how much will it facilitate collusion? From the social planners' point of view, what would be the best way to regulate the markets on price posting?

Inspired by Rust and Hall (2003), my dissertation tries to tackle these questions with theoretical models and experimental tests. There are certainly limitations in this dissertation and I will further my study on this topic in the future. I also hope that my research can lead more attention to related issues and more economists will start working on them. With a better understanding of how the markets evolve with endogenous price posting, policy makers can design better regulations (or deregulate the markets) to improve market efficiency.

Dedication

To my parents, who know when to support me and when to let go.

Acknowledgments

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Last but not least, I want to thank seminar participants in the applied micro seminar at University of Maryland, College Park and those who gave me comments at Peking University, SEC (US Securities and Exchange Commission) Office of Economic Analysis, George Mason University Graduate Student Workshop in Experimental Economics, the 75th Annual Meeting of Southern Economic Association, the 2006 International Industrial Organization Conference, and the 2006 Western Economics Association International Conference.

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Chapter 1

Introducing Endogenous Search Cost

Search cost and its effects on market structure have been widely discussed since Stigler (1961). However, few economists study how search cost is endogenously affected by firms or individual traders. Unlike early studies which model either a search market or a posted price market, this paper studies how market evolves when each firm can chose whether or not to publicly post its prices. Price posting reduces search costs for customers and attracts more demand. But at the same time, it exposes a firm to the risk of more direct price competition. Comparing the benefits and costs, is it more profitable for a firm to post prices? Which factors encourage price posting? Is it possible to have multiple firms voluntarily posting their prices at the same time? How are prices determined? And how does the price posting option affect market efficiency?

These questions arise naturally in the real markets. Consider the car retailing market as an example. It can take a car buyer several hours to get a final price quote from a car dealer. This is costly for both the buyers and the dealers. But since it is so costly for buyers to compare prices offered by different dealers, they will buy cars when the expected gains from further search are lower than the extra costs they must bear, even if they know there are better deals somewhere else. In 1993, Carmax entered the market and introduced "No Haggle" prices. It posts its prices for every single car in their inventory on the website. There is absolutely no room to bargain. A buyer can easily see Carmax's prices online and the search costs become nearly zero. In the airline ticket market, there are multiple retailers posting their prices online and some traditional travel agencies hiding their prices. In some other markets, we have not seen a firm posting its prices. More interestingly, while most firms start to post their prices to reduce search costs, some firms try to make it more difficult to discover their prices, although it is contrary to our intuition. B&H, an audio photo shop asks customers to get the prices of certain products by requesting E-mails, one E-mail for each product. A number of other stores practise similar strategies. Are they actually hiding the prices to increase search cost and thus avoid direct competition? But, if their competitors are not raising search costs as well, will the ones doing it benefit?

Having these puzzling questions in mind, I build a new model to look for market equilibrium with firms or individual traders choosing whether or not to post their prices and thus endogenously affect search costs for their consumers. I find that multiple price posters will not coexist in the long run equilibrium unless they can agree on posting the same price. A firm only wants to be a price poster when it is efficient enough compared to its competitors. A lower cost of posting prices encourages the most efficient firm to post price. So, when information technology improves, we should see more firms or traders publicly posting their prices. Without multiple firms agreeing on posting the same price, voluntary price posting increases market efficiency over the search market, unless one firm has too much cost advantage over its competitors.

To test these theoretical predictions, I run a lab experiment in which human subjects play sellers and the computer simulates buyers. The experimental results are consistent with the comparative status predicted in the theory. I also observe that people tend to post their prices more than the noncooperative equilibrium level. Also, price posting, especially mandatary price posting, helps sellers to collude on higher prices and decreases market efficiency.Therefore, policy makers should think twice before imposing regulations on price posting. A better antitrust enforcement is needed when we seek for more price transparency.

In Chapter 2 and Chapter 3 I will deliver the theory. In Chapter 2, I expand the model in Rust and Hall (2003) by assuming that all firms choose whether or not to post their prices. Because of the limitations of this model with a continuum of firms, I also build a model with discrete firms, which will be shown in Chapter 3. It give me more freedom to look at markets with different distributions of seller unit costs. It also allows a better comparison of profits from posting prices and hiding prices. In Chapter 4, I describe the experimental design and show the results I get. Then, I conclude and make some policy implications. I will finish with a discuss on future studies.

Chapter 2

A Model with A Continuum of Firms

2.1 Introduction

Early studies consider search market and posted price market as two competing market structures. Posted price markets are usually believed to be more efficient than decentralized search markets, where no one posts prices and each customer has to carry out a sequential search at certain costs. [1] Gehrig (1993) finds that the market maker(who post publicly observable prices) always coexists with the search market and charges the same bid-ask spread and trades the same volume, no matter how much the search costs in the search market are. On the contrary, Neeman and Vulkan (2001) conclude that the market maker can never coexist with the search market in equilibrium.

Robert and Stahl (1993) show a unique mixed strategy equilibrium exhibiting price dispersion when homogeneous firms face a costly price advertisement decision. They find that when advertisement cost is lower, equilibrium prices are closer to competitive levels.

Rust and Hall (2003) combine posted price market with search market where

[1] In the tourist trap model in Diamond (1971), all the sellers will charge the monopoly price in the unique equilibrium. If it is instead a posted price market with homogeneous firms, Bertrand competition will drive prices down to marginal cost and the market is fully efficient.

firms have homogeneous costs for the first time. They introduce a monopoly market maker to Spulber's 1996 model with buyers, sellers and only middlemen (whose prices can only be obtained through a costly search process) and analyze the conditions for this market maker to enter profitably. They find that being a monopoly market maker is profitable if only the market maker is efficient enough to operate profitably as a middleman in the original middlemen market. A possible coexistence of one market maker and some efficient middlemen is shown. The market maker will charge a higher bid-ask spread than middlemen do. Customers with high search costs go to the market maker directly, while the ones with low search costs search among middlemen for a better deal.

Rust and Hall successfully picture the possible coexistence of a market maker and middlemen in the same market. The problem is, Rust and Hall's paper does not make price posting fully endogenous. The entrant does not consider entering as a middleman, nor do the existing middlemen react to the entry by posting their own prices. So, it only partially solves the market equilibrium. When the necessary information technology is available to all the firms, it makes more sense to think that whether or not to post prices is an endogenous choice of firms. In reality, market makers like Carmax certainly had an option to enter the market just as another traditional dealer. On the other hand, after Carmax started posting their prices online, some traditional dealers such as Autonation and Koons started doing so, too.

I expand the model in Rust and Hall (2003) by adding two new features: First, all firms choose whether or not to post their prices, depending on which option is more profitable, taking into account the possible reactions of their competitors. Second, new entrants are introduced when there is already one market maker.

Since the continuous model in Rust and Hall (2003) has many limitations, I also build a discrete model in the same spirit. The discrete model is better for comparing profits being a market maker and a middleman. The essential outcomes of the continuous model are confirmed in the discrete model. Furthermore, since the discrete model has more freedom in firms' unit costs, it generates richer results.

With the added flexibility, my models yield results different from Rust and Hall's. I find that a firm wants to become a market maker only when it has a sufficiently low unit cost compared to its competitors, but the unit cost should not be too low, either. If a firm is not efficient enough and it posts its price, either it will be undercut by the more efficient firms, or its price has to be so low that the gain from price posting is not enough to cover the posting cost. On the other hand, if a firm has too much cost advantage, the other firms are not able to compete with it no matter if this firm posts its price or not. This firm can not steal demand from other firms by posting its prices because it is already a monopolist. Thus, the gain from price posting can not cover the posting cost, either. The likelihood for price posting in this model is much lower compared to that in Rust and Hall's. In their paper, any existing firm has incentive to post its price. In my paper, even the most efficient firm sometimes find price posting less profitable. Being the only price poster is more profitable when there are more firms competing against each other, since the increase in demand will be bigger. I also find that when another firm becomes the most efficient one, the incumbent price poster sometimes will hide its prices again.

Posting prices increases consumer surplus and market efficiency, unless one firm has too much cost advantage. In the latter case, the monopoly market maker will post a price much higher than what it would charge in an all-middlemen market.

In section 2, I deliver the theory with a continuous model similar to Rust and Hall's. In section 3, I present a discrete model with three firms. In each section, the analysis includes three steps. First, I review a dynamic equilibrium with only middlemen. Second, assuming that the new technology of posting prices becomes available to all the intermediaries, I discuss whether the existing middlemen will become market makers. Third, in a more dynamic setting, I show whether a new entrant will enter as a market maker or a middleman and how incumbents will respond to the entry. In section 4, I conclude and address some policy implications. In section 5, I discuss some possible future research on this topic.

2.2 A Model with a Continuum of Middlemen

To directly compare the results to Rust and Hall (2003), I first use this continuous model similar to theirs. Consider an intermediary market of homogeneous product. There are a continuum of heterogeneous buyers and sellers. A seller of type v can provide at most one unit of the good at a cost of v. A buyer of type v can buy at most one unit of the good and is willing to pay at most v to consume it. At the beginning of each period, a new generation of buyers and sellers with mass 1 and valuation v randomly drawn from the uniform distribution on interval [0, 1] enter the market. The unitary supply-demand assumption implies that a buyer or a seller exits the market once she makes a transaction.

Assume that buyers and sellers can not trade directly with each other. They have to go through intermediaries. There are originally a continuum of heterogeneous intermediaries of mass M. Their marginal costs of executing each trade between a buyer and a seller are distributed uniformly over the interval $[\underline{K}, 1]$. This cost distribution is common knowledge. Intermediaries are infinitely lived and each of them sets a pair of stationary bid/ask prices [a(K), b(K)] to maximize her expected discounted profit. Both the intermediaries and the individual sellers and buyers have the same discount factor $\rho \in (0, 1)$. Assume that they are all risk neutral.

Originally, all the intermediaries do not post their prices. Buyers and sellers know the distribution of prices. But they do not know which middleman sets which bid/ask prices. In each period, a seller or a buyer can only randomly get price quote from one middleman. Then, she can choose to make a transaction immediately or to keep searching. When she gets worse prices in the future, she can always trade at an earlier quoted price without extra cost.[2] Search cost here is in terms of loss from delay of transaction.

As is well shown in the search literature, the best strategy for a seller or a buyer is to choose a reservation price according to her value. When a seller/buyer has a reservation price higher/lower than the best possible bid/ask price in the market, she will stay outside the market. If a seller or a buyer decides to search, whenever she gets a quote better than her reservation price, she should trade at this quote

[2]When buyers are risk neutral, recall option does not make a difference in the equilibrium.

immediately. Intuitively, the reservation price of a seller or a buyer increases in her value of the good. So, we expect the higher value buyers and lower value sellers to trade earlier, and those low value buyers and high value sellers decide not to search or trade.

But with the new technology, all the intermediaries will have one more choice – to post their prices, or, in another word, to become market makers. Buyers and sellers know the prices set by market makers when they enter the market. Thus, if both market maker(s) and middlemen exist, buyers and sellers will also have one more choice – to trade with a market maker immediately instead of searching in the all-middlemen market. If all the intermediaries post their prices, buyers and sellers will simply trade with the market maker who provides the best price. Then it becomes a posted price competition, or, a simple Bertrand competition. Assume the entry cost of becoming a market maker is positive but very small, and an intermediary can adjust its price immediately in react to other firms' moves.

My model is different from Rust and Hall's (2003) in the following ways:

1. All the intermediaries can choose whether or not to post prices.

2. I assume that the total number of intermediaries is M instead of 1.[3] I add this assumption to appropriately compare the profits being a middleman and being a market maker. With the total number of intermediaries normalized to one, as in

[3]M should be a big number so that I can use continuous unit costs of intermediaries as a proxy of discrete unit costs in reality. Here, I assume that $M > \frac{(4-3\rho)}{(1-\rho)(1-\underline{K})}$. This makes the number of profitable middlmen coexisting with the most efficient intermediary when it is a market maker at least two.

Rust and Hall (2003), when a portion of them operate, the volume and profit of one middleman can be bigger than the aggregate amounts of all middlemen. This is obviously not reasonable and the more severe consequence is that the amplified profit of a middleman can easily exceed that of a market maker.

This assumption does not change the equilibrium prices. I only have to divide the trade volume and profit of each middleman by M.

3. In Rust and Hall (2003), middlemen can make transactions at the beginning of the game in a dealer market, but they have to wait for a period when there is a market maker. This makes profits in the two markets incomparable. I assume that it takes customers at least one period to trade with middlemen with or without a market maker.

Again, this technical change will not affect the market equilibrium, except that we need to discount volume and profit in the all-middlemen market in Rust and Hall by ρ.

4. Instead of having a proportion of buyers and sellers randomly exiting the market and replaced by some new buyers and sellers, I assume that a new generation of buyers and sellers of the same mass enter the market in each period. This makes it possible to have stationary pricing in an equilibrium. It is true that within each generation, the higher value buyers and lower value sellers will trade earlier, and thus become inactive earlier. But if we have this game infinitely repeated, given stationary prices, in each period we will always have active sellers and buyers from earlier generations and a whole new generation. So, if only the total number of active sellers and buyers in each period is finite, stationary bid/ask prices results in

stationary distributions of values of active sellers and buyers in each period. And this, on the other hand, gives intermediaries no incentive to change their bid/ask prices, given that those prices are already profit-maximizing. In the analysis I will show that the total number of active sellers and buyers in each period is indeed finite. There may exist an equilibrium with nonstationary pricing, but things can get very complicated and it will be hard to compute the equilibrium. If bid-ask spreads decreases over time, patient traders may wait for better prices in the future and this can hurt intermediaries and lower market efficiency. Increasing bid-ask spreads over time yields lower profits, too. In this paper, I only look for an equilibrium with stationary pricing, just like in Rust and Hall.

Like assumption 2 and 3, this change on Rust and Hall's model does not affect the structure of the equilibrium in their paper. We only need to take the exit rate λ in Rust and Hall as zero and inflate volume and profit in Rust and Hall's results by $1/(1-\rho)$.

The first best is to have the most efficient intermediary set a bid-ask spread equal to its unit cost and intermediate all the profitable transactions immediately. This most efficient intermediary makes zero profit. The highest possible welfare of this market is equal to the total discounted consumer surplus

$$W^{1st} = \frac{(1-\underline{K})^2}{4(1-\rho)}. \tag{2.1}$$

2.2.1 Market Equilibrium With Only Middlemen

Like Rust and Hall (2003), I start with an all-middlemen market where all the intermediaries do not post their prices. The following is the market equilibrium with only middlemen as shown in Spulber's (1996) and Rust and Hall (2003), modified with the above changes. Interested readers can refer to their papers for details.

Without any market maker, the marginal middleman in the market, who makes zero profit, has unit cost

$$\overline{K}_d^d = \frac{4\delta + \underline{K}}{1 + 4\delta} = \frac{4 - 4\rho + \underline{K}}{4 - 3\rho}, \tag{2.2}$$

where

$$\delta \equiv \frac{1}{\rho} - 1. \tag{2.3}$$

A middleman with unit cost K sets bid-ask prices

$$a_d^d(K) = \frac{1}{4}[\frac{2 + 12\delta + \underline{K}}{1 + 4\delta} + K], \tag{2.4}$$

$$b_d^d(K) = \frac{1}{4}[\frac{2 + 4\delta - \underline{K}}{1 + 4\delta} - K], \tag{2.5}$$

trades a volume of

$$Q_d^d(K) = \frac{(1 + 4\delta)(\overline{K}_d^d - K)}{16M\delta^2(1 - \rho)(1 - \underline{K})}, \tag{2.6}$$

and earns a total discounted profit of

$$\pi_d^d(K) = \frac{1 + 4\delta}{32M\delta^2(1 - \rho)(1 - \underline{K})}(\overline{K}_d^d - k)^2. \tag{2.7}$$

So, all the operating middlemen's ask prices are uniformly distributed on interval

$$[\frac{1 + 6\delta + \underline{K}(1 + 2\delta)}{2 + 8\delta}, \frac{1 + 8\delta + \underline{K}}{2 + 8\delta}], \tag{2.8}$$

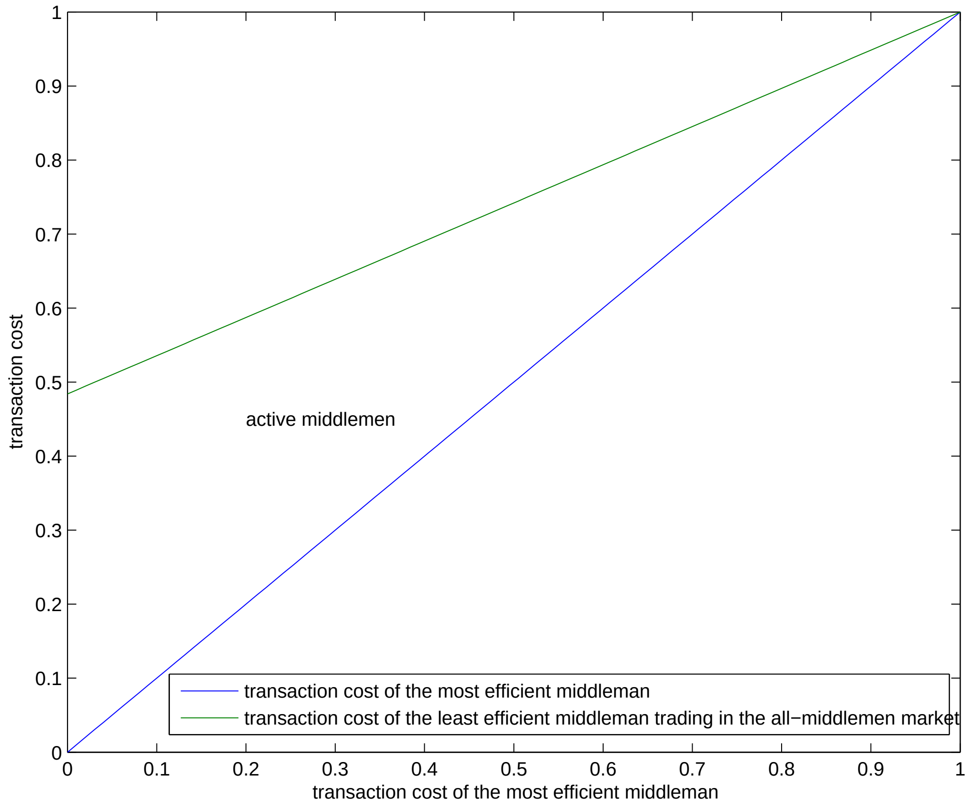

Figure 2.1: Equilibrium Unit Costs in The Middlemen Market (ρ=5/6)

and their bid prices are uniformly distributed on

$$[\frac{1-\underline{K}}{2+8\delta}, \frac{(1-\underline{K})(1+2\delta)}{2+8\delta}]. \tag{2.9}$$

Their aggregate total discounted profit is

$$\pi^d = M\int_{\underline{K}}^{\overline{K}_d^d} \pi_d^d(K)dK = \frac{2(1-\underline{K})^2}{3\rho(1+4\delta)^2}. \tag{2.10}$$

Figure 2.1 shows the range of unit costs of active intermediaries in an all-middlemen market. Figure 2.2 and Figure 2.3 show the equilibrium bid/ask prices and profits of middlemen. In the all-middlemen market, because of the search costs,

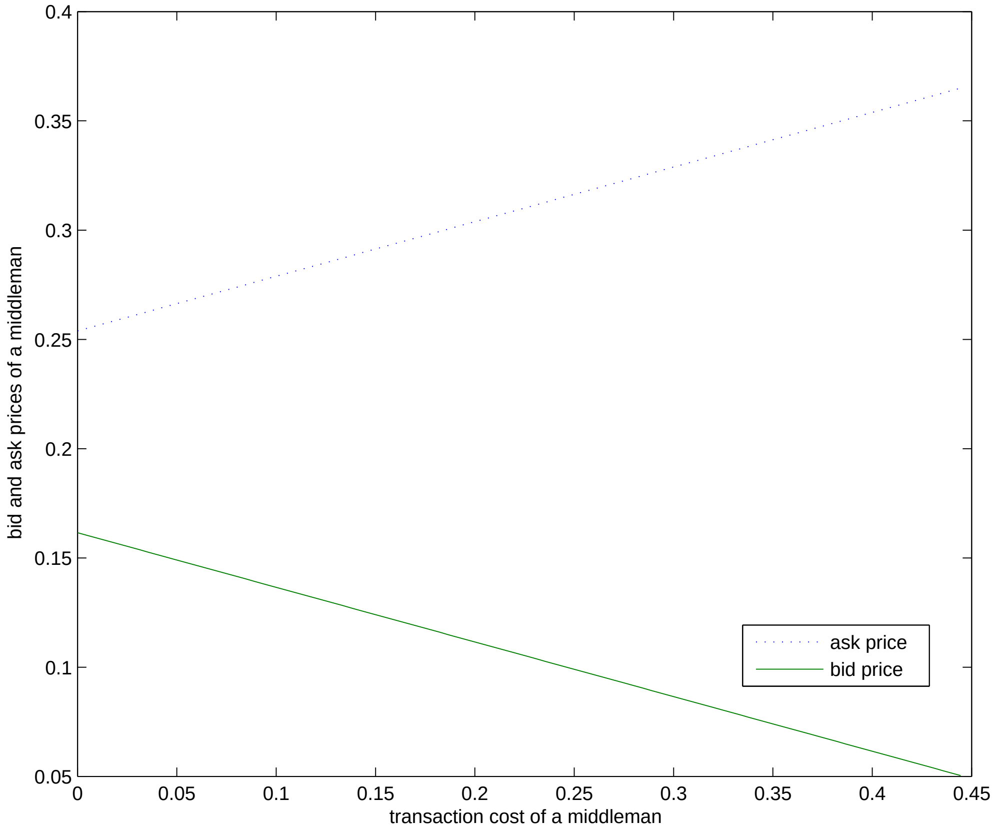

Figure 2.2: Bid And Ask Prices in The Middlemen Market (ρ=5/6,$\underline{K}$=0)

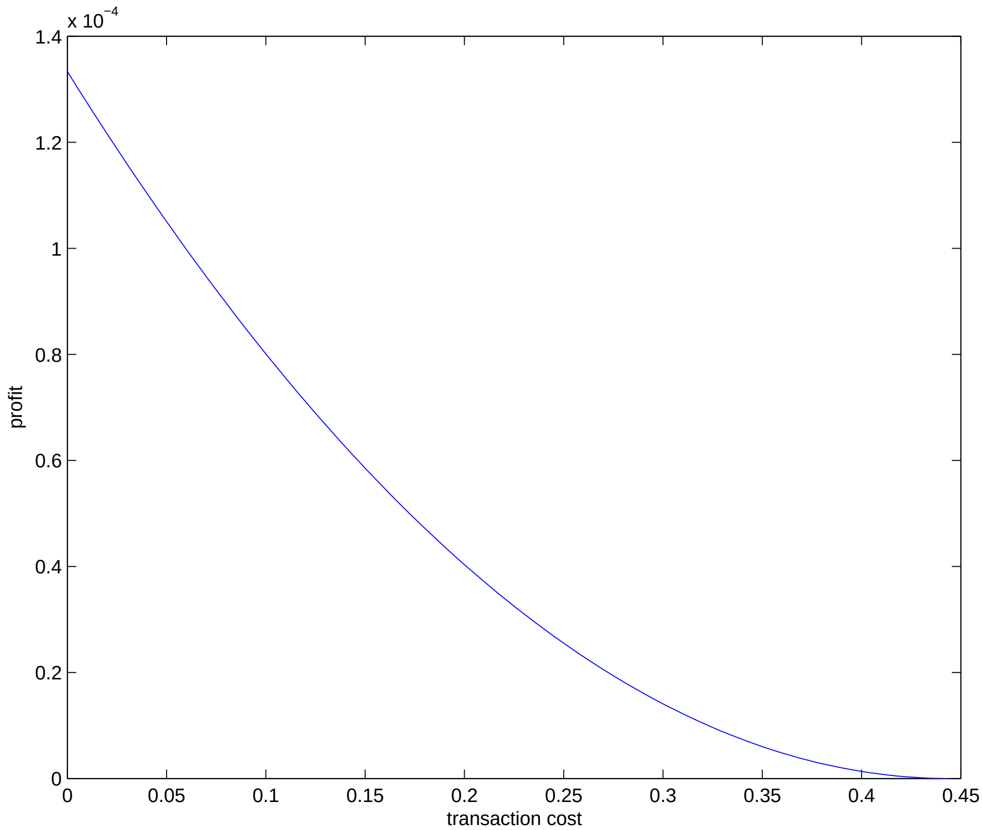

Figure 2.3: Profits in The Middlemen Market (ρ=5/6,$\underline{K}$=0,M=20)

middlemen do not compete against each other directly. So, some efficient middlemen are able to set bid-ask spreads higher than their unit costs and make positive profits. Deadweight loss is generated by both the high spreads and the search process, which results in both search costs for individual traders and delay and loss of transactions for the middlemen.

The consumer surplus of buyers and sellers is

$$S_c^d = S_p^d = \frac{\rho}{(1-\rho)^2}\int_{-v_c}^{1}[v - r_c^d(v)]dv = \frac{2(1-\underline{K})^2}{(1+4\delta)^2}[\frac{1}{6} + \frac{(1-\underline{K})}{8(1+4\delta)}]. \quad (2.11)$$

The total welfare of this all-middlemen market is

$$W^d = \pi^d + S_c^d + S_p^d \quad (2.12)$$

$$= \frac{(1-\underline{K})^2}{(1+4\delta)^2}[\frac{2+\rho}{3\rho} + \frac{(1-\underline{K})}{4(1+4\delta)}] \quad (2.13)$$

$$= \frac{\rho^2(1-\underline{K})^2}{(4-3\rho)^2}[\frac{2+\rho}{3\rho} + \frac{\rho(1-\underline{K})}{4(4-3\rho)}] \quad (2.14)$$

$$= \frac{4\rho^2(1-\rho)}{(4-3\rho)^2}[\frac{2+\rho}{3\rho} + \frac{\rho(1-\underline{K})}{4(4-3\rho)}]W^{1st}. \quad (2.15)$$

When $\rho = \frac{5}{6}$ (or $\delta = 0.2$) and $\underline{K} = 0$, this is only 24% of the full efficiency. The higher $\underline{K}$ (the unit cost of the most efficient middleman) is, the lower the efficiency of an all-middlemen market will be compared to the first best.

2.2.2 Market Equilibria with the Option of Price Posting

In this section, I show the possible market equilibria if each intermediary can endogenously choose whether or not to post its bid/ask prices. I first review the equilibrium with one market maker found in Rust and Hall 2003. Then, I compare an intermediary's profit being a market maker and being a middleman to see whether it is more profitable to post prices, assuming that the other intermediaries use their optimal strategies. The effect of entry cost and the speed of price adjustment will be discussed.

2.2.2.1 Rust and Hall's (2003) Market Equilibria with One Entrant Posting Price

The following is the analysis with one potential market maker as is in Rust and Hall (2003). I will again skip the detailed calculations since they are very similar to Rust and Hall's. The only difference is that in Rust and Hall, the trade volume for the market maker is only for the first period. But when new buyers and sellers come in the market, the low value sellers and high value buyers will trade with the market maker immediately, too. So, the market maker's profit should be inflated by $\frac{1}{1-\rho}$.

Consider a market maker with unit cost K_m trying to enter the market. Assume that at the beginning of the game, all the buyers and sellers know this market maker's quote. Now a buyer or a seller has one more choice: to trade with the market maker immediately without any search cost. As I have mentioned earlier, the high value buyers and low value sellers will trade with the market maker immediately; the low value buyers and high value sellers will not search or trade, and the middle value buyers and sellers with search for a better deal from the middlemen with reservation value strategy. Figure 2.4 shows the decision rules of buyers and sellers when $\rho = 5/6$.

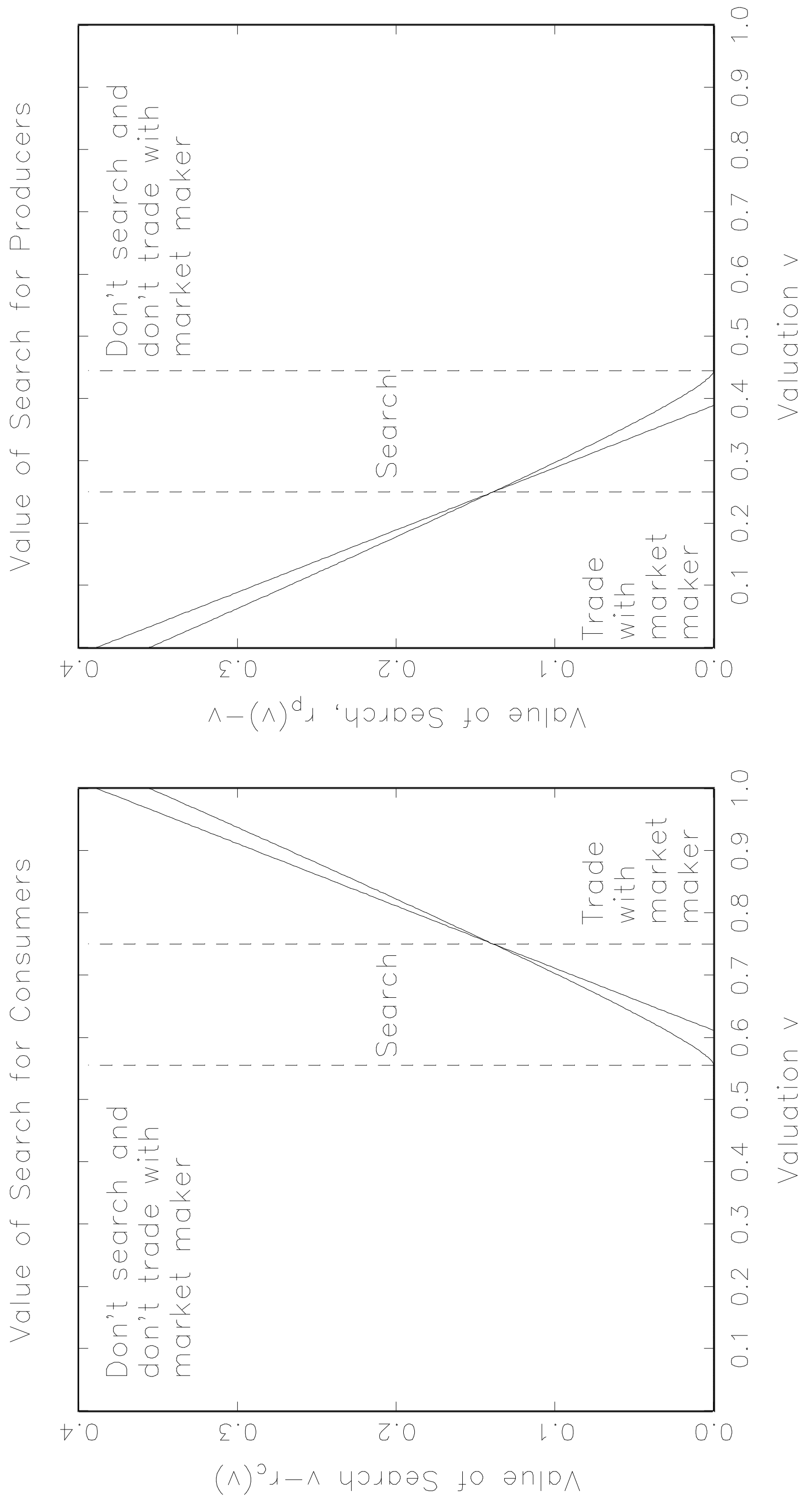

Figure 2.4: Search Strategies of Buyers And Sellers with A Market Maker Coexisting with Middlemen ($\rho = 5/6$)

After solving the equilibrium of a dynamic search model with both a continuum of middlemen and one market maker, Rust and Hall find that only a market maker with unit cost

$$K_m < \overline{K}_m = \frac{4\delta + \underline{K}}{4\delta + 1} \tag{2.16}$$

can enter the market profitably. Notice that this threshold is equal to $\overline{K}_d^d$, the transaction cost of the marginal firm in the all-middlemen market. This means any intermediary who can profitably operate in the all-middlemen market can make profit as a monopoly market maker.

After this entrance, there are three types of equilibria, depending upon K_m relative to $\underline{K}$, the lowest unit cost of middlemen. Some middlemen can coexist with the market maker if they are efficient enough. The inefficient middlemen exit the market. Even when all the middlemen are not efficient enough to stay, they may still limit the prices set by the monopoly market maker. But when they are very inefficient, the market maker will simply set its unconstrained monopoly prices.

To show these results formally, define

$$\underline{K}_l(K_m) = \frac{(1 + K_m)(4\delta + 1) - 1}{8\delta + 1} \tag{2.17}$$

and

$$\underline{K}_u(K_m) \;\; = \frac{1 + K_m}{2}. \tag{2.18}$$

When $\underline{K} \in [0, \underline{K}_l(K_m))$, the market maker coexists with the most efficient middlemen, who have unit costs lower than

$$\overline{K}_d^m(K_m) = \frac{1 + K_m}{2} + \frac{\underline{K} - 1}{8\delta + 2}. \tag{2.19}$$

The market maker's prices are given by

$$b_m(K_m, \underline{K}) = 1 - a_m(K_m, \underline{K}) = \frac{1 - K_m}{4} + \frac{1 - \underline{K}}{16\delta + 4}. \tag{2.20}$$

His trade volume is given by

$$Q_m(K_m) = \frac{4\delta + 1}{16\delta(1 - \rho)}(\frac{4\delta + \underline{K}}{4\delta + 1} - K_m). \tag{2.21}$$

His profit is given by

$$\pi_m(K_m) = \frac{4\delta + 1}{32\delta(1 - \rho)}(\frac{4\delta + \underline{K}}{4\delta + 1} - K_m)^2 \tag{2.22}$$

Middlemen's ask prices are uniformly distributed on

$$[\frac{3 + K_m}{8} + \frac{(8\delta + 1) + \underline{K}(8\delta + 3)}{32\delta + 8}, \frac{3 + K_m}{4} + \frac{\underline{K} - 1}{16\delta + 4}], \tag{2.23}$$

and their bid prices are uniformly distributed on

$$[\frac{1 - K_m}{4} + \frac{1 - \underline{K}}{16\delta + 4}, \frac{5 - K_m}{8} - \frac{(8\delta + 1) + \underline{K}(8\delta + 3)}{32\delta + 8}]. \tag{2.24}$$

Sellers who value the good less than $(1 - \rho)Q_m$ and buyers who value the good more than $1 - (1 - \rho)Q_m$ trade with the market maker directly. Sellers with high value and buyers with low value do not search or trade. The remaining sellers and buyers search in the all-middlemen market until they find a price better than their reservation prices or exit the market before they trade.

When $\underline{K} \in [\underline{K}_l(K_m)\, , \underline{K}_u(K_m))$, the market maker's entry drives all middlemen out of business, and the market makers sets "limit prices" to deter the most efficient middleman from entering, which is given by

$$b_m = 1 - a_m = \frac{1 - \underline{K}}{2}. \tag{2.25}$$

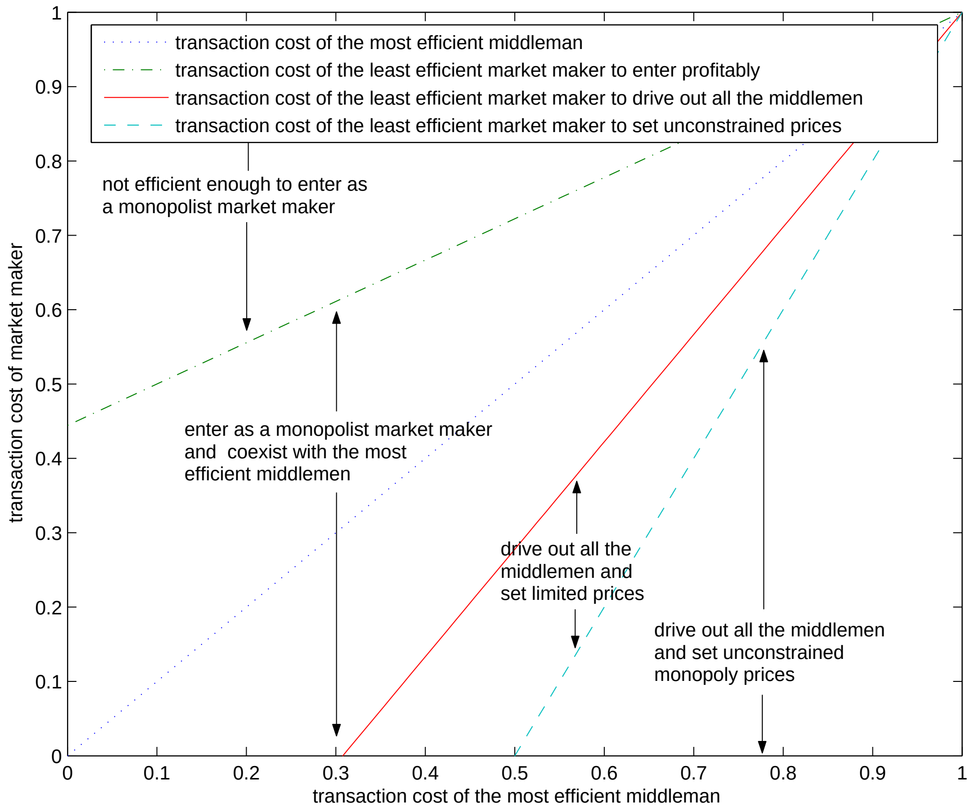

Figure 2.5: Entry Rules of Market Maker in Rust&Hall, (ρ=5/6)

If $\underline{K} \in [\underline{K}_u(K_m), 1]$, the market maker sets unconstrained monopoly bid/ask prices

$$b_m = 1 - a_m = \frac{1 - K_m}{4}.$$

Figure 2.5 shows these entry rules of market maker in Rust and Hall (2003).

Any profitable entry of market maker improves social welfare and yields more transactions in the equilibrium. Entry of a market maker with unit cost lower than

$$\underline{K}_m = \frac{36\delta^2 + 16\underline{K}\delta^2 + 29\underline{K}\delta + 4\underline{K}}{52\delta^2 + 29\delta + 4} \tag{2.26}$$

increases total discounted profit of all intermediaries.

2.2.2.2 Market Equilibria with the Original Intermediaries choosing whether to post prices

Given the results of the above model, we may ask: "Why wouldn't middlemen compete with this market maker by becoming market makers, too?" If middlemen can transform themselves into market makers instead of only adjust their prices, the equilibrium in Rust and Hall (2003) may not be a long run equilibrium.

To make it simple, first I assume intermediaries already existing in the market bear little cost transforming from middlemen to market makers or from market makers to middlemen. This would be reasonable when costs of posting prices is negligible compared to other costs, especially non-price-informing advertising cost. However, I assume that it takes no time for a market maker to change its prices. Therefore, a price war won't be costly for the winner. This makes it possible for a market maker to set a higher bid-ask spread than some middlemen's unit costs. These assumptions will be relaxed later in this paper.

Now, let us look at the market equilibrium in this market when intermediaries can freely choose between being market makers and being middlemen.

Theorem 2.1 *Without multiple firms agreeing on posting the same price, there can only be at most one market maker.*

(See appendix for proof.)

This theorem holds in general since I did not use any particular assumption in my model. Nevertheless, I am going to show that in my model, any monopoly market maker emerging from the original population of intermediaries has to coexist with middlemen. This may not be true if we have different distribution of intermediaries' unit costs.

Corollary 2.1 *Any intermediary with unit cost* $K \in [\underline{K}, \overline{K}]$ *has to coexist with some middlemen if she ever becomes a monopoly market maker.*

(See appendix for proof.)

Corollary 2.1 tells us that if all the existing intermediaries are originally middlemen, no one among them is able to drive away all the other middlemen when she becomes a market maker.

Now, let's look at the condition under which a middleman wants to become a monopoly market maker.

Corollary 2.2 *The least efficient intermediary is always indifferent between being a monopoly market maker and being a middleman in the all-middlemen market. Any other intermediary prefers being a monopoly market maker than being a middleman in the all-middlemen market if and only if* $M(\frac{1}{\rho} - 1)(1 - \underline{K}) > 1$. *This condition is always satisfied under the assumption* $M > \frac{(4-3\rho)}{(1-\rho)(1-\underline{K})}$.

(See appendix for proof.)

Here, we know that when it is more profitable for one intermediary to be a monopoly market maker than to be a middleman, it must be more profitable for any other intermediary to be a monopoly market maker, too.

An interesting fact here is that an intermediary always sets the same prices being a monopoly market maker as she does in a dealer market. The only reason that she can get a higher profit from price posting is the higher trade volume she gets once the search costs on her prices are eliminated.

Quite intuitively, theorem 2 shows that when there are more middlemen in the market, when people are less patient, and when the unit cost is smaller, an intermediary prefers being a monopoly market maker more.

When there are many middlemen competing with each other, customers randomly meet them and the trade volume of each middleman is small. Thus, becoming a market maker can increase trade volume by a bigger amount and is more profitable. Also, to make market making more profitable, customers' search costs should be high enough. Here, the search costs are in terms of delay of transaction. So, the discount factor is a key component of search costs. If customers are extremely patient, they will keep searching until they find a very good deal. Then few people will trade with the market maker.

Under our assumption about the number of intermediaries, all the operating middlemen have incentive to become a monopoly market maker. However, it is not possible for anyone other than the most efficient intermediary to be a monopoly market maker. This is because if a less efficient intermediary becomes a monopoly market maker, a more efficient intermediary will have incentive to compete as a market maker, too.

Corollary 2.3 *If intermediaries simultaneously decide whether or not to post their* *prices, the most efficient intermediary has to be a market maker if there is any market maker.*

(See appendix for proof.)

So, no one other than the most efficient intermediary is possible to be a monopoly market maker. Now, we have two possibilities left: either the most efficient intermediary becomes a monopoly market maker, or some intermediaries coexist as market makers. We know that only the former is possible without multiple firms agreeing on posting the same price.

The market equilibrium with the most efficient intermediary being a monopoly market maker is shown in the following theorem:

Theorem 2.2 *The most efficient middleman, who has unit cost $\underline{K}$, can benefit from becoming a monopoly market maker if $M(\frac{1}{\rho}-1)(1-\underline{K}) > 1$. This is satisfied under the assumption $M > \frac{(4-3\rho)}{(1-\rho)(1-\underline{K})}$.*

After this transformation, middlemen with unit costs smaller than

$$\overline{K}_d^m(\underline{K}) = \frac{1+\underline{K}}{2} + \frac{\underline{K}-1}{8\delta+2} \tag{2.27}$$

can survive and coexist as middlemen. The market maker sets the same bid/ask prices as she used to set as a middleman:

$$b_m = 1 - a_m = \frac{(1-\underline{K})(1+2\delta)}{2+8\delta}. \tag{2.28}$$

Its profit as a monopoly market maker is

$$\pi_m(\underline{K}) = \frac{\delta(1-\underline{K})^2}{2(1-\rho)(4\delta+1)}. \tag{2.29}$$

Middlemen's ask prices are uniformly distributed on

$$(\frac{(5\delta+1)+\underline{K}(3\delta+1)}{8\delta+2}, \frac{(6\delta+1)+\underline{K}(2\delta+1)}{8\delta+2}], \tag{2.30}$$

and their bid prices are uniformly distributed on

$$\frac{(1-\underline{K})(2\delta+1)}{8\delta+2}, \frac{(1-\underline{K})(3\delta+1)}{8\delta+2}). \tag{2.31}$$

(See appendix for proof.)

Figure 2.6 shows the unit cost of active intermediaries when the most efficient intermediary becomes a market maker and sets the bid/ask prices given in theorem 2.2.

Notice that this equilibrium is very interesting: The most efficient intermediary sets the highest spread. The less efficient ones undercut this spread but since they hide themselves with higher search costs, they do not compete with the most efficient one directly and get to survive.

The total number of middlemen in this market is

$$(\frac{1+\underline{K}}{2} + \frac{\underline{K}-1}{8\delta+2} - \underline{K})M = \frac{2\delta(1-\underline{K})}{4\delta+1}M. \tag{2.32}$$

To make this number at least two, we need

$$M > \frac{4\delta+1}{\delta(1-\underline{K})} = \frac{(4-3\rho)}{(1-\rho)(1-\underline{K})}. \tag{2.33}$$

This is where the assumption about M comes from.

Recall that the aggregate profit in the all-middlemen market is

$$\pi^d = \frac{2\rho\delta^2(1-\underline{K})^2}{3(1-\rho)^2(1+4\delta)^2}. \tag{2.34}$$

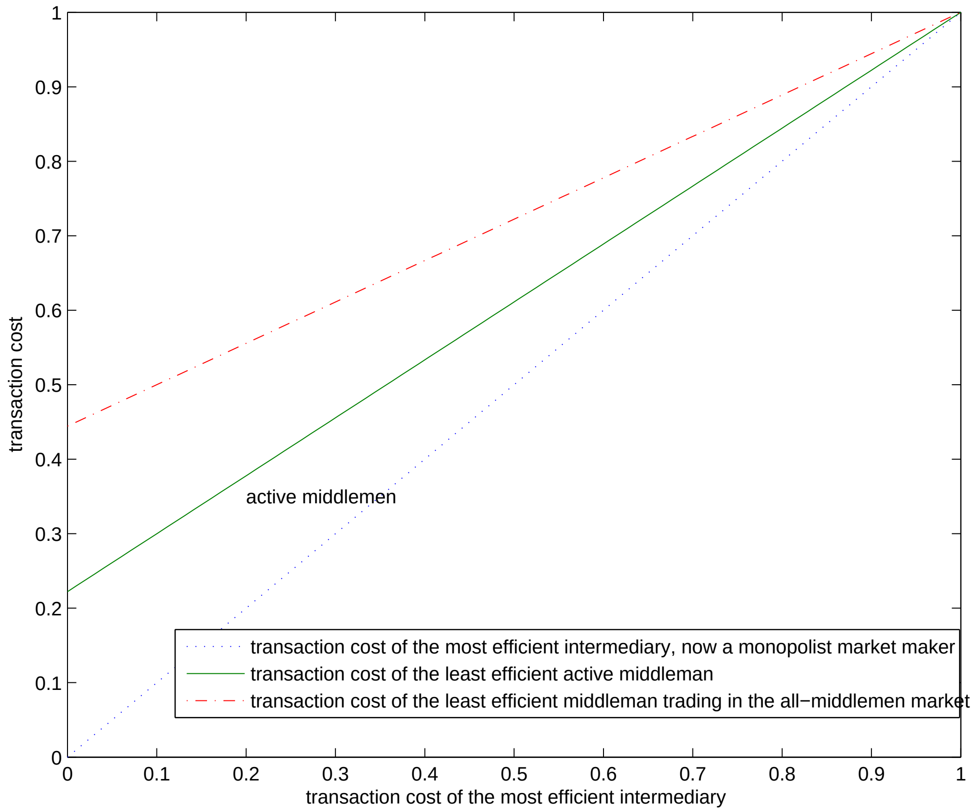

Figure 2.6: Equilibrium in Which The Most Efficient Intermediary Becomes A Monopolist Market Maker (ρ=5/6)

The ratio of market maker's profit and middlemen's aggregate profit is

$$\frac{\pi_m(\underline{K})}{\pi^d} = \frac{3(1+4\delta)}{4\rho\delta} = 3(\frac{1}{\rho} - \frac{3}{4}) \geq 1. \tag{2.35}$$

Market making even yields a higher profit than the aggregate profit in the all-middlemen market for this most efficient intermediary. This means middlemen themselves can not prevent the evolution of market structure from happening by bribing the most efficient intermediary. Also, since the equilibrium prices with the market maker are lower than those in an all-middlemen market, consumer surplus is higher, too. So, the market with a market maker is more efficient.

Also, we can show that the ratio of market maker's trade volume and total trade volume in an all-middlemen market is

$$\frac{Q_m(\underline{K})}{Q^d(\underline{K})} = \frac{(1+4\delta)}{4\delta\rho} = \frac{4-3\rho}{4\rho} = \frac{1}{\rho} - \frac{3}{4} > 1. \tag{2.36}$$

The aggregate demand for the all-middlemen market is smaller than the demand for this most efficient intermediary as a market maker, too.

In this market, a middleman with unit cost K sets bid/ask prices

$$1 - a_d^m(K) = b_d^m(K) = \frac{1}{4}[\frac{2+6\delta-(2\delta+1)\underline{K}}{1+4\delta} - K], \tag{2.37}$$

and trades a volume of

$$D_d^m(K) = \frac{1+4\delta}{8M\delta^2(1-\underline{K})}[\frac{2\delta+(2\delta+1)\underline{K}}{1+4\delta} - K]. \tag{2.38}$$

Its profit is

$$\pi_d^m(K) = (a_d^m(K) - b_d^m(K) - K)D_d^m(K) \tag{2.39}$$

$$= \frac{1+4\delta}{16M\delta^2(1-\underline{K})}[\frac{2\delta+(2\delta+1)\underline{K}}{1+4\delta} - K]^2 \tag{2.40}$$

$$= \frac{1+4\delta}{16M\delta^2(1-\underline{K})}[\overline{K}_d^m - K]^2. \tag{2.41}$$

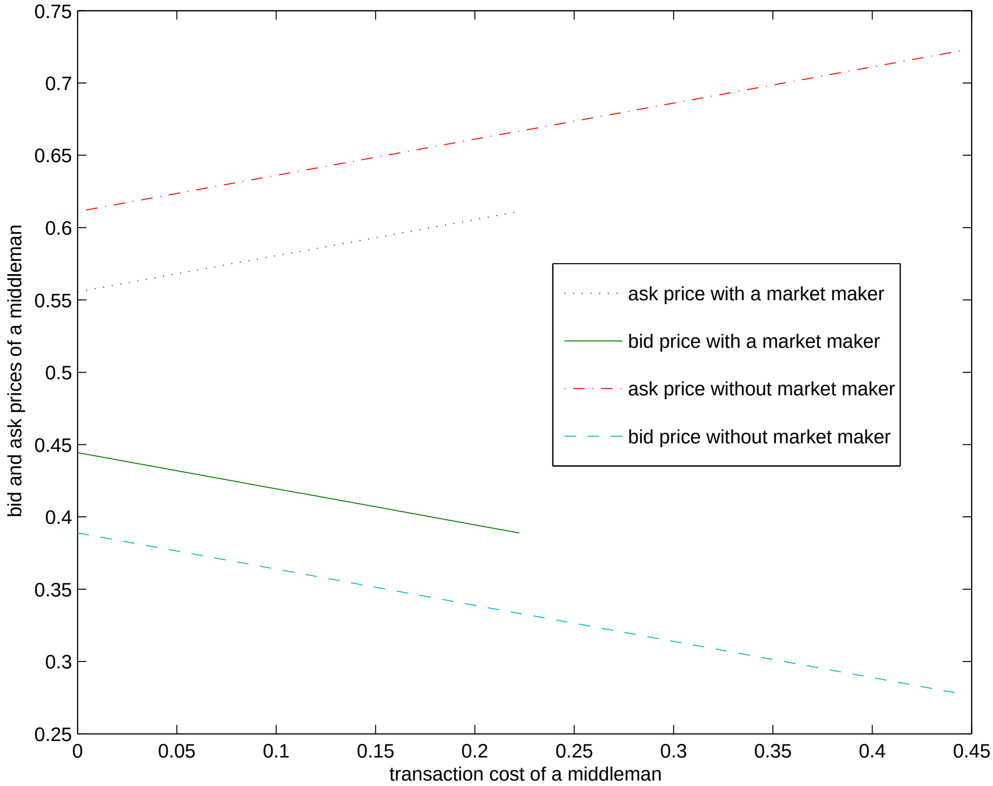

Figure 2.7: Bid And Ask Prices With And without Market Maker (ρ=5/6,Kl=0)

The aggregate profit of middlemen in this market is

$$\pi_d^m = \int_{\underline{K}}^{\overline{K}_d^m} \pi_d^m(K)dK \tag{2.42}$$

$$= \frac{(1-\underline{K})^2}{6\rho(1+4\delta)^2}. \tag{2.43}$$

2.2.2.3 The Entry of A New Intermediary

Over time, technology may improve and there might be new entrants who are more efficient. A new entrant can also choose to either become a market maker or

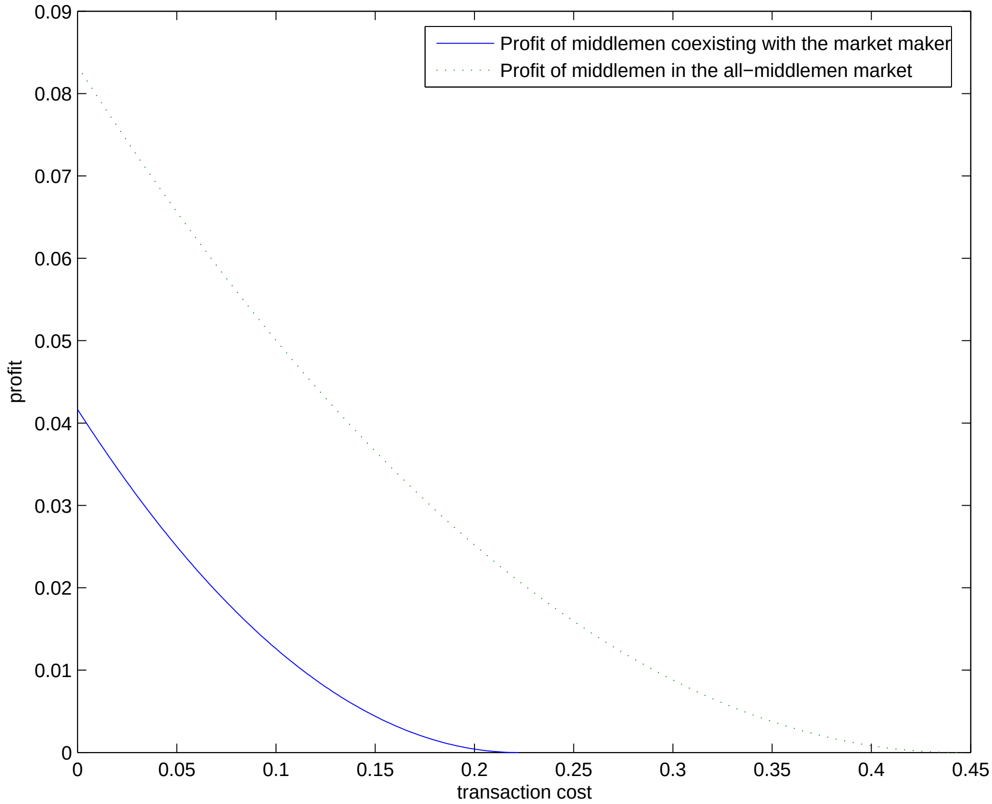

Figure 2.8: Profits of middlemen with and without market maker (ρ,Kl=0,M=20)

a middleman. I am going to show their decision rules and the changes in market equilibrium in the following theorem.

First, let us define

$$\underline{K}_l^e = \frac{(8\delta+1)\underline{K} - 4\delta}{4\delta+1} \tag{2.44}$$

and

$$\underline{K}_u^e = 2\underline{K} - 1. \tag{2.45}$$

Also, recall that in theorem 2.2, when the most efficient intermediary with unit cost $\underline{K}$ is a monopoly market maker, the least efficient middleman trading in the market has unit cost given by

$$\overline{K}_d^m(\underline{K}) = \frac{1+\underline{K}}{2} + \frac{\underline{K}-1}{8\delta+2}. \tag{2.46}$$

Theorem 2.3 *Assume now the most efficient intermediary with unit cost* $\underline{K}$ *is a monopoly market maker, coexisting with middlemen with unit costs uniformly distributed on* $(\underline{K}, \overline{K}_d^m(\underline{K})]$*. Consider a new entrant with unit cost unit cost* K^e*. If* $\underline{K} \leq K^e < \overline{K}_d^m(\underline{K})$*, the new entrant will become a middleman. If* $\underline{K}_l^e < K^e < \underline{K}$*, the new entrant can replace the old market maker and the old market maker will transform herself into a middleman. The new market maker's prices are given by*

$$b_m = 1 - a_m = \frac{1-K^e}{4} + \frac{1-\underline{K}}{16\delta+4}. \tag{2.47}$$

And middlemen with unit costs higher than the following exit the market:

$$\overline{K}_d^m(K^e) = \frac{1+K^e}{2} + \frac{\underline{K}-1}{8\delta+2}. \tag{2.48}$$

If $\underline{K}_u^e < K^e < \underline{K}_l^e$*, the new entrant can become a market maker and drive away all the other market maker and middlemen. The new monopoly market maker is going* *to set limited prices*

$$b_m = 1 - a_m = \frac{1 - \underline{K}}{2}. \tag{2.49}$$

If $K^e \leq \underline{K}^e_u$, the new entrant can not only become a market maker and drive away all the other market maker and middlemen. but also set unconstrained monopoly bid/ask prices

$$b_m = 1 - a_m = \frac{1 - K^e}{4}. \tag{2.50}$$

(See appendix for proof.)

Figure 2.9 shows these entry rules of a new entrant when the search cost is endogenous and the most efficient incumbent is a market maker. We can compare it to Figure 5 and see the difference between my results and Rust and Hall's.

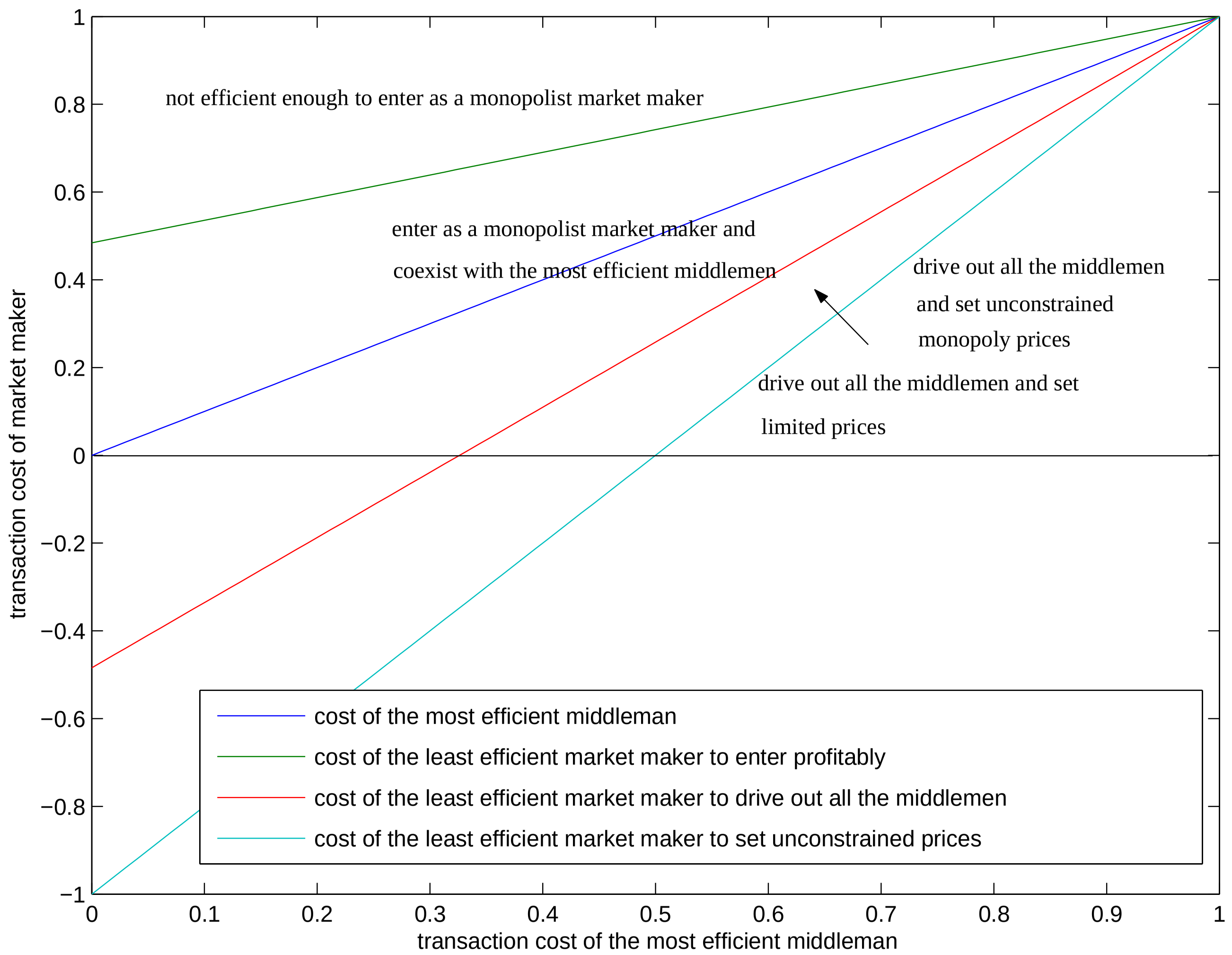

Figure 2.9: Entry Rules When The Most Efficient Incumbent Is A Monopolist Market Maker

Theorem 2.3 shows us that under some circumstances, a market maker can benefit from transforming into a middleman, or say, raise the search cost on its own prices. It is quite intuitive to think that raising the search cost on prices offered by all firms can increase their profits. But it is surprising to see that unilaterally raising search cost on one's own prices sometimes can be beneficial, too. It is easier to understand it when we keep in mind that a monopoly market maker can charge a bid-ask spread higher than its unit cost. A middleman can undercut that spread without facing a direct Bertrand competition. So a slightly less efficient intermediary can make a positive profit by setting a bid-ask spread somehow lower than the market maker's but higher than its own unit cost.

This theorem explains why some firms try to raise the search costs on their prices. Although it brings inconvenience to their costumers, they may benefit from avoiding direct price competition with other firms. It is interesting that these firms are indeed offering better prices but they may not be the most efficient firm.

2.2.2.4 Entry Cost and the Speed of Price Adjustment

In the above analysis, I assume that the entry cost of becoming a market maker is positive but negligible. If the entry cost is big, there may be multiple equilibria and more importantly, there may be some equilibria where the most efficient intermediary is not a market maker but someone else is. The equilibria will depend on how much the entry cost is. When the entry cost is too big, no firm will find price posting profitable.

We need this entry cost to be positive, though. When it is zero, no one will become a market maker. Traditional theories tell us that entry cost lowers the level of competition and efficiency. It is counterintuitive that a positive entry cost sometimes helps the market to find its first market maker and improves efficiency. In the above model, without multiple firms agreeing on posting the same price we will see no market maker if entry cost is zero. This is because if the most efficient intermediary posts any bid-ask spread higher than its transaction cost, the second most efficient intermediary, who has a unit cost infinitely close to the lowest unit cost, can post a slightly lower bid-ask spread and take over the market before the incumbent fights back. Hence, market making leads to Bertrand competition and the most efficient intermediary has to set a bid-ask spread equal to its cost and will make zero profit. But, when there is a small but positive entry cost, if only the most efficient intermediary can react to a price-undercut fast enough, it can post a bid-ask spread higher than its cost. Because now if other intermediaries undercut the market maker's bid-ask spread, they will be defeated immediately and lose money. In this specific model, the most efficient intermediary is able to post its all-middlemen market bid-ask spread and also enjoy a much bigger demand for reducing the search costs. As a result, market making will be more profitable for it. However, once there is a market maker, this entry cost disencourages other intermediaries (including some new entrants who may be more efficient than the incumbent market maker) from posting prices. So, entry cost has a mixed effect here. This is analogical to giving patent to an inventor, which encourages invention but lowers efficiency ex-post.

Also, I assumed that intermediaries can adjust their prices in no time. Thus, the price war can end immediately and is costless for the winner. For this reason, when the most efficient intermediary becomes a market maker, it can charge a bid-ask spread higher than the second most efficient intermediary's unit cost, which is virtually the same as its own cost. If any other firm tries to compete with the most efficient intermediary as a market maker, the most efficient intermediary can win the price war costlessly and the competitor will exit the market. This gives room for the market maker to make positive profit. If this game is reduced to a pure Bertrand competition, where the market maker has to set spread equal to the most efficient middleman's unit cost, then in this continuous model, even the most efficient intermediary can not make positive profit being a market maker and thus no intermediary has incentive to become one. All the intermediaries will stay as middlemen even if the technology allows them to post their prices. When the unit cost is discrete, the most efficient firm can only benefit from becoming a market maker if it is sufficiently more efficient than all the other firms.

In the following chapter, I discuss these issues in more detail using a discrete model.

Chapter 3

A Model with Discrete Firms

3.0.3 The Model

In the above analysis, we have to assume that the number of firms in the market is big enough so that we can use continuous model to approximate a discrete market in reality. This causes a problem, though, since we know that when there are many firms competing against each other, the gain from market making is big. So, it might overstate the profitability of posting prices. To relax this assumption and make market maker and middleman more comparable, I build the following discrete model with three firms. It can be easily generalized into an N firm model, and the qualitative results should remain the same. This discrete model also allows more flexibility in the distribution of firms' unit costs. The results are consistent with the continuous model but much richer.

To make it simple, this is no longer an intermediary market. Firms are producers and sellers, and individual consumers are buyers. Firms decide their prices and price posting strategies, while buyers behave just like those buyers in the above continuous model.

Assume that there are three firms producing homogeneous products in one market and they can stay in the market for as many periods as they want to. They have constant unit costs K_1, K_2, K_3, respectively. Assume $K_1 \leq K_2 \leq K_3$.There is no fixed cost to stay in the market and produce the goods. The cost of posting a price is F. Costs are common knowledge among firms. There is no capacity constraint. There is no inventory problem, either. Firms only pay production costs for the units they sell. The common discount factor of firms is $\rho \in (0, 1)$.

In each period, a new generation of consumers with valuation v˜U[0,1] and unit demand enter the market. Each generation has the same population and it is normalized to 1.

Assume that all parties in this market are risk neutral.

At the beginning of each period, firms choose whether or not they post their prices and what the prices are. Every time a firm chooses to post a new price, it pays F immediately.

A consumer knows all the market makers' prices immediately after entering the market. A consumer also knows the prices charged by middlemen, but she does not know who is charging which prices. It takes a consumer with valuation v one period and a search cost $s \times v$ to get price information from a random middleman. Here, s is a constant number between 0 and 1. In each period, a consumer can choose either to exit the market, or trade at the lowest known price, or keep searching. Once she has discovered a firm's price, she will not go to the same firm in her next random search. She can always go back to an early offer without cost.[1]

Originally, no firm posts its price since the posting cost F is extremely high. When the new information technology becomes available to every firm, posting cost

[1]Again, when buyers are risk neutral and search optimally, recall option does not make a difference in the equilibrium.

is lower and firms begin to choose both their prices and whether or not to post their prices.

Assume firms and consumers can not foresee any future change in unit cost, posting cost, or new entries. I am more interested in a long run equilibrium where prices are stationary. This should be reasonable when a search period is very short compared to the time length between cost changes or new entries. Since a consumer can be active for at most 4 periods, most of the time there will be no cost change or new entry in the market. Therefore, consumers do not expect prices to change and firms have no incentive to change their prices without any cost change or new entry, if these prices are already equilibrium prices. When cost changes or new entries happen, firms can face some residual demand from previous periods which makes the distribution of consumer valuation changing slightly over time. But the valuation changes should have little effects if only the discount factor ρ is big enough. Prices and posting status should go to the new long run equilibrium levels quickly, if not immediately.

A stationary price equilibrium can be described with a 1×6 vector, $(I_1, I_2, I_3, P_1, P_2, P_3)$. I_i is 1 if firm i posts its price and is 0 otherwise. P_i is the price of firm i.

3.0.4 Solving The Equilibrium

In this discrete model, the sequential search problem faced by consumers gets more complicated. In the continuous model, a consumer draws from the same price distribution in each period. But in a discrete model, the sequential search becomes a drawing without replacement and the price distribution of unvisited middlemen depends on which middlemen a consumer has already visited. The optimal search strategy is no longer choosing a simple reservation value. Instead, a consumer needs to compare the expected gain from searching, from trading immediately and from exiting the market, given the distribution of middlemen's prices and the already discovered prices. Since the number of firms is finite, the search process is finite for a consumer. Thus, we can use backward induction to find the optimal strategy for a consumer.

3.0.4.1 when no firm posts price

Before the modern information technology became available, the cost to post prices publicly was too high. Therefore, no firm considers posting price. Later, I will discuss under what post costs this will be true. When no firm posts price, the equilibrium looks like $(0, 0, 0, P_1, P_2, P_3)$. We only need to figure out the equilibrium prices.

Using backward induction, we start with consumer behavior, given firms' prices. Figure 3.1 shows the decision tree of a consumer with valuation v in a market where no seller posts price. Periods in this graph are specific to the consumer of concern. For this consumer, whichever period she enters the market is called period 1. P_1, P_2 and P_3 are the prices set by firm 1, 2 and 3, respectively, and $P_1 < P_2 < P_3$. The value under each final node is this consumer's payoff when that decision is made. The inequalities following "if" are conditions for a consumer to make the corresponding decisions, given that this consumer has reached these decision nodes. V_e is the valuation of the marginal consumer who is indifferent between exiting the market and searching. V_{it} is the valuation of the marginal consumer who is indifferent between trading immediately and searching some more when P_i is the lowest price she has discovered in her period t.

Before we list all the possible nodes and actions, we can eliminate some of them because we assume consumers search optimally. Once a consumer decides to search in period 1, she should not exit the market later because she could have done better by exiting at the beginning. Since P_1 is the lowest price, we know that if a consumer decides to search, once she discovers P_1, she should trade immediately. We also know that if a consumer decides to forgo P_2, she should not trade at P_3, a higher price, in the future.

The marginal values are easy to calculate. Using backward induction, we start from the last period. In period 4, an active consumer will only see P_1 because it is the last period and if she sees any other price in this period, she must have seen P_1 earlier. Then, she would have traded and exited the market in an earlier period. In period 4, she should trade at P_1 if only $(1-3s)v - P_1 \geq 0$. This has to be true if this consumer decides to search in period 1. So, the expected surplus of facing P_1 in period 4 is

$$S_{14}(v) = (1-3s)v - P_1. \tag{3.1}$$

Now we look back. Similarly, the expected surplus of facing P_1 in period 3 is

$$S_{13}(v) = (1-2s)v - P_1. \tag{3.2}$$

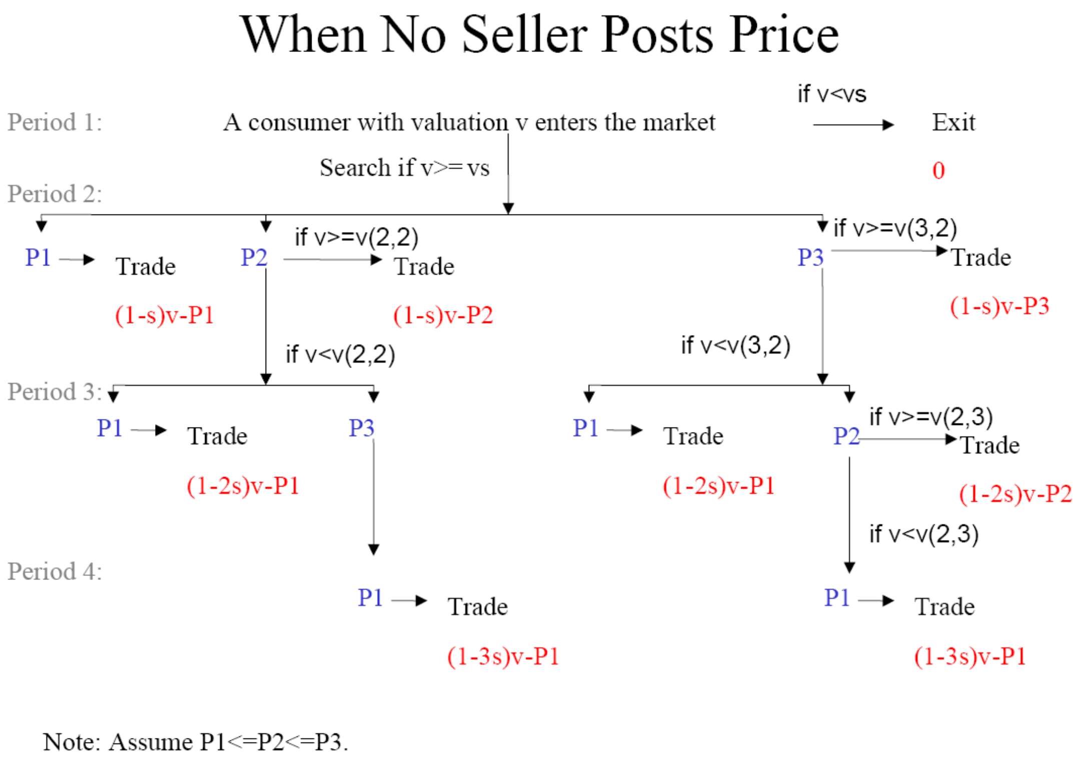

Figure 3.1: A Market where No Seller Post Price

If a consumer finds P_2 in period 3, she should compare the surplus from trading at P_2 immediately and the surplus from searching one more period. A marginal consumer should have valuation V_{23}, which satisfies

$$(1-2s)*V_{23}-P_2=S_{14}(V_{23})=(1-3s)*V_{23}-P_1. \tag{3.3}$$

So,

$$V_{23}=(P_2-P_1)/s. \tag{3.4}$$

The expected surplus of facing P_2 in period 3 is

$$S_{23}(v) = \max\{(1-2s)*v-P_2, S_{14}(v)\} \tag{3.5}$$

$$= \max\{(1-2s)*v-P_2, (1-3s)v-P_1\}. \tag{3.6}$$

Back to period 2, when a consumer discovers P_3, she should compare the surplus from trading at P_3 immediately and the surplus from searching one more period. In case of search, with equal probability she will find P_1 and P_2. A marginal consumer should have valuation V_{32}, which satisfies

$$(1-s)*V_{32}-P_3 = [S_{13}(V_{32})+S_{23}(V_{32})]/2 \tag{3.7}$$

$$= [(1-2s)V_{32}-P_1+\max\{(1-2s)*V_{32}-P_2, (1-3s)V_{32}-P_1\}]/2 \tag{3.8}$$

So,

$$V_{32}=max(2(P_3-P_1)/3s, (2P_3-P_1-P_2)/2s). \tag{3.9}$$

Following this logic, we can calculate all the marginal values. Note that we want all the marginal values to be between 0 and 1, since that is the range of consumers' values. If a marginal value falls out of this interval, we will take 0 or 1 instead, whichever is closer to the marginal value.

Now, we can compute the demand for each firm. We use D_i to denote the total expected demand of firm i and D_{it} as the expected demand of firm i in period t from generation 1. For instance, the expected demand of firm 2 in period 2 from generation 1 is D_{22}. The demand is from customers who decide to search at the beginning ($v > V_e$) and then find it better not to search any more when they randomly visited firm 2 in period 2 with probability 1/3 ($v > V_{22}$). Thus,

$$D_{22} = (1 - max(V_e, V_{22}))/3. \tag{3.10}$$

Similarly,

$$D_{23} = (V_{32} - max(V_e, V_{23}))/6. \tag{3.11}$$

Since a new generation of consumers enter the market in each period, the total demand of firm 2 is

$$D_2 = [D_{22} + D_{23}]/(1 - \rho). \tag{3.12}$$

After we get a firm's expected demand, its expected profit is easy to calculate. In this example, since firm 2 is not posting its prices, its profit is simply

$$\pi_2 = (P_2 - K_2)D_2. \tag{3.13}$$

Knowing the profit functions, we can find the best response function for each firm and look for possible equilibrium. But as we can see in the above calculation, the profit functions can be quite complicated. They may not be differentiable everywhere and they may have multiple local maximums. (See Figure 3.2.) The shape of a profit function depends on other firms' prices and posting decisions. Therefore, it is very hard to get a closed-form solution analytically. However, I was able to solve the problem numerically.

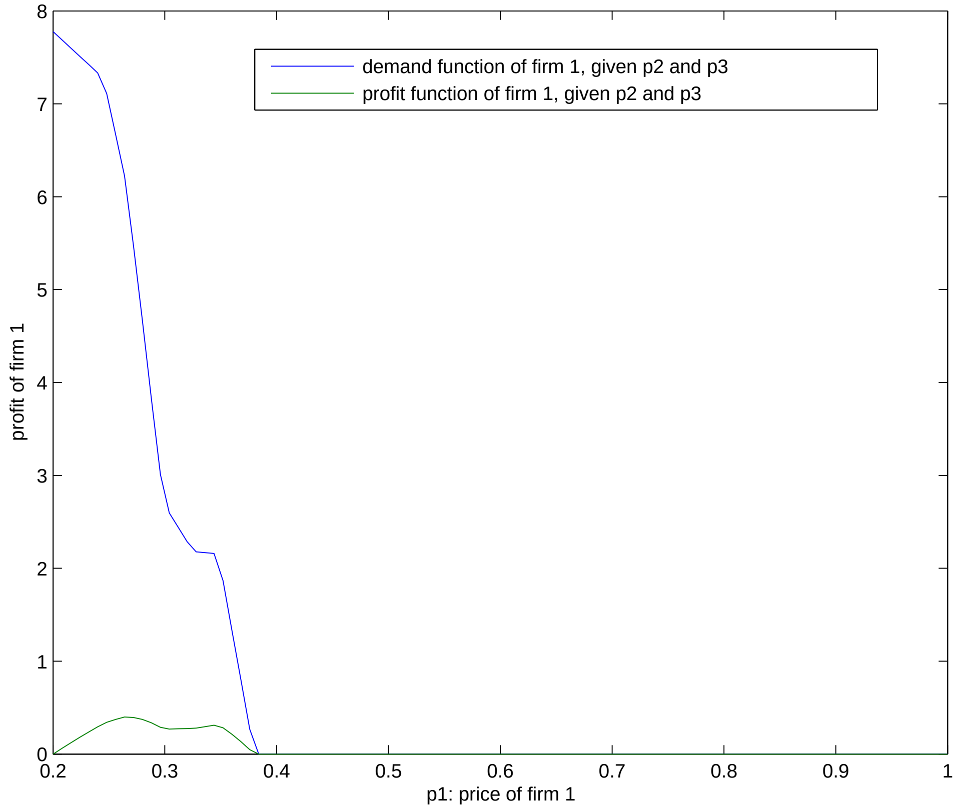

Figure 3.2: Demand and profit function of firm 1 (K=[0.2 0.22 0.24], p2=0.3, p3=0.34)

Starting with the case when post cost is extremely high and no one posts price. In Matlab, given costs and other firms' prices, I use a grid search to find a firm's best response price. Using costs as firms' starting prices, I let firms take turns to adjust their prices to their current best responses. This process goes on until the prices converge to the equilibrium. I find that the prices converge very fast when I use rough grids, and the starting prices do not matter.[2]

In Table 1 we show some examples of the equilibrium prices, demands, profits, consumer surplus and social welfare. Using row 1 as an example, when the unit costs of firm 1, 2 and 3 are 0.2, 0.21, and 0.22, respectively, if no firm posts price, the equilibrium prices are 0.27, 0.28, and 0.29, respectively. In this equilibrium, a firm with higher unit cost posts higher price.

3.0.4.2 When There Is At Least One Price Poster

When the information technology is improved and the price posting cost lowers, firms start to consider price posting. Taking other firms' strategies into consideration, a firm only wants to post its price if it expects higher profit from it. When a firm posts its price, it may attract more demand since price posting eliminates search costs for consumers. But at the same time, a firm may lose all the demand if another firm posts a slightly lower price. So, price posting can lead to more direct price competition and drive the prices down.

[2]When firms' units costs are very similar, if we use fine grids the prices go in cycles in a small domain. In that case, an exact equilibrium does not exist but a rough one does, if firms have big price increments.

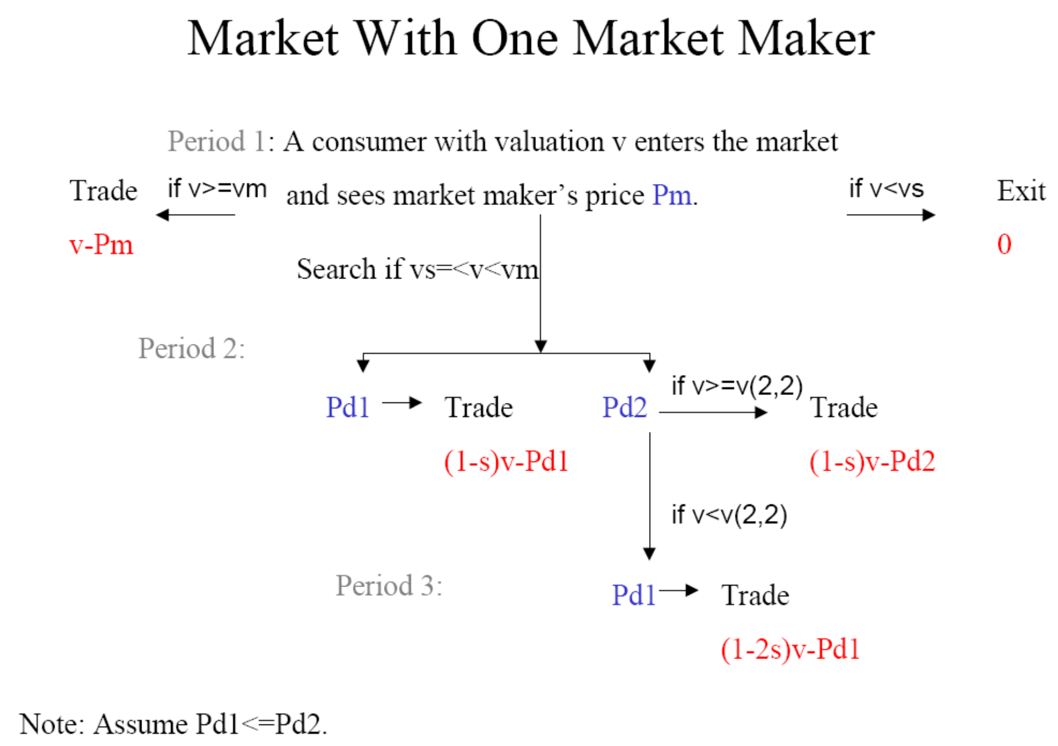

Figure 3.3: A Market where One Firms Posts Prices

Again, we start with consumer behavior. If one firm is posting its price, the search problem changes slightly. (See figure 3.3.) Assume the posted price is P_m and the hidden prices are P_{d1} and P_{d2}, with $P_{d1} < P_{d2}$. Then, a consumer with value v faces the following decision tree:

Now, in period 1, a consumer needs to compare her surplus from trading at the posted price P_m, her expected surplus from searching, and her surplus from exiting, which is zero. Following the above procedures, we can find the marginal values for each decision node. A consumer with valuation higher than V_m trades with the market maker immediately. A consumer with valuation lower than V_e exits the market in period 1. If a consumer has valuation between V_e and V_m, she should search for the hidden prices.

Again, we can calculate the demand and profit for each firm. The only difference is that the market maker needs to pay a cost F for posting price.

$$\pi_m = (P_m - K_m)D_m - F. \tag{3.14}$$

If there are multiple market makers, the search problem becomes simpler. (See figure 3.4 and figure 3.5.) A consumer will only consider the lowest posted price and the middleman's price, if there's any. Thus, a market maker posting a price higher than another posted price will get zero demand and negative profit. When multiple market makers post the same lowest price, they share their demand.

Now let us look at firm behavior. When price posting is optional to firms, we need to find out both the price posting decisions and the prices in an equilibrium. The triplet of 1 or 0 indicating three firms' price posting decision, (I_1, I_2, I_3), has eight possible combinations in total. (000)means no one posts price; (100) means only firm 1 posts price; ...; and (111) means all three firms post their prices. In a noncooperative game, we can show that most price posting combinations among these eight can not be in an equilibrium.

For each combination of unit costs $(K_1\ K_2\ K_3)$, fixing the price posting combination, we can find the restricted equilibrium prices using the successive iteration algorithm described before. This means, if no firm is going to change its price posting status, we find their best response price functions and the fixed point. We can then calculate the restricted equilibrium profit for each firm under each price post-

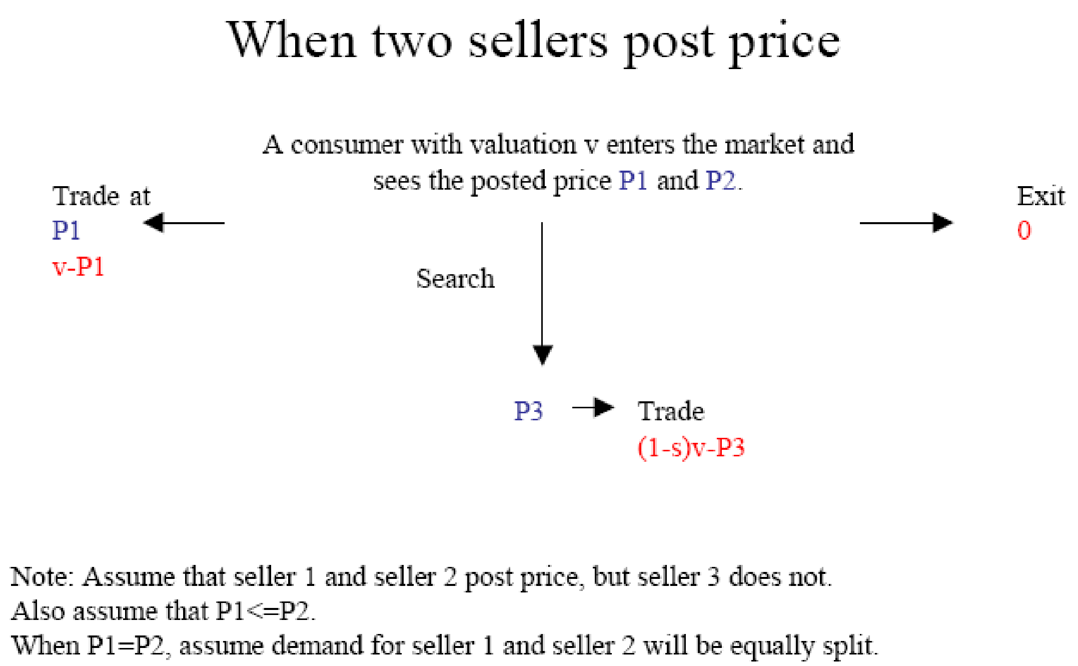

Figure 3.4: A Market where Two Firms Posts Prices

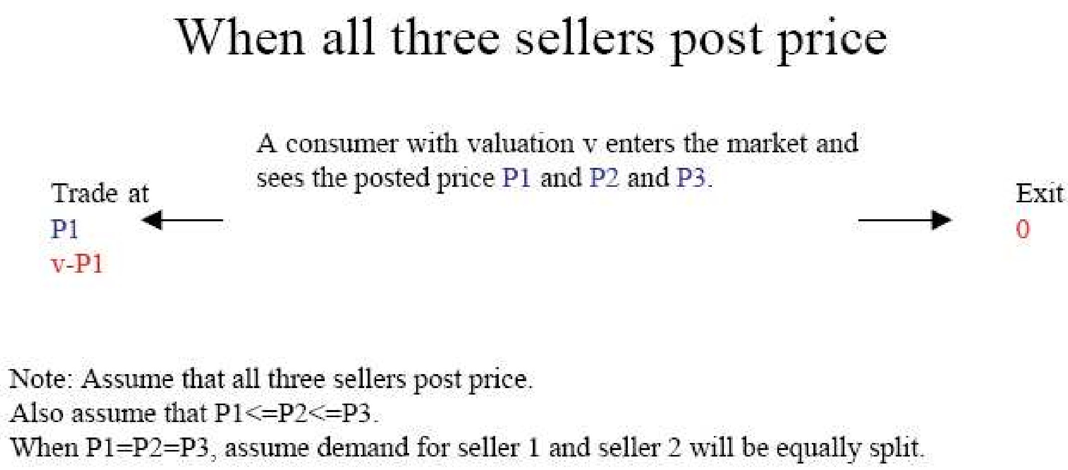

Figure 3.5: A Market where Three Firms Posts Prices

ing combination. We also need to make sure that undercutting the posted price for one period is not profitable for any firm that is not posting price. For example, for the case where firm 1 is the only price poster, we find P_1^u, firm 1's posted price in the fixed point, and a price P_1^l, so that firm 2's total discounted profit from posting a price slightly lower than P_1^l and going to a Bertrand competition against firm 1 afterwards is zero. Then we take the lower price between P_1^u and P_1^l as the restricted equilibrium price posted by firm 1, i.e., $P_1(100) = min(P_1^u, P_1^l)$. If P_1^u is smaller, the fixed point prices are the restricted equilibrium prices. If P_1^l is smaller, fix firm 1's price and find the fixed point of firm 2 and firm 3's best response functions. Price of firm i in the restricted equilibrium at the price posting combination (000) is denoted by $P_i(000)$ and the corresponding total discounted profit is denoted by $\Pi_i(000)$, and so on.

The two following matrices show the three firms' profits under each price posting combination.

When firm 3 hides its price:

firm 1(row),firm 2(column)	post price	hide price
post price	$\Pi_1(110), \Pi_2(110), \Pi_3(110)$	$\Pi_1(100), \Pi_2(100), \Pi_3(100)$
hide price	$\Pi_1(010), \Pi_2(010), \Pi_3(010)$	$\Pi_1(000), \Pi_2(000), \Pi_3(000)$

When firm 3 posts its price:

firm 1(row),firm 2(column)	post price	hide price
post price	$\Pi_1(111), \Pi_2(111), \Pi_3(111)$	$\Pi_1(101), \Pi_2(101), \Pi_3(101)$
hide price	$\Pi_1(011), \Pi_2(011), \Pi_3(011)$	$\Pi_1(001), \Pi_2(001), \Pi_3(001)$

First, just like in the continuous model, we should not see multiple market makers unless they can effectively cooperate on charging the same price and each earns more profit than it would otherwise get. This in because a noncooperative game, when multiple firms post their prices at the same time, they are in a Bertrand competition and only the most efficient firm can make a positive profit.[3] Those who earn zero profit in this Bertrand competition can be better off if they do not post their prices, since at least they do not have to pay the post cost, then. The following proposition is equivalent to Theorem 2.1. for the continuous model in section 2. The proof is exactly the same, too.

Theorem 3.1 *Without multiple firms agreeing on posting the same price, there can only be at most one market maker.*

(See appendix for proof.)

Now, any price posting combination with more than one price poster is eliminated. We only have $(000), (100), (010)$ and (001) left. Now, we show that the last two can not happen in an equilibrium when firm 1 has enough cost advantage.

Corollary 3.1 *When no firm is currently posting price, a more efficient firm can benefit more from being the only price poster.*

(See appendix for proof.)

Theorem 3.2 *If even the most efficient firm can not benefit from being the only price poster, there is a unique equilibrium where no one posts price. Firm i charges price $P_i(000)$, the restricted equilibrium price, given that no one posts price.*

[3]When multiple firms have the lowest unit cost, Bertrand Equilibrium predicts that they all earn zero profit.

(See appendix for proof.)

From calculation on the same grid search as in proof for Corollary 2.1, we also find the following features.

Corollary 3.2 *When the most efficient firm has a cost advantage of at least 0.04, whenever a less efficient firm gets more profit from being the only price poster than in the original market where no one posts price, the most efficient firm gets a higher profit in the Bertrand competition than hiding its price when the less efficient firm is posting price.*

This means that when the most efficient firm has enough cost advantage, it is the only firm which can post price in an equilibrium. If any other firm posts price, the most efficient firm can always benefit from posting a lower price.

Theorem 3.3 *When the most efficient firm has enough cost advantage, if it gets more profit from being the only price poster than in the market where no one posts price, the unique equilibrium is that only the most efficient firm posts its price. The equilibrium price posting statuses and prices are* $(100\ P_1(100)\ P_2(100)\ P_3(100))$*, where* $P_i(100)$ *are restricted equilibrium price of firm i as described before. If firm 2 or firm 3 deviates by posting a price lower than* $P_1(100)$*, firm 1 will post the Bertrand price, i.e.,* K_2 *or* K_3*, starting in the next period.*

This outcome is more efficient than any situation when a less efficient firm is the only price poster. First, a price poster gets a bigger market share. So, when the most efficient firm is the only price poster, most units sold the market are produced at a lower unit cost. Second, the prices are lower when the most efficient firm is the only price poster. This is shown in the following corollary.

Theorem 3.4 *A more efficient firm posts a lower price in the restricted equilibrium where it is the only price poster.*

When the most efficient firm does not have enough cost advantage and a less efficient firm can benefit from being the only price poster, there are multiple equilibria, as listed below:

1. Only firm 1 posts its price.

The equilibrium price posting statuses and prices are (100 $P_1(100)$ $P_2(100)$ $P_3(100)$), where $P_i(100)$ are restricted equilibrium price of firm i as described before. If firm 2 or firm 3 deviates by posting a price lower than $P_1(100)$, firm 1 will post the Bertrand price, i.e., K_2 or K_3, starting in the next period.

2. Only firm 2 posts its price.

The equilibrium price posting statuses and prices are (010 $P_1(010)$ $P_2(010)$ $P_3(010)$), where $P_i(010)$ are restricted equilibrium price of firm i as described before. If firm 1 or firm 3 deviates by posting a price lower than $P_1(100)$, the price posters have a Bertrand competition starting in the next period.

3. Only firm 3 posts its price (when K_3 is low enough) .

The equilibrium price posting statuses and prices are (001 $P_1(001)$ $P_2(001)$ $P_3(001)$), where $P_i(001)$ are restricted equilibrium price of firm i as described before. If firm 1 or firm 2 deviates by posting a price lower than $P_1(100)$, the price posters have a Bertrand competition starting in the next period.

The lower surfaces in Figure 3.6 and 3.7 show us the unit costs of firm 1 which makes firm 1 indifferent between being the only price poster and being in a market where no firm posts price, given the other two firms' unit costs. In both figures, $\rho = 0.99$ and $s = 0.05$. In Figure 3.6, posting cost is 1. In Figure 3.7, posting cost is 3. I call them "indifference surfaces". In Figure 3.6, given the other firms' unit costs, K_2 and K_3, if firm 1's unit cost is below the indifference surface, being the only price poster is more profitable for firm 1. Otherwise, firm 1 is better off by hiding price. This tells us that price posting is only profitable when firm 1 has enough cost advantage. In Figure 3.7, however, there are two indifference surfaces. Price posting is more profitable for firm 1 only when firm 1's unit cost is between the two indifference surfaces. This is because when firm 1 has too big a cost advantage, the other two firms are not really able to compete and price posting can not increase the demand enough to cover the big post cost. So, when the cost of posting price is big, posting price is more profitable than hiding price when a firm has enough cost advantage upon its competitors, but not too much.

The half transparent upper surfaces are the 45-degree surfaces which indicate the lower cost among K_2 and K_3. The fact that in each figure, the indifference surface is strictly below the 45-degree surface means that the less efficient firms can not benefit from being the only price poster.

So, assuming firm 1 has the lowest unit cost, from Proposition 2 we know that when $F = 1$, $\rho = 0.99$ and $s = 0.05$, if K_1 is above the indifference surface and below the 45-degree surface in Figure 3.6, no one in this market will post price. From Proposition 3 and Proposition 4 we know that if is above the indifference

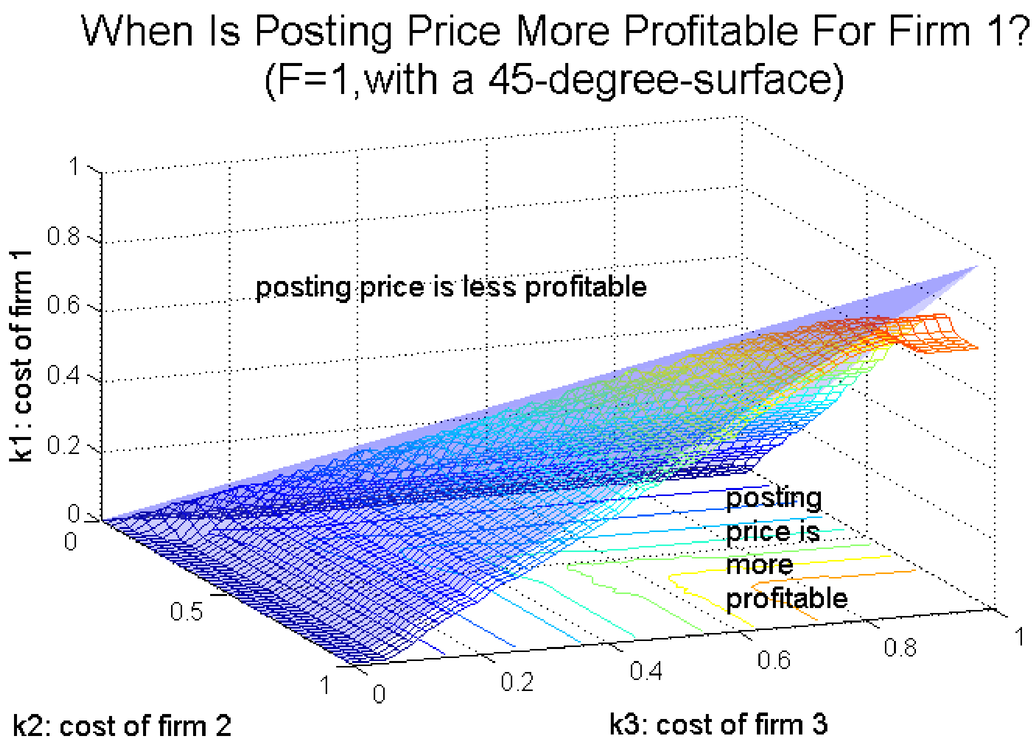

Figure 3.6:

surface, there will be one price poster and firm 1 being the only firm posting price is an equilibrium. If firm 2 and firm 3 are efficient enough, they can hide their prices, which are lower than firm 1's posted price, and survive. Otherwise they can not make any profit. When $F = 3$, $\rho = 0.99$ and $s = 0.05$, if K_1 is between the two indifference surfaces in Figure 3.7, there will be one price poster and firm 1 being the only price poster is an equilibrium. For any other unit cost combinations below the 45-degree surface, no one in this market will post price.

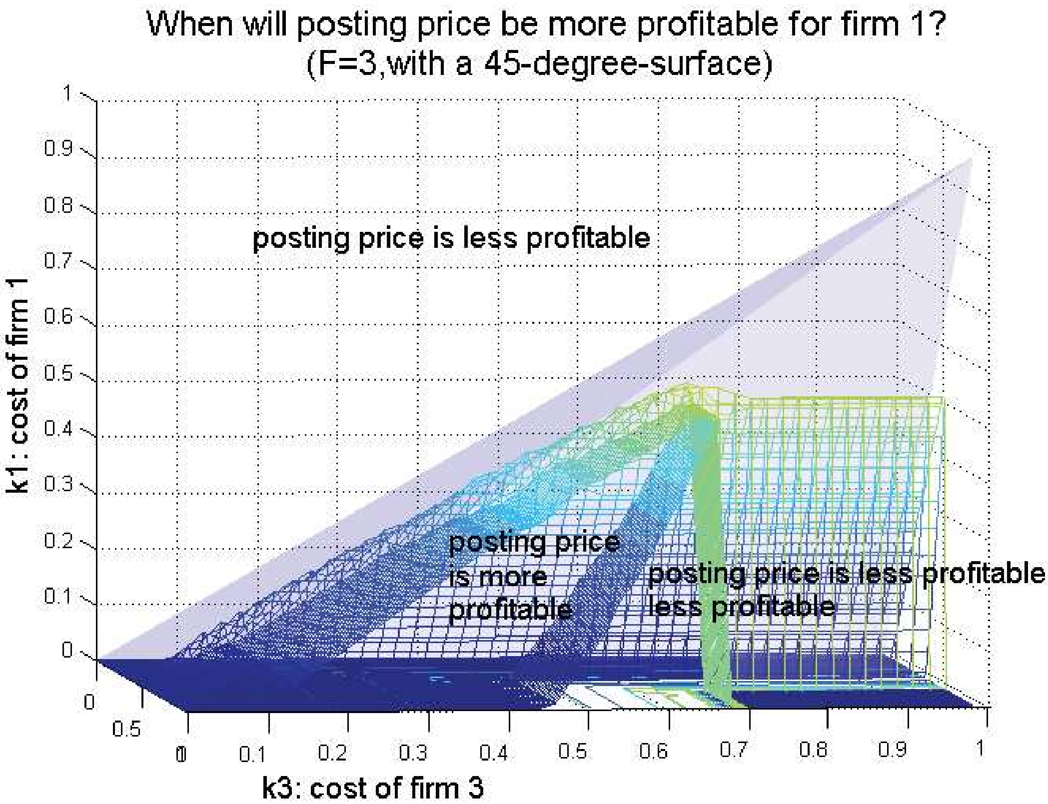
When will posting price be more profitable for firm 1?
(F=3,with a 45-degree-surface)
k1: cost of firm 1
k3: cost of firm 3
posting price is less profitable
posting price
is more
profitable
posting price is less profitable
less profitable
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Figure 3.7:

3.0.5 Examples

Some sample results are presented in the table below. The first column in the table is row number. The column titled "K" shows the unit costs of the three firms. F is the cost of posting price. M is the number of price poster. Here, when M=1, firm 1 is the only price poster. As in Corollary 2.2 and Proposition 3, we can show that under these parameters, firm 2 and firm 3 can not be the only price poster. The columns "Price" , "E(Demand)" and "E(Profit)" show the restricted equilibrium prices, expected demands, and expected profits of firm 1, 2 and 3, respectively. When M=1, the first number in the column "Price" is the posted price of firm 1. "*" in the column "Price" means the corresponding firm has exited the market. CS is total discounted consumer surplus. W is total discounted social welfare, which is equal to total profits plus consumer surplus.

3.0.5.1 Hiding Prices

Let K=[K_1, K_2, K_3]=[0.2, 0.21, 0.22]. $F = 1$, $s = 0.05$, $\rho = 0.99$.

As shown in the Table in Figure 3.8, row 1 and row 2, when all firms are middlemen, firm 1's profit is 2.102, but when firm 1 is a market maker and the other two firms are middlemen, firm 1's profit is only 1.513.

So, firm 1 will choose not to post prices, nor will the other two firms. We see an inefficient all-middlemen market. This is mostly because the three firms have similar costs. Although firm 1 is the most efficient, its price is limited by the other two firms when it posts price. In this special case, it is much lower than its original

K	F	M	Price	E(Demand)	E(Profit)	CS	W
0.20 0.21 0.22	*	0	0.27 0.29 0.29	30.99 23.07 16.57	**2.10** 1.74 1.10	23.28	28.53
	1	1	0.24 0.22 0.23	71.38 2.68 2.68	**1.51** 0.02 0.02	29.18	30.73
	0.1	1	0.24 0.22 0.23	71.38 2.68 2.68	**2.41** 0.02 0.02	29.18	31.63
	0	1	0.21 * *	79.00 0.00 0.00	**0.79** 0.00 0.00	31.21	32.00
	0.1	3	0.61 0.61 0.61	13.17 13.17 13.17	**5.23** 5.10 4.97	7.80	23.10
0.10 0.21 0.22	*	0	0.17 0.22 0.23	67.89 8.09 5.36	**4.62** 0.12 0.06	30.15	34.95
	1	1	0.23 0.21 0.22	77.40 0.00 0.00	**8.75** 0.00 0.00	29.93	38.68
		1	0.22 0.21 *	77.94 0.00 0.00	**8.40** 0.00 0.00	30.37	39.77
		1	0.55 * *	45.00 0.00 0.00	**20.25** 0.00 0.00	10.13	30.38

Figure 3.8: Examples of Restricted-Equilibria

level in the all-middlemen market. Therefore, although firm 1 can get a much bigger market share by posting its price, the gain in sales is not enough to cover posting cost.

3.0.5.2 When Information Technology Improves

In the above example, if the cost of posting prices becomes lower, to be exact, if $0 < F \leq 0.411$, posting price will be more profitable for firm 1. (Table 1 row 3 shows us the equilibrium when $F = 0.4$.) We will see firm 1 become a market maker and in this special case, the other two firms make small positive profits. So, when the development of information technology lowers posting cost, it can encourage the most efficient firm to post its price and improve market efficiency when this price is not too high. The total welfare will rise from 28.525 to 31.327.

Notice that it is to firm 1's interest not to set its price so low that the other two firms make zero profit. Thus, we see a market structure resembling the current car retail market–one firm posts its prices, gets a major market share and a big profit, while some other firms hide their prices and get small profits from customers with low search costs seeking for better deals.

3.0.5.3 When A Firm Has A Big Cost Advantage

Now, let us look at another cost distribution. Assume firm 1 has a lower unit cost, 0.1, and the posting cost F is back to 1. As shown in Table 1 row 5 and row 6, when all firms are middlemen, firm 1's profit is 4.616, but when firm 1 is a market maker and the other two firms are middlemen, firm 1's profit is 8.752.

So, firm 1 will choose to post prices. The other two firms will not post prices. The market becomes more efficient. However, since here firm 1 has a much lower cost than the other two firms, it can set a higher price as a market maker. This lowers the total consumer surplus. When consumers with high values (those who originally would trade with firm 3) benefit from the transparent price of the market maker, those consumers with low values now lose the opportunity to find a good deal. We see something counterintuitive: lowering search costs is not always good for all the consumers.

If firm 3 exits the market, the equilibrium will be like in Table 1, row 7. Firm 1 now lowers its price and leave firm 2 no profit. If firm 2 exits as well and it is costly for it to come back, firm 1 can set an even higher price and make more profit. When the fixed cost for firm 2 to re-enter is very high, firm 1 can even set its unlimited monopoly price (see Table 1, row 8). Now the market is less efficient than the original all-middlemen market.

But, when the other two firms are too inefficient and the cost of posting price is fairly high, a very efficient firm will not post its price. Table 1, row 9 and row 10 show that when K=[0.2, 0.6, 0.8], $F = 3$, $s = 0.05$, $\rho = 0.99$, hiding price is more profitable for firm 1. Because firm 2 and firm 3 have costs so much higher than firm 1's, that they can not limit firm 1's price under either market structure, firm 1's gain from posting price can not cover the posting cost. Row 11 and row 12 show us that when firm 1's unit cost rise to 0.4, the other two firms do limit its price. So posting price helps firm 1 to earn more profit and we will see one market maker with no coexisting middlemen. Furthermore, we can compute that when $K_2 = 0.6, K_3 = 0.8$, firm 1 will only post price when its unit cost is between 0.33 and 0.48.

3.0.5.4 When a market maker encounters a new challenger

In the long run, new firms may enter the market, or, firms can reduce their unit costs so that the cost distribution changes. To stay with a three firm game, here I will only show examples with an originally less efficient firm lowering its cost. But the qualitative results hold for completely new entrants as well.

Following the example where K=[0.2, 0.21, 0.22], $F = 0.4$, $s = 0.05$, $\rho = 0.99$ (Table 1, row 3), let us assume that firm 3 improves its technology and cuts its unit cost to 0.191 (Table 1, row 13). Originally, firm 1 posts its price and the other two firms coexist as middlemen. Now, firm 3 is more efficient than firm 1 and will start posting price. Firm 1 will lose in a price war against firm 3 and should exit the market. But unlike in a simple Bertrand competition, firm 1 can switch back to be a middleman and survive. Then, firm 3 wants to be a middleman, too, since it is more profitable. Ironically, a cost reduction leads the market back to an inefficient all-middlemen market. Prices become higher and both consumer surplus and welfare drop.

However, if firm 3 reduces its unit cost more, it will want to stay as a market maker. Table 1 row 15 and row 16 shows that when $K_3 = 0.17$, posting price is much more profitable. The market will not degrade to an all-middlemen market and the efficiency will improve.

If firm 3's cost is so low that firm 1 can not survive as a middleman, both firm 1 and firm 2 will exit the market and firm 3 will become a monopoly market maker.

3.1 Conclusions

This paper uses a continuous model and a discrete model to show that in general, a firm does not have much incentive to post its price unless it has sufficiently low cost compared to its competitors. This makes a higher threshold than what is shown in Rust and Hall (2003). There will not be multiple price posters coexisting in a market, unless they can explicitly or implicitly collude to make market making more profitable. When the entry cost gets lower, we are more likely to see a price poster. When a more efficient entrant enters the market, the incumbent sometimes should hide its price to survive. Thus, when firms can choose to hide their prices, many of them will choose not to post prices. Most of the time, price posting improves market efficiency compared to the all-middlemen market. This is because price posting usually results in lower prices and lower search costs born by both firms and their customers. But when one firm has too much cost advantage, it will set a higher price as a monopoly price poster. So, price posting sometimes decreases consumer surplus and/or market efficiency .

These results can explain why some middlemen are not willing to post prices and some firms even try to raise search costs although it causes social waste. When hiding prices is not allowed, as in Nasdaq, market makers use preferencing as a method to bypass the rules compete indirectly to some extent.

In reality, we do see some competing firms posting prices at the same time. The reason may be that they have product differentiation, or they collude with each other. It is also possible that the situation is temporary. One firm will eventually win and the other firms either stop posting prices or exit the market completely, just like the case with Carmax and Autonation.

Although this paper shows that often firms do not want to post price and the market efficiency is low under many circumstances, the overall trend should still be that price transparency and market efficiency will improve over time. When information technology keeps improving, the cost of posting prices will keep dropping, too. This will encourage some efficient firms to post their prices and potential entrants will further limit the incumbents' prices. Also, when consumers get used to transparent pricing, they may not want to search for hidden prices any more. Firms will also suffer reputation loss if they hide their prices. When efficient entrants join the competition and existing firms lower their costs over time, one firm is less likely to have a cost advantage so huge that the market efficiency decreases with price posting.

The results also have some policy implications for market regulators. Lowering posting cost will help improving market efficiency. Price comparison services (such as BizRate.com and Shopping.com) help improving efficiency. A regulator can also force firms to post their prices. Nevertheless, if firms can effectively collude or use alternative methods to bypass direct price competition, encouraging or forcing them to post prices sometimes can help them achieve a higher collusive price. The practice of preferencing in Nasdaq is an example and needs more empirical study.

3.2 Future Research

3.2.1 Experiment

To test the theoretical predictions in this paper, I conduct a lab experiment. A controlled experiment has its unique advantages. First, in experiments we can easily satisfy some assumptions made in the theoretical models. We can directly compare outcomes across different treatments. Second, we can control sellers' transaction costs and traders' search costs, which are unobservable in real life. Third, we can control whether subjects can communicate with each other and observe their conversations. Finally, subjects in an experiment may not act optimally or risk neutrally, which may have insight we can not reach in theories.

The experiment I conduct is as following: I use human subjects to represent sellers in the discrete model. They are randomly matched into groups of three. At the beginning of each session, each subject is assigned a constant unit cost. Costs are common knowledge. There is no capacity constraint. Information about the demand side is revealed. A subject can choose whether or not to post her price and what the price is for each period. The posted prices will be known by all. Unpublished prices can be only found out after paying a search cost. After subjects choose their strategies, expected demand for each seller is calculated and shown by computer. Within one round, subjects can always change their actions.

A continuous inflow of profit is determined by the current chosen actions of all the three sellers in one market. The same group of subjects with given costs repeat interaction for a randomly determined number of rounds.

According to the theoretical predictions, important treatment factors include:

1. Distribution of sellers' cost
2. Entry cost
3. Possibility of communication

In the communication treatment, subjects can chat with each other using MSN messenger.

The experimental results support the comparison status in my theory. I find that sellers are more likely to post their prices when they have lower unit costs compared to their competitors. A lower cost of posting costs encourages sellers to post prices. Voluntary price posting usually lower prices and improve efficiency. But mandator price posting can facilitate collusion and lead to higher prices and lower efficiency. Overall, subjects post their prices more than theory predicts. But some of them learn to hide their prices over time.

3.2.2 Negotiation and Preferencing

In this paper, I focus on lower search costs as the result of price posting, although eliminating negotiation and price discrimination is certainly another possible consequence. I want to show the separate effect of search cost on market efficiency. At the same time, some firms indeed charge uniform prices while imposing the search costs on their prices. Negotiation and price discrimination will be a very interesting thing to look at in study of price posting behavior. I will explore the possible equilibria with this complication in my future research.

The practice of preferencing in Nasdaq is also a related topic to look at. People widely agree that market makers in Nasdaq frequently use preferencing (getting orders from brokers though networking, not quoting the best prices). Many researchers use it to explain the high prices in Nasdaq. But very few papers theoretically or empirically study it. Since Nasdaq itself is a very important market and this problem also have implications in other markets, preferencing deserves more attention. I plan to tackle this problem through different approaches in the near future.

Chapter 4

A Lab Experiment

4.1 Introduction

In the last two chapters, I try to answer these questions with theoretical models. I find that in a non-cooperative game, a firm wants to post prices only when it has certain cost advantage over its competitors. Without multiple sellers agreeing on posting the same price, no more than one firm will post its price. A price-posting firm will either coexist with some competitors who are efficient enough to survive, or drive all the competitors out. When they coexist, the posted price is higher than the unposted ones. Consumers with higher search costs trade at the posted price immediately and others search for a better deal. When price-posting results in a competition so fierce that even the most efficient firm cannot benefit from it, no one will post price. A lower cost of posting prices encourages the price posting. Price posting improves market efficiency unless one firm has too much cost advantage. But in a cooperative game, price posting can help firms effectively collude. This is because when prices are posted, colluding firms can effortlessly monitor their partners' behavior and quickly punish any deviation.

Some anecdotal evidences can support my theoretical predictions. In the car retail market, traditional dealers coexist with Carmax. Carmax posts the price of every single car in their inventories both online and in stores and uses no negotiation.

By doing this, it attracts customers who have higher search costs, although the traditional dealer can sell cars at lower prices. These stores are making good profits and expanding rapidly. Another firm called Autonation tried to compete again Carmax in the same way but failed. Now, we do not see two car retailers posting prices in the same market. In the airline ticket market, travel agents usually sell cheaper tickets but one needs to make a long list of phone calls to get a good deal. At the same time, travel websites provide tickets at higher prices but lower search costs. A more interesting example is that in a tourist market in Shanghai, China, retailers do not even tell customers their prices by speaking it out. Instead, a retailer inputs a price on calculator and shows it only to the customer who is asking. Price discrimination can be one driving force of this phenomenon but clearly raising search cost and softening competition is another big objective for these sellers. Also, the development of Internet has dramatically lowered the posting cost and probably is a main reason why more and more firms are posting their prices.

It would be ideal if we can use naturally occurring data to test these theories. Unfortunately, it is hard to find appropriate data for empirical analysis. Even if we can get transaction level price data, there are still many unobservable variables such as costs, consumer preferences, consumer search, etc. Also, in reality, the changes of costs usually accompany other changes in the market, which makes it hard to distinguish the effects of different factors. The most difficult part is to observe collusion, since no firm would admit that it is colluding. Of course, if we can see transaction prices, we can detect collusion by looking for obvious correlation between prices. But, we still need cost information and demand information to make sure that the prices are significantly higher than the competitive level and the correlation between prices is not driven by reasons other than collusion. On the other hand, a controlled experiment has its unique advantages on empirically testing these theories. First, in experiments we can easily satisfy some assumptions made in the theoretical models. Second, we can control sellers' transaction costs and buyers' valuations and search costs, which are unobservable in real life. Therefore, we can calculate theoretical predictions and observe welfare in the experiment. Third, in the experimental lab, we can control whether subjects can communicate with each other and observe their conversation. In the communication treatments, we are able to obtain direct evidence on collusion and find out how people collude. Finally, in a highly controlled environment, we can directly compare outcomes across different treatments.

The experiment I conduct is as following: I use human subjects to represent sellers in a homogeneous product market. They are randomly matched into groups of three. At the beginning of each treatment, each subject will be assigned a constant unit cost. These unit costs are common knowledge and differ across sellers. There is no capacity constraint. Information about the demand side is revealed. There are two control treatments-the dealer market treatment, where price posting is not an option; and a posted-price market, where price posting is mandatory. In the core treatments, price posting is optional. A subject can choose both her price and whether or not to post her price. All will know the posted prices immediately without paying any cost. Unpublished prices can only be found out at random by consumers after paying certain search costs. A subject can input different actions and the computer will show expected demand for each action if it is played for the whole period, given other sellers' current chosen actions. Then, a subject can choose an action from her self-created action list. Once an action is chosen, there will be a continuous profit inflow proportional to the expected demand for the whole period. Within one round, subjects can constantly adjust their actions. It is a repeated game. The same group of subjects with given costs will repeat interaction for a randomly determined number of rounds. I alter the production costs, the fixed cost of posting prices, and the possibility of communication among subjects across treatments to show the effect of these factors on market structure.

Experimental results suggest that one is more likely to post prices when he or she has lower unit cost and when the fixed cost of posting prices becomes lower. On average, price posting lowers effective prices when communication among subjects is not allowed but raises prices when subjects can communicate with each other.

The most related experimental paper in the literature is Cason and Datta (2006). They use a laboratory experiment to study pricing and advertising behavior in a market with costly buyer search. Their study looks for unique symmetric mixed strategy equilibrium with homogeneous sellers. Sellers either charge a high-unadvertised price or randomize in an interval of lower advertised prices. They find that increases in either search or advertising costs raise equilibrium prices, and equilibrium advertising intensity decreases with lower search costs and higher advertising costs. Sellers also post lower advertised than unadvertised prices as predicted. In all their treatments, however, sellers advertise more intensely than in equilibrium and price much lower than the equilibrium price interval and earn profits that average only 12 to 40 percent of the equilibrium level.

My paper has similar features such as costly price advertising and endogenous advertising decision. But it also differs from Cason and Datta's in many ways. In my study, sellers have heterogeneous costs and buyers have heterogeneous search costs and I find pure strategy equilibrium; communication is allowed in some treatments; and there are technology changes over time.

Two other highly related experimental papers are Robert Stahl (1993) and Potter et al (1998). Robert Stahl show that in the market with identical firms with zero marginal cost, perfect competition is achieved when advertisement cost is zero. When advertisement is costly, entry drives prices higher. Prices are higher than marginal cost if only search cost is positive. Potter et al let experimental subjects choose whom to inform about their prices in a market with buyers and seller setting their bid and ask prices. Their results show that subjects tend to inform everyone on the other side of the market, but not their own competitors. The differences in our results are quite reasonable, though. In Potter et al (1998) the two sides of the market are symmetric, but in my set up sellers have more power and individual buyers are price takers and searchers. In Potter et al (1998) sending information to only one other subject is very risky because that subject may receive several prices at the same time and thus will be able to choose the best. But in my model an individual consumer only observe one price in each period and it is costly to keep searching. So sellers may take advantage of the search cost and set higher prices.

Earlier lab experiments compare search market with posted price market. Cason, Friedman, and Milam (2003) find that efficiency is lower, sellers' prices are higher, and prices are stickier under haggle than under posted offer. Ketcham, Smith, and Williams (1984) show the opposite under certain conditions.

There are some other experimental papers on search. But most of them focus on consumer search behavior, not firm behavior of endogenously choosing search cost . Some non-experimental papers or articles mention firm behavior on setting search costs. Bakos (1997), Pazgal Vulcan (1998), Quick (1998) claimed that some firms resist lower search cost and block themselves from search websites. Bounds (1999) noted that large and established retailers prefer having their own websites to letting some third party websites post their price information.

Over all, this experiment is the first to look at behavior of heterogeneous sellers on costly price posting. Like Cason and Datta (2006), it makes buyers' search costs on prices partially endogenous choices of sellers. But it adds one more dimension to Cason and Datta (2006) since sellers can have different costs and thus price dispersion can exist in a pure strategy equilibrium.

Davis and Holt (1996) argues that there might be more collusion in a posted price market. When everyone can see what the prices are, it is easier to detect deviation and give punishment. It would be hard to model this since we do not know how much posting prices can increase collusion. In this experiment, I use both communication treatments and noncommunication treatments to study how price posting interact with collusion.

The rest of the paper is organized as following. In section 2, I describe the experimental design. In section 3, I present the experimental results. In section 4, I conclude and address some policy implications. I will also discuss some possible future research on this topic.

4.2 Experimental Design

The experiment I conduct is as following: Since the seller side is thinner and thus sellers are more powerful, and most importantly, only the sellers make price posting decisions in my model, they are the focus of the experiment. So, I use human subjects to represent sellers and a computer program to calculate demand for each seller, given their prices and posting status. Subjects are randomly matched into groups of three. At the beginning of each treatment, each subject will be assigned a constant unit cost. These unit costs are common knowledge and differ across sellers. There is no capacity constraint. Information about the demand side is revealed. In the core treatments, price posting is optional. A subject can choose whether or not to post her price and what the price is for each period. All will know the posted prices immediately without cost. Consumers can only find out unpublished prices after paying certain search costs. After all the subjects choose their strategies, computer calculates demand for each seller. Within one round, subjects can constantly adjust their strategies. It is a repeated game. The same group of subjects with given costs will repeat interaction for a randomly determined number of rounds.

Subjects are paid in cash at the end of each experimental session, depending on the total profits they earn in the experiment. The exchange rate is 1US$ *forevery*300*experimenta*

According to the theoretical predictions, important treatment factors include: 1. Distribution of sellers' cost 2. Fixed cost of posting price 3. Possibility of collusion

T	Unit Cost Price* (posted)	Price Posting Option	Communication (sample size in groups)	Post Cost
1	20 21 22 28 29 30	No (Dealer Market)	Yes, No (94, 90)	-
2	20 21 22 28 29 30	Yes	Yes, No (87, 94)	100
3	20 21 22 24 22 23	Yes	Yes, No (91, 90)	10
4	10 21 22 21 22 23	Yes	Yes, No (41, 47)	100
5	20 21 22 21 22 23	No (Post Price)	Yes, No (64, 83)	100

Figure 4.1: Treatments

Therefore, I alter the levels of these factors across treatments. In the collusion treatment, subjects can communicate with each other using MSN messenger.

After the experiment, subjects report their strategies and demographic characters on a questionnaire. This provides us more information than the posting status and prices we can observe in the experiment.

There are two comparison treatments: 1. Posted price market (e.g., Nasdaq, online retailing): All sellers are required to post prices. More competition is expected. However, there is also a higher possibility of collusion. 2. All middlemen market (e.g., tourist-trap, traditional car dealers): Without posting prices being an option, all sellers are middlemen and there is less competition. Prices are expected to be higher.

The table in Figure 4.1 lists the proposed treatments where subjects decide whether to post prices. Note that in this table and in the experiment, the numbers are magnified by 100 from the model. This is just to make it easier to input numbers. When subjects get paid, the profits are reduced at an exchange rate of 1000 experimental dollars to 3 U.S. dollars.

Communication treatments and non-communication treatments are conducted on different subjects. But subjects go through different treatments where the other factors vary. So, this is a partly between and partly within experimental design. All subjects go through treatment 1 to 5 either with communication or without communication.

The experiment is more dynamic than the theoretical model. Therefore, depending on the timing, there exist multiple equilibria when sellers have similar costs. I expect to see sellers with lower costs to post their prices more often. When the cost advantage is big enough (like in treatment 4), the most efficient seller should be the only price poster.

I design the experiment in this more dynamic manner for technical reasons. First, I want subjects to be able to change their action within a period to achieve more learning. This way, the market will move toward an equilibrium faster. Also, when I use a more static version in the pilot, where the profits are realized only in the end of each round, people practice ”sniping” to limit their competitor’s information on their actions. This creates a lot of noise. The current version with subjects freely changing their actions in a period and getting a continuous inflow of profits seems to work better.

4.3 Experimental Results

So far, 147 subjects have participated in the experiment. Most subjects are undergraduate students at University of Maryland. Some subjects are graduate students and some are working. There are students majored in economics as well as in other subjects.

Among the 147 subjects, 75 had the communication treatments and 72 had the non-communication treatments. Each subject went through the five treatments shown in the table of treatments, either without or with communication. In each treatment, subjects start with a trial round, which is not paid and not included in the data analysis. In each session, the computer draws the numbers of rounds in each treatment randomly. Therefore, the number of group*round varies across treatments. The numbers in brackets in column "communication" in Table 2 show the number of group*round in each treatment. The subject payments range between $5 and 45$. The average payment is around 15.

Figure 4.2 shows the average effective prices (which yield positive demands) by treatment, without and with communication. The lighter green bars are the average effective prices without communication. The darker red bars are the average effective prices with communication. The blue lines are the theoretical predictions of the average effective prices in the non-cooperative equilibria. We can see that in the non-communication treatments, optional price posting results in lower effective prices, but mandatory price posting results in higher effective prices. In the communication treatments, however, both optional price posting and mandatory price posting result

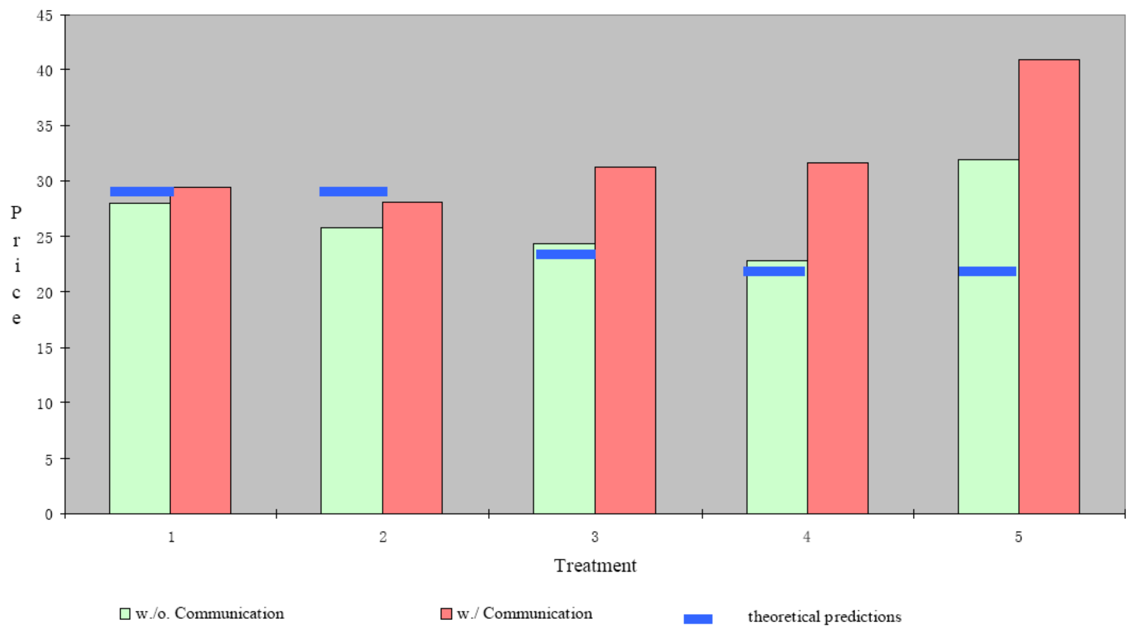

Figure 4.2: Average Effective Price

in higher effective prices. Without or with communication, mandatory price posting results in higher effective prices than optional price posting. Communication yields higher prices in every treatment, but the difference is higher with price posting. If we weight the effective prices by demand, the results look similar, except that in treatment 4 with communication, where one seller has a significantly lower cost, the average demand-weighted price is lower than those in the other treatments with communication. This is more consistent with the theoretical predictions. Figure 4.3 shows the average demand-weighted prices by treatment.

From both Figure 4.1 and Figure 4.2, we can see that in treatment 1, 3, and 4 without communication, the average effective prices and the average demand-weighted prices are very close to the non-cooperative equilibrium prices. In treat-

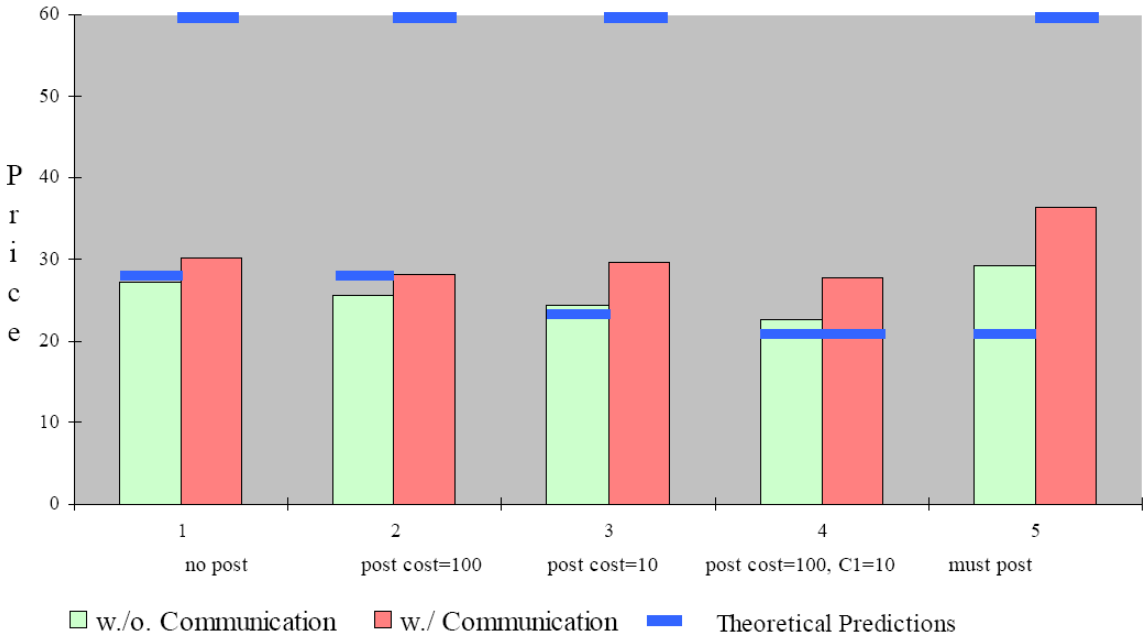

Figure 4.3: Average Demand Weighted Price

ment 2 without or with communication, prices are lower because some sellers post their prices, although they are not supposed to do so in the non-cooperative equilibrium. In treatment 5, where price posting is mandatory, prices are higher because it is easier to monitor collusion and react to any deviation. Even when communication is not allowed, some sellers successfully collude by using posted prices as signals for collusion.

One can argue that the order effect plays a role here. Because subjects always go through these five treatments in the same order, when they get more experienced with the market and their competitors, they become better at collusion. Later in this section, I will use regressions to control for order effect.

Figure 4.3 shows the percentage of sellers with positive demand in each treat-

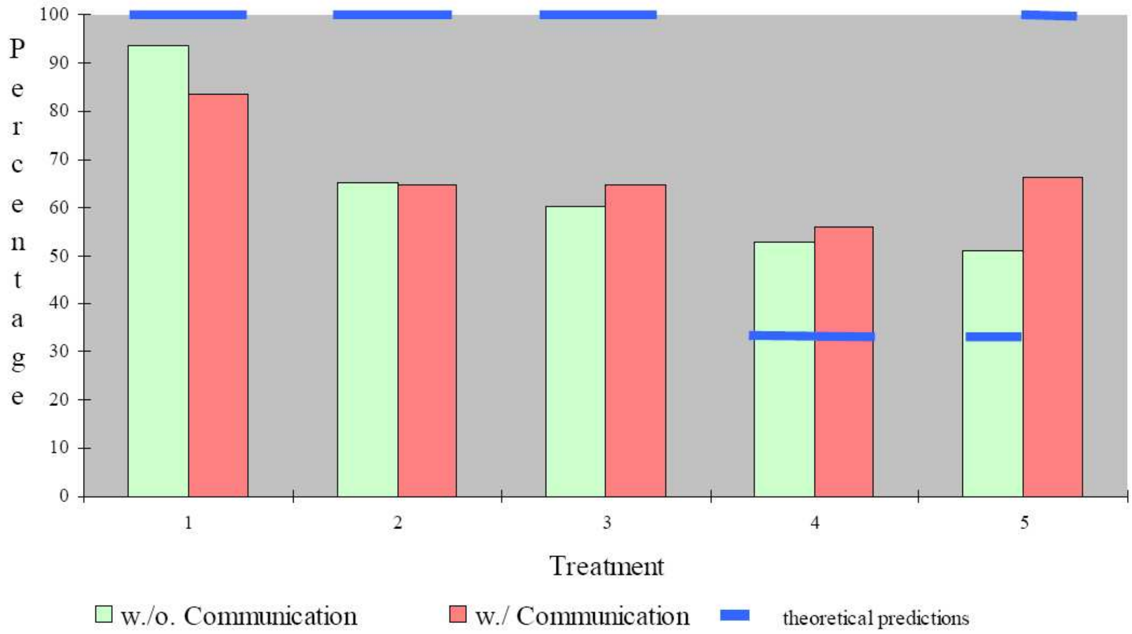

Figure 4.4: Percentage of Sellers with Positive Demand

ment. We can see that when price posting is not an option, almost everyone gets positive demand. When price posting is optional, some sellers post their prices and more direct competition is triggered. Therefore, only 60

Figure 4.4 to Figure 4.7 show the average effective prices and percentage of sellers with positive demand by treatment and cost, without or with communication.

Figure 4.8 shows the average number of price posters by treatment, without or with communication. Figure 4.9 shows the average number of price posters with positive demand by treatment, without or with communication.

We can see that in general, sellers with lower costs charge lower prices and get positive demand more often. In treatment 2, the theoretical prediction says that without multiple sellers agreeing on posting the same price, no one should post price

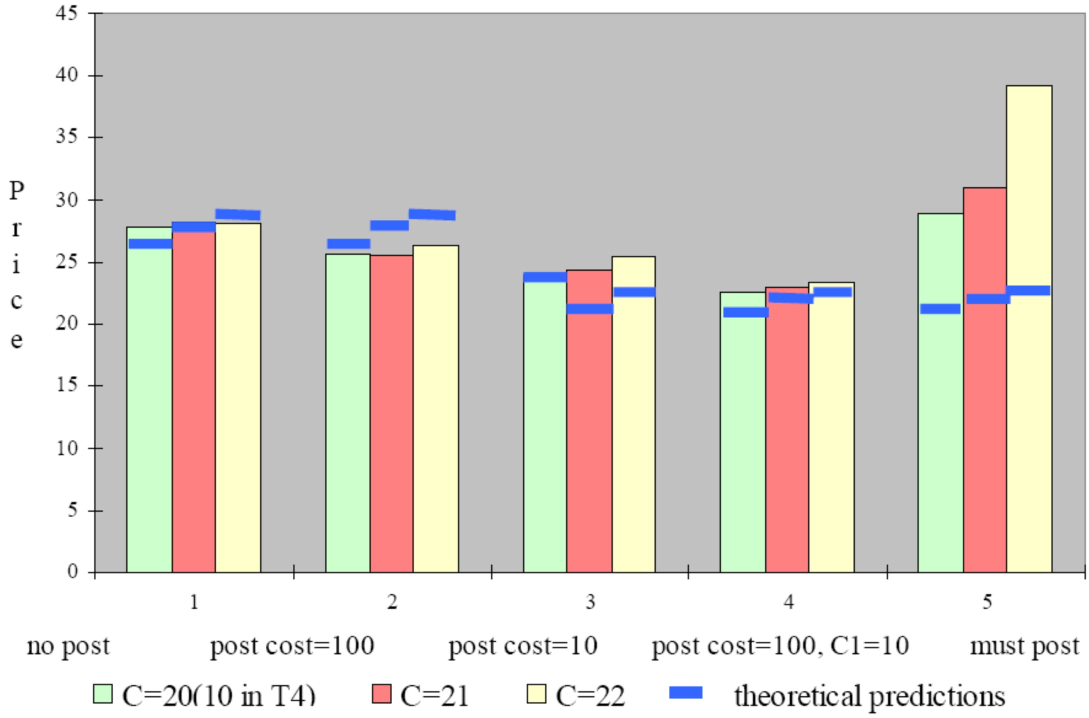

Figure 4.5: Average Effective Price by Cost, w./o. Communication

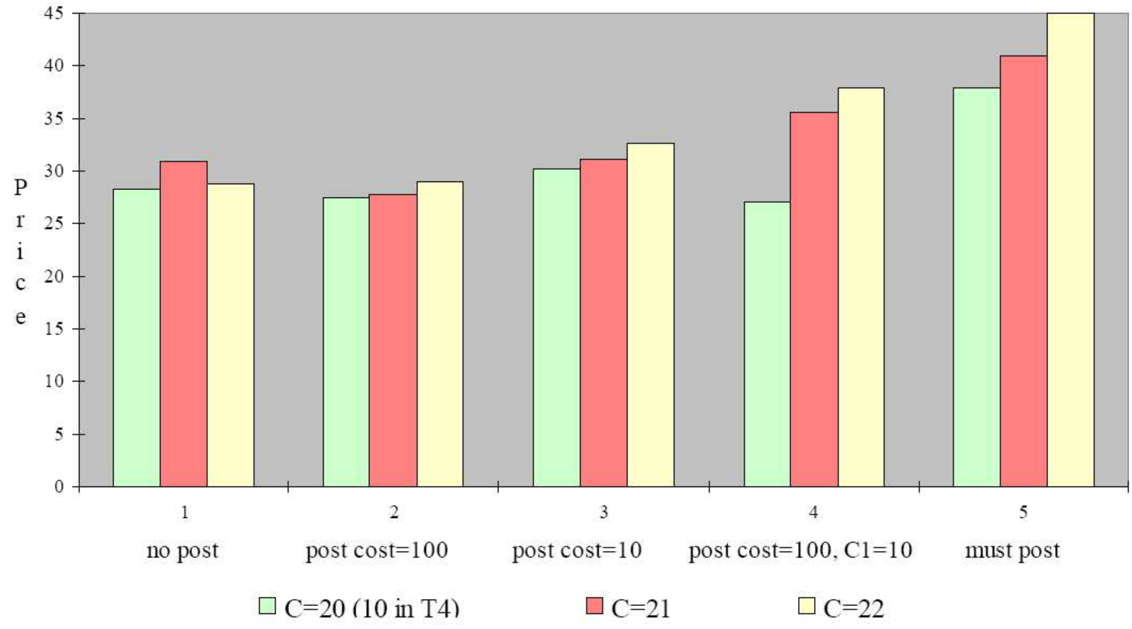

Figure 4.6: Average Effective Price by Cost, w./ Communication

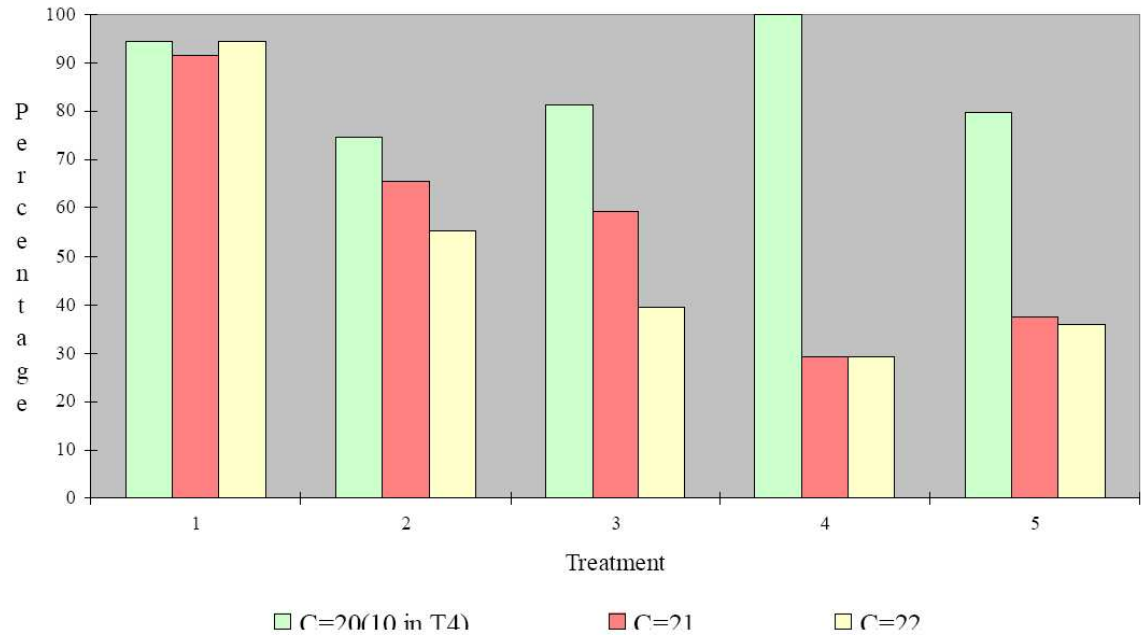

Figure 4.7: Percentage of Firms with Positive Demand by Cost,w./o. Communication

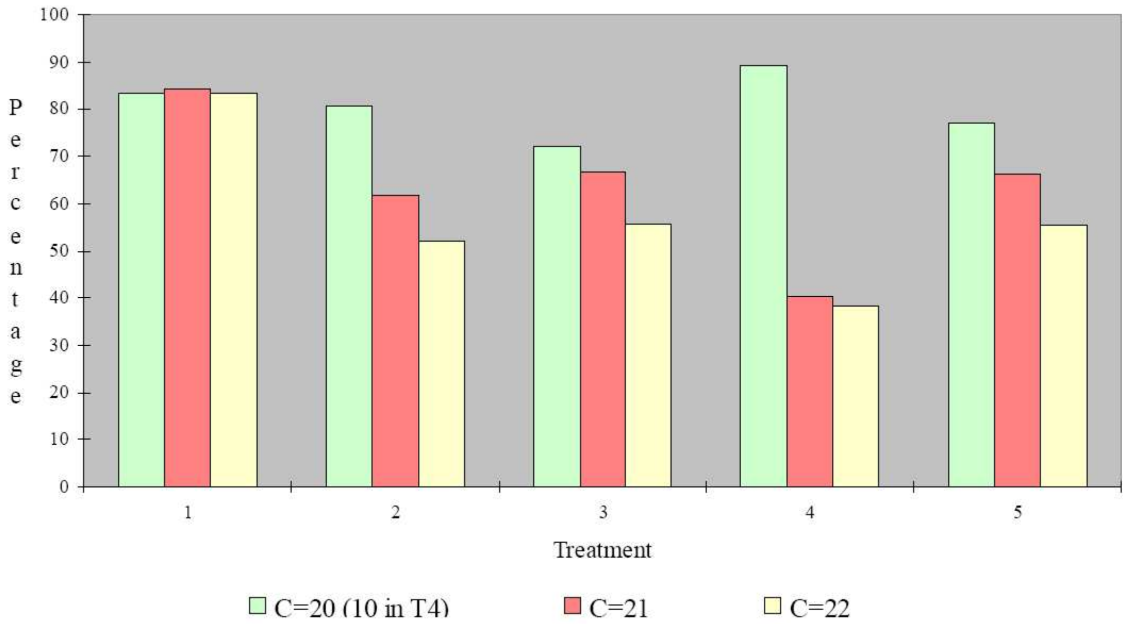

Figure 4.8: Percentage of Firms with Positive Demand by Cost, w./ Communication

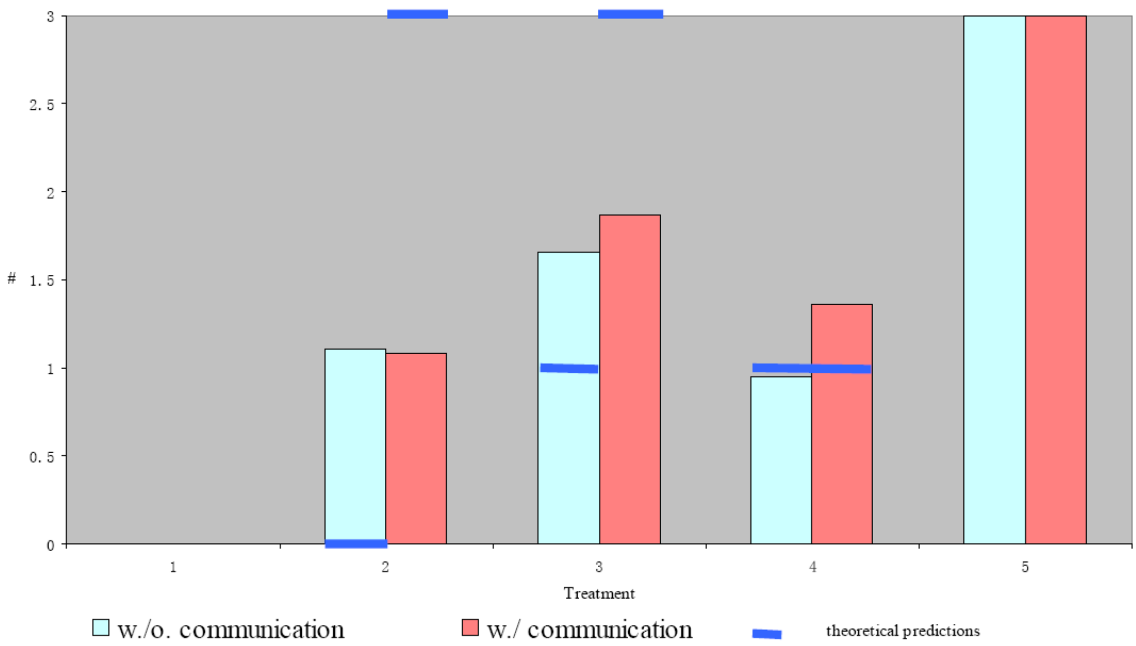

Figure 4.9: Number of Price Posters

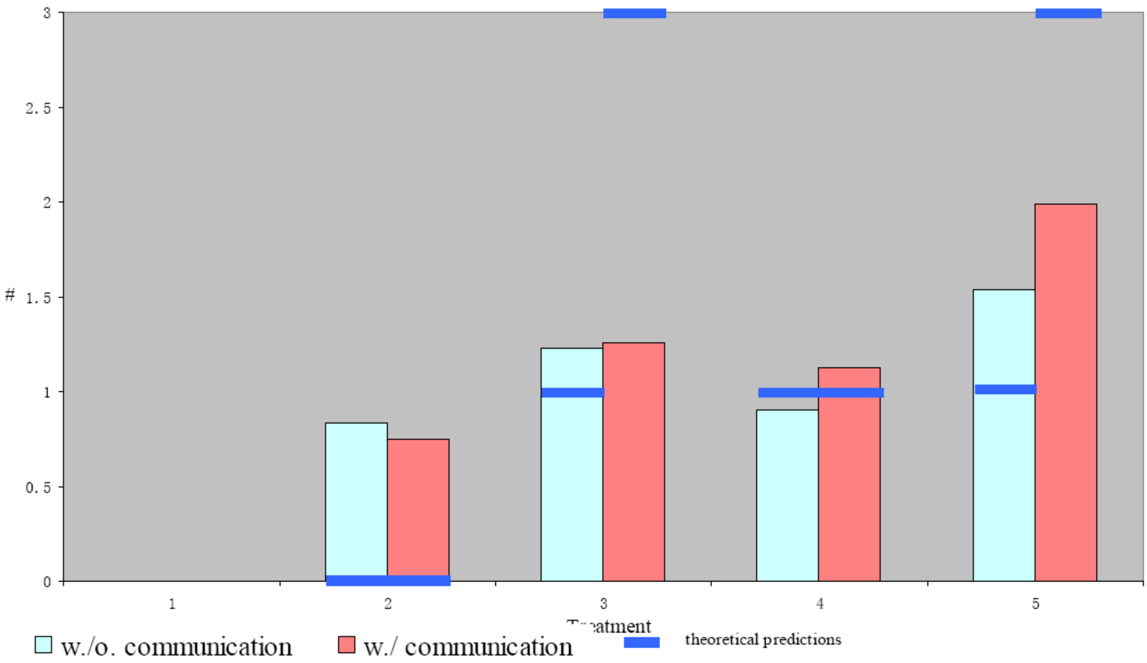

Figure 4.10: Number of Effective Price Posters

since the posting cost is too high and no one can make more profit by posting price. But in the experiment, some subjects choose to post price and that results in lower prices and fewer sellers with positive demand. In treatment 3, the prediction says that without multiple sellers agreeing on posting the same price, one seller should post price since now the posting cost is low enough to make being the only price poster more profitable than hiding price with everyone else. In the experiment, we do see more sellers posting prices than in treatment 2. The average number of effective price posters is bigger than one in both communication and non-communication treatments. This means that some degree of collusion is going on, with or without communication, because we will not see multiple sellers charging the same price in a Bertrand competition when sellers have different costs. In treatment 4, the average

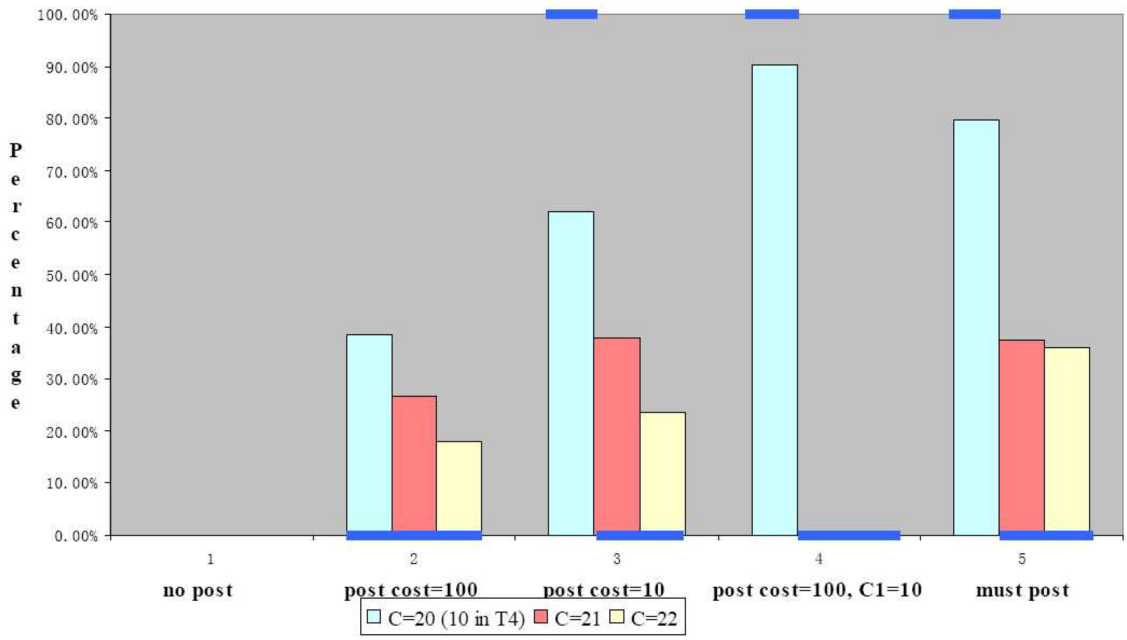

Figure 4.11: Percentage of Effective Price Posters by Cost, w./o. Communication

number of effective price poster is close to one, which is consistent with the theory. We will discuss this in more details in the following paragraphs. In treatment 5, the average number of effective price poster is 1.5 without communication and 2 with communication. Clearly, there is more collusion going on when price posting is mandatory. When we look at the communication transcripts, it is clear that many sellers did try to agree on charging a same price much higher than the competitive level. And quite a few groups did charge the price they agree on.

Figure 4.10 and Figure 4.11 show the average number of effective price posters by treatment and cost, without or with communication, respectively.

We can see that in general, sellers with lower costs are more likely to post their prices, especially when the cost advantage is big. When the unit costs are similar

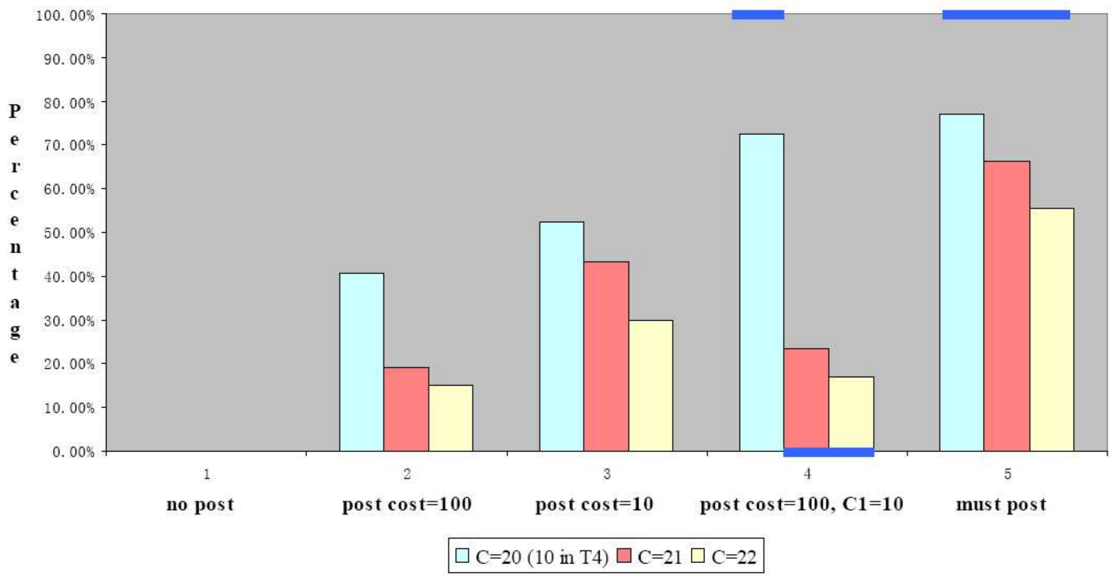

Figure 4.12: Percentage of Effective Price Posters by Cost, w./ Communication

(treatment 2 and 3), there can be multiple equilibria since some less efficient sellers may move faster and poster their prices earlier than the more efficient ones. Since a seller receives a continuous inflow of profit for 3 minutes in each round, a late mover may not want to undercut a posted price since the profit from sale she can get in the remaining time can be smaller than the post cost. However, since it is easier for the most efficient sellers to fight back when other sellers undercut their prices, the relatively inefficient sellers are less likely to post their prices. We do see that higher percentages of sellers with lower unit costs post their prices effectively. In treatment 4, where sellers have unit costs 10, 21 and 22, respectively, without communication, 90

Also, a lower cost of posting prices raises the percentage of sellers who post their prices. Compare treatment 2 and treatment 3 without communication, we see

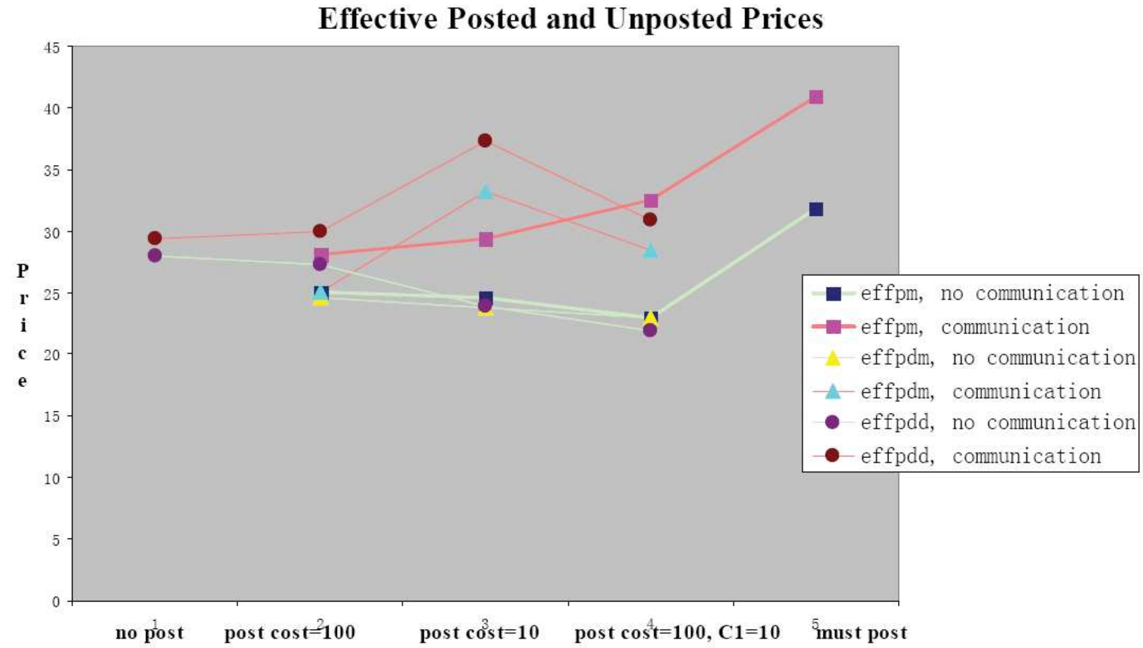

Figure 4.13: Average Effective Posted and Unposted Prices, w./ Communication

that a higher percentage of the all types of sellers post their prices when post cost is 10 instead of 100.

Figure 4.12 illustrates the average posted and unposted effective prices by treatment, without and with communication. The squares are the average posted effective prices. The triangles are the average unposted effective prices when there is at least one posted price in the same market. The dots are the average unposted effective prices when all prices in the same market are hidden. Those connected by light green lines are without communication and those connected by dark red lines are with communication.

We can see that as predicted, on average, the posted prices are higher than

IPost	1	2	3	4	5	6
Cost Advantage	0.028***	0.035***	0.036***		0.034***	
Posting cost	-0.002***	-0.002***	-0.002***	-0.004***	-0.002***	-0.004***
Cost	-0.014			-0.052***		-0.053***
Other Post	0.009	0.006	0.008	-0.016	0.003	-0.011
Communication	0.029	0.034	0.017	0.005	0.011	0.007
Period in Treatment	-0.018	-0.019*	-0.019*	-0.019*	-0.020*	
Cumulative Period	-0.004	-0.006		0.005		0.005
Treatment Number			0.043			

***: Significant at 1% level; **: Significant at 5% level; *: Significant at 10% level.

Figure 4.14: Marginal Effects in Price Posting Decision – Probit with Individual Fixed Effects

the unposted prices coexisting with them. Prices in the search markets where all prices are hidden are higher than those prices in markets with at least one price poster. Prices in communication treatments are always higher. When price posting is not an option, the prices in treatments with and without communication are almost the same. When price posting is introduced, prices with communication are dramatically higher (around 5 to 15 experimental dollars more) than the prices without communication. Again, one can argue that there is order effect here. The following regressions will partially answer this question.

The table in figure 4.14regressions of the price posting decision on cost, post cost, communication, and time trend, with individual fixed effects and clustered on subjects. Each observation is one subject's price posting decision at the end of a period. Only observations in treatment 2, 3 and 4 are used. If we cluster the data on groups, the results are similar. The independent variable called "period within treatment" is the number of period in that particular treatment for an observation. Its marginal effect accounts for a linear learning effect within treatment. The independent variable called "cumulative period" indicates the cumulative period number for an observed price. For example, it would be 9 for an observation in treatment 2, round 4 if this subject played 5 rounds in treatment 1 before treatment 2. It only captures a linear learning effect over time in all the treatments. If learning is not linear or if there is strong order effect on treatments, this regression does not pick it up very well.

We can tell that sellers with bigger cost advantages are more likely to post prices, sellers are more likely to post prices when it cost less to do so. Also, since more sellers post prices more than the theoretical prediction levels, within each treatment, they learn from the loss and fewer people post their prices over time. Communication does not affect sellers' price posting decision significantly.

The table in figure 4.15average demand-weighted price, effective price and the difference between observed price and predicted price in the static noncooperative equilibrium. Independent variables include subject's own price posting status (IPost), whether someone else in the market is posting prices (Someone Posts), whether multiple sellers in a market are posting different prices (Diff. Post), whether multiple sellers in a market are posting the same price (Same Post), unit cost, cost advantage, price posting cost, treatment dummies and time variables. The regres-

Regression	Average Transaction Price (1)	Average Transaction Price (2)	Effective Price (1)	Effective Price (2)	Price Deviation (1)	Price Deviation (2)
IPost				2.325**	-1.110	
Someone Posts				-2.371***	0.504	
Competition Post				-3.137***	-0.465	-1.126*
Collusion Post				3.598***	2.624***	1.972**
Unit Cost				0.288***	-0.314***	
Cost Advantage						-0.151**
Posting cost			0.295**	0.016**	-0.034***	-0.029***
Communication	7.109***	6.739***	6.358***	6.117***	6.073***	6.143***
Treatment 1	1.217*	1.858***	2.081***	-0.186	-1.524	-2.033***
Treatment 3	-0.406	0.302	1.021*			
Treatment 4	-1.893***	-1.428**	1.786*			
Treatment 5	6.526***	6.287***	9.749***	8.142***	14.442***	14.354***
Period in Treatment		0.599***	0.529***	0.514***	0.520***	0.524***
Cumulative Period	-0.072			-0.174***	-0.236***	-0.264***
Constant	24.195***	21.775***	16.143***	17.896***	9.589***	3.023***

***: Significant at 1% level; **: Significant at 5% level; *: Significant at 10% level.

Figure 4.15: Regressions on Prices – OLS with Individual Fixed Effects

sions include individual treatment effects and are clustered on groups. Again, if we cluster on subjects, the results look similar.

From Table 4, we can see that after taking the learning effects and interdependence of data within groups into consideration, without communication, introducing price posting option lowers the prices significantly. With communication, sellers charge significantly higher prices. Mandatory price posting raise prices significantly, too. When multiple sellers in a market are posting different prices, prices in a market are closer to the competitive levels. When multiple sellers in a market are posting the same prices, prices in a market are significantly higher.

The observed prices in treatments without communication are on average very close to my theoretical predictions and the variances are relatively small. The prices in treatments with communication are on average higher than theoretical predictions of non-collusive prices and lower than the monopoly prices. The variances are much bigger with communication and/or with mandatory price posting. Some groups fail to collude at all; some are cautious in raising prices so their prices are only a little higher than the competitive levels; some are very successful and charge the monopoly prices, the majority are somewhere in the middle.

4.4 Conclusions And Future Study

4.4.1 Conclusions

My experimental results demonstrate that

1. Sellers are more likely to post prices when they have lower unit cost. When

one seller has a big cost advantage, she will be the only price poster. When the costs are similar, the more efficient sellers are more likely to post their prices and the less efficient sellers tend to survive by hiding their prices.

2. Sellers are more likely to post prices when the cost of posting prices is lower. When the fixed cost of posting prices drops from 100 experimental dollars to 10 experimental dollars, sellers, especially the most efficient sellers are more likely to post their prices

3. Optional price posting usually lowers effective prices and improve efficiency.

4. Subjects tend to post their prices more often than the stationary equilibrium levels. But over time, some people learn to hide their prices.

4. Mandatory price posting helps subjects collude with each other more effectively and set higher prices. The price increase is very significant when communication is allowed.

4.4.2 Policy Implications

In general, people think of price transparency as a desirable feature of the market. For sure, price posting lowers consumer search costs. But we have to take the possibility of collusion into account. When prices are all posted, it is easier for colluding parties to monitor each other's behavior and react to any deviation quickly. So, regulations on mandatory price posting sometimes can facilitate collusion and decrease consumer surplus and sometimes even lower market efficiency.

If collusion can be controlled, price posting will in general improve market efficiency, unless one party has too much cost advantage upon the competitors. Lowering the fixed cost of posting price can encourage price posting and thus improve efficiency.

Also, when one firm is posting prices, allowing some other firms to compete with unposted price can limit the posted price and improve market efficiency.

4.4.3 Future Study

I have recorded the whole history of the experiment but I am only using the ending prices in each round in this paper. It will be interesting to look at the price formation, especially when sellers are trying to collude.

After the experiment, each subject answer a questionnaire. There are questions about their demographic information, their business experience and experimental experience, their risk posture (preferences over risky and safe lotteries), and their strategies played in the experiment. I will look at them and try to use them as instrument variables in the regressions.

In this experiment, I use a partially between, partially within design. The order effect is inevitable. Even after controlling the time trend in the regressions, the results are still not as clean as in a between experiment. So, running all treatments between subjects will be a good robust check.

There can be many variations of this experiment. We can change the search costs, number of sellers, etc. We can also add human subjects as buyers and introduce negotiation and price discrimination.

Chapter A

Proofs

Proof of Theorem 2.1:

Without multiple firms agreeing on posting the same price, market makers have a Bertrand competition so that only the most efficient one(s) can survive and possibly make a positive profit. If there is one market maker with the lowest cost, and she does not prefer to be a middleman, neither does any middleman want to become a market maker, then we have a monopoly market maker. If there are more than one firm with the lowest cost among market makers, they compete all the profit away in a Bertrand competition and would rather make some positive profit as middlemen. So there will be no market maker in that case.

Combine the above two cases, there can only be at most one market maker without multiple firms agreeing on posting the same price.

End of proof.

Proof of Corollary 2.1: $\forall K \in [\underline{K}, \overline{K}]$, according to equation 2.17,

$$\underline{K}_l(K) = \frac{(1+K)(4\delta+1)-1}{8\delta+1} \geq \underline{K}_l(\underline{K}) = \frac{(1+\underline{K})(4\delta+1)-1}{8\delta+1} > \underline{K} \tag{A.1}$$

So, no matter which intermediary with transaction cost $K \in [\underline{K}, \overline{K}]$ becomes a monopoly market maker, some efficient intermediaries will always survive as middlemen in this market.

End of proof.

Proof of Corollary 2.2:

First, the least efficient middleman, who has unit cost $\overline{K}_d^d = \frac{4\delta+\underline{K}}{4\delta+1}$, is always indifferent between being a middleman and being a monopoly market maker, since she makes zero profit either way:

$$
\begin{aligned}
& a_m(\overline{K}_d^d) - b_m(\overline{K}_d^d) && \text{(A.2)}\\
= \;& 1 - 2b_m(\overline{K}_d^d) && \text{(A.3)}\\
= \;& 1 - 2(\frac{1-\overline{K}_d^d}{4} + \frac{1-\underline{K}}{16\delta+4}) && \text{(A.4)}\\
= \;& 1 - 2(\frac{1-\frac{4\delta+\underline{K}}{4\delta+1}}{4} + \frac{1-\underline{K}}{16\delta+4}) && \text{(A.5)}\\
= \;& \frac{4\delta+\underline{K}}{4\delta+1} && \text{(A.6)}\\
= \;& \overline{K}_d^d && \text{(A.7)}
\end{aligned}
$$

Assume an intermediary has unit cost K , $K \in [\underline{K}, \overline{K}_d^d)$.

As a middleman in the dealer market, where all the other intermediaries with unit costs uniformly distributed on $[\underline{K}, \frac{4\delta+\underline{K}}{4\delta+1}]$ are also middlemen, its profit is

$$\pi_d^d(K) = \frac{\rho(1+4\delta)}{32M\delta(1-\rho)^2(1-\underline{K})}(\frac{4\delta+\underline{K}}{1+4\delta} - k)^2 \tag{A.8}$$

If she becomes a monopoly market maker, she has to coexist with middlemen with unit costs uniformly distributed on $[\underline{K}, \overline{K}(K)]$, where

$$\overline{K}_d^m(K) = \frac{1+K}{2} + \frac{\underline{K}-1}{8\delta+2}, \tag{A.9}$$

its profit will be

$$\pi_m(K) = \frac{4\delta+1}{32\delta(1-\rho)}(\frac{4\delta+\underline{K}}{4\delta+1} - K)^2 \tag{A.10}$$

The ratio of these two profits is

$$\frac{\pi_m(K)}{\pi_d^d(K)} = M(\frac{1}{\rho} - 1)(1 - \underline{K}) \tag{A.11}$$

An intermediary with unit cost K gets more profit being a monopoly market maker than being a middleman if this ratio is greater than 1, i.e.,

$$M(\frac{1}{\rho} - 1)(1 - \underline{K}) > 1.$$

Since we have assumed that

$$M > \frac{(4 - 3\rho)}{(1 - \rho)(1 - \underline{K})},$$

we have

$$M(\frac{1}{\rho} - 1)(1 - \underline{K}) > \frac{4 - 3\rho}{\rho} > \frac{4 - 3}{\rho} > 1. \tag{A.12}$$

End of proof.

Proof of Corollary 2.3:

Assume two intermediaries have unit costs K_1 and K_2, respectively. Further,

$$\underline{K} \leq K_1 < K_2 \leq \overline{K}_d^d. \tag{A.13}$$

When firm 2 becomes a market maker, as a middleman, firm 1 has to lower its spread and will also lose some demand. So, its profit gets smaller, i.e.,

$$\pi_d^m(K_1) < \pi_d^d(K_1). \tag{A.14}$$

But if she competes as a market maker, she can defeat firm 2 since she is more efficient. When it is more profitable for firm 2 to become a monopoly market maker, it is more profitable for firm 1 to become a monopoly market maker, too. That is,

$$\pi_d^d(K_1) < \pi_m(K_1). \tag{A.15}$$

End of proof.

Proof of Theorem 2.2:

The first part comes directly from Corollary 2. Then, replace K with $-K$ in equation 2.20 and 2.22, we can get the prices and profit of the most efficient intermediary as a monopoly market maker. Similarly, we can get the distribution of middlemen's prices from equation 2.23 and 2.24.

Also, A middleman with transaction cost K sets bid-ask prices

$$1 - a_d^m(K) = b_d^m(K) = \frac{1}{4}[\frac{2 + 6\delta - (2\delta + 1) - K}{1 + 4\delta} - K], \tag{A.16}$$

End of proof.

Proof of Theorem 2.3:

First, an entrant less efficient than the old market maker can not defeat her by competing as a market maker. A Bertrand competition will give a less efficient market maker zero profit and the new entrant definitely prefers being a middleman and make some positive profit, given that she is more efficient than the least efficient middleman in the market.

If the entrant has the same transaction cost as the incumbent does, without the two firms agreeing on posting the same price, the entrant can not get any profit , either. Again, she prefers becoming a middleman.

If the new entrant is more efficient than the old market maker, then she can defeat the incumbent in a Bertrand competition. The old market maker will get zero profit staying as a market maker. But if only she is efficient enough to survive as a middleman, she can make a positive profit. According to equation (3.5) and conditions in Rust and Hall, the condition is given by

$$-K_l(K^e) \ = \frac{(1+K^e)(4\delta+1)-1}{8\delta+1} > -K \tag{A.17}$$

And that is equivalent to

$$K^e > \frac{(8\delta+1)-K-4\delta}{4\delta+1}, \tag{A.18}$$

or $K^e > -K_l^e$.

When the new entrant is so efficient that this inequality does not hold, the old market maker can not even make any profit as a middleman. And since she is already more efficient than the other middlemen, no one can coexist with the new entrant.

Using equation (3.6) and conditions in Rust and Hall,, we know that the new market maker sets limited prices when

$$-K_l(K^e) \ = \frac{(1+K^e)(4\delta+1)-1}{8\delta+1} < -K < -K_u(K^e) \ = \frac{1+K^e}{2}, \tag{A.19}$$

which is equivalent to

$$2-K-1 < K^e < \frac{(8\delta+1)-K-4\delta}{4\delta+1}, \tag{A.20}$$

or $-K_u^e < K^e < -K_l^e$.

Finally, the entrant can set unconstraint prices if she is extremely efficient, which is given by $K^e < -K_u^e$.

End of proof.

Proof of Theorem 3.1:

When multiple firms post their prices without an agreement on posting the same price, Bertrand Equilibrium leads to negative profits for less efficient firms who are posting prices. That is, $\Pi_2(110) = \Pi_2(111) = \Pi_3(111) = \Pi_3(101) = \Pi_3(011) = -F$. If a firm hides its price, it will get non-negative profit for sure. So, less efficient firms would prefer hiding their prices when a more efficient firm is posting price. We should not see multiple price posters in a non-cooperative equilibrium.

End of proof.

Proof of Corollary 3.1:

Define Δ_{ij}^p as the difference in gain from price posting for firm i and firm j.

$$\Delta_{12}^p = [\Pi_1(100) - \Pi_1(000)] - [\Pi_2(010) - \Pi_2(000)]. \tag{A.21}$$

$$\Delta_{13}^p = [\Pi_1(100) - \Pi_1(000)] - [\Pi_3(001) - \Pi_3(000)]. \tag{A.22}$$

$$\Delta_{23}^p = [\Pi_2(010) - \Pi_2(000)] - [\Pi_3(001) - \Pi_3(000)]. \tag{A.23}$$

Here, $[\Pi_1(100) - \Pi_1(000)]$ is the gain from being the only price poster for firm 1. This term can be negative and it is actually a loss. But since we only care about the difference in gain between two firms, it does not matter. Since the effects of posting cost F cancel out in the two gains we are comparing, F is irrelevant to Δ_{ij}. In a restricted equilibrium, profit stays the same in each period for each firm, so ρ only changes the magnitude of total discounted profit and Δ_{ij}, not the sign and the relative value of Δ_{ij}.

I run a grid search of 50 values on each dimension of $(K_1\ K_2\ K_3)$, and 20 values on s. All the 2,500,000 points in the grid search also have the features in the above corollary. From calculation, we find that at all these 2,500,000 points, $\Delta_{ij}^p > 0$ for

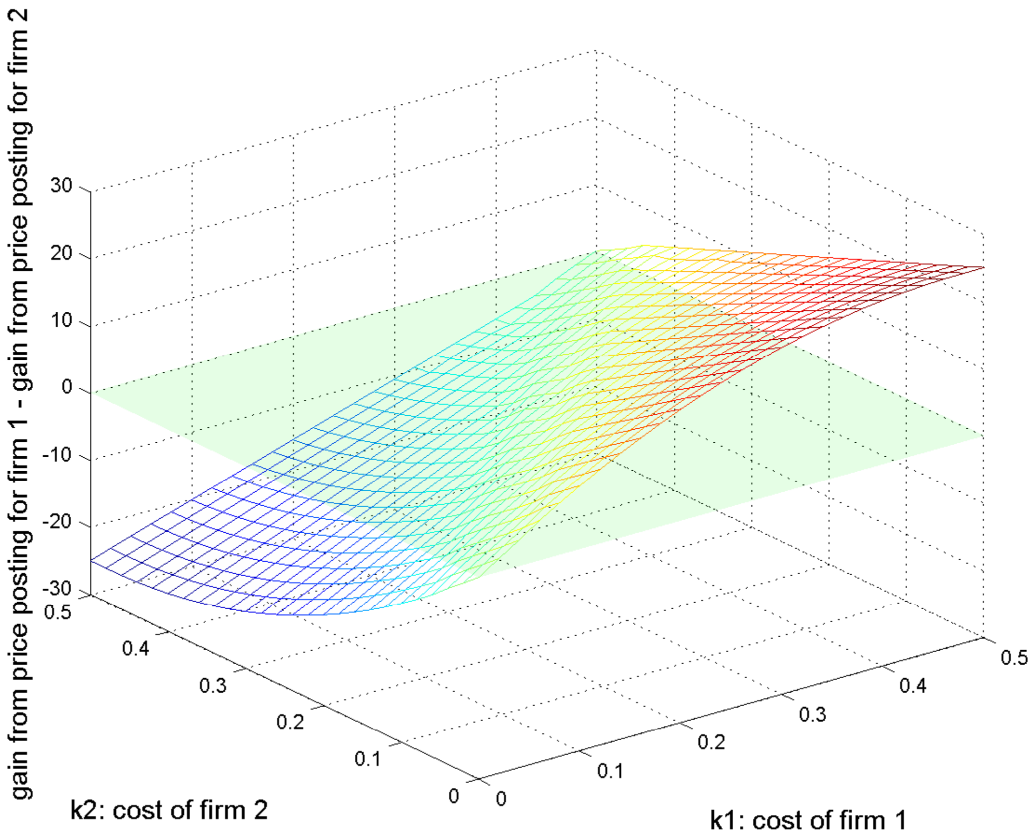

Figure A.1: Who Benefits More From Being The Only Price Poster? (K3=0.5, S=0.05, =0.99)

any $i, j \in \{1, 2, 3\}$, where $K_i < K_j$.

Figure A.1 shows us Δ^p_{ij} at different K_1 and K_2, when $K_3 = 0.5$, $\rho = 0.99$ and $s = 0.05$. We can see that $\Delta^p_{ij} > 0$ when$K_1 < K_2$, $\Delta^p_{ij} < 0$ whenever $K_1 > K_2$, and $\Delta^p_{ij} = 0$ when $K_1 = K_2$. Also, we can see some monotonicity in the figure: fixing K_1 or K_2, the bigger the difference is in firms' unit costs, the bigger the difference is in their gain from being the only price poster.

When we change K_3 and/or s (see figure A.2 and A.3), the results are similar.

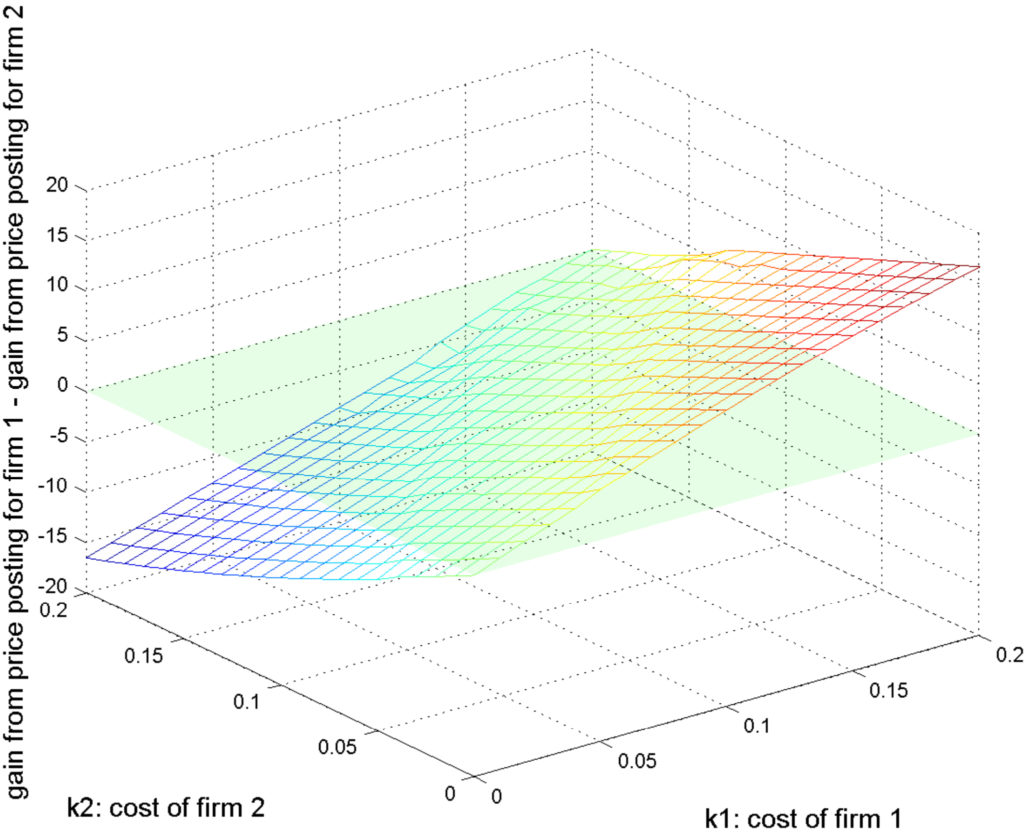

Figure A.2: Who Benefits More From Being The Only Price Poster? (K3=0.2, s=0.05, ρ =0.99)

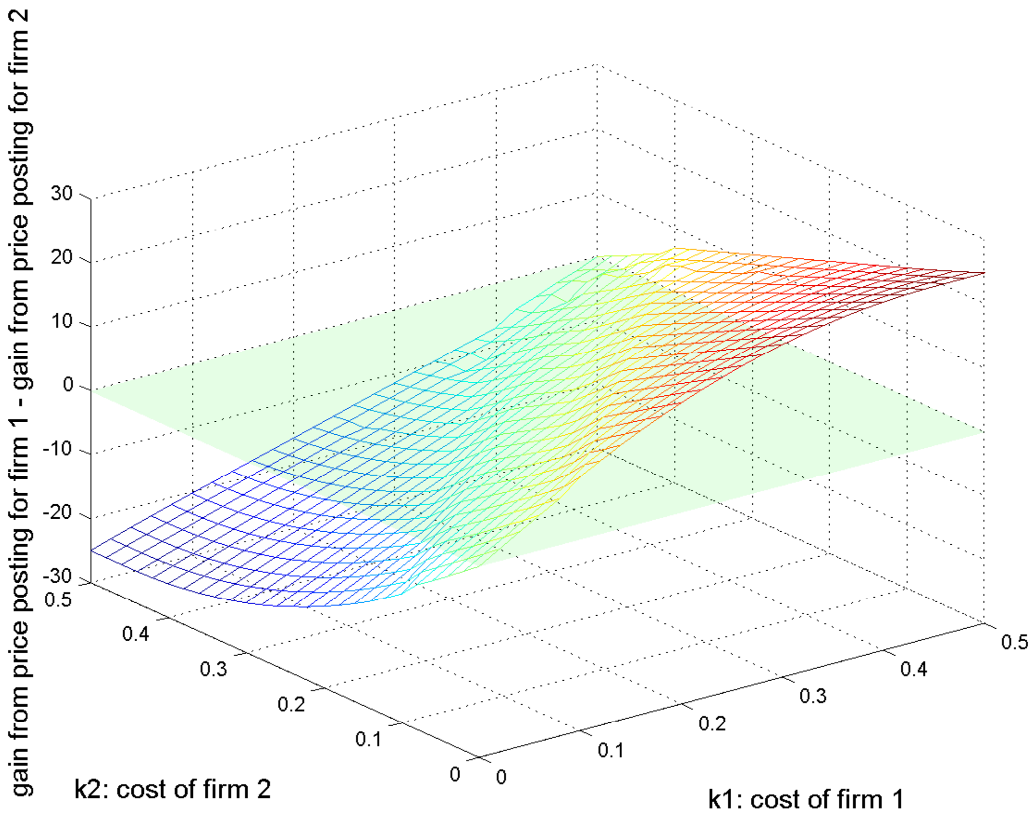

Figure A.3: Who Benefits More From Being The Only Price Poster? (K3=0.5, S=0.1, =0.99)

End of proof.

Proof of Theorem 3.2:

A firm has no incentive to post price if even being the only price poster is not more profitable than before. If no firm can gain from being the only price poster, no one will post price and the market will keep the status quo. From Corollary 2.1, we know that if the most efficient firm does not gain from being the only price poster, the other firms do not, either. Therefore, the restricted equilibrium with no firm posting price is the only equilibrium.

End of proof.

Proof of Corollary 3.2:

Define Δ_{12}^b as the difference in firm 1's profit from a Bertrand competition with firm 2 and its profit from hiding its price when firm 2 is posting its price, minus the difference in firm 2's profit from being the only price poster and its profit from hiding its price when no one posts price:

$$\Delta_{12}^b = [\Pi_1(110) - \Pi_1(010)] - [\Pi_2(010) - \Pi_2(000)]. \tag{A.24}$$

Here, $\Pi_1(110)$ is firm 1's profit from a Bertrand competition with firm 2, where firm 1 posts a price equal to firm 2's unit cost. So, $\Pi_1(110) = (K_2 - K_1)(1 - K_2) - F$. Similarly, we define Δ_{13}^b, where $1 \leq i < j \leq 3$.

$$\Delta_{13}^b = [\Pi_1(11*) - \Pi_1(001)] - [\Pi_3(010) - \Pi_3(000)]. \tag{A.25}$$

Again, F is irrelevant to Δ_{ij}^b and ρ only changes the magnitude of Δ_{ij}^b, not the sign and the relative value of Δ_{ij}^b.

From calculation on the same grid search, we find that at all these 2,500,000 points, $\Delta_{ij}^b > 0$ whenever $K_i < K_j$.

of **Theorem 3.3:** First, if the most efficient firm gets more profit from being the only price poster than in the market where no one posts price, no one posting price is not an equilibrium since the most efficient firm has incentive to deviate by posting its price.

Second, any restricted equilibrium with a less efficient firm being the only price poster can not be an equilibrium, either. Use firm 2 as an example. If firm 2 being the only price poster is an equilibrium, firm 2 must expect more profit from being the only price poster, i.e., $\Pi_2(010) - \Pi_2(000) > 0$. But from Corollary 2.2, we know that when the most efficient firm has enough cost advantage, $\Pi_1(110) - \Pi_1(010) > \Pi_2(010) - \Pi_2(000) > 0$, which means that firm 1 prefers competing against firm 2 by posting price to hiding its price while firm 2 posts price. So, firm 2 being the only price poster can not be an equilibrium. Same logic applies to firm 3.

Finally, the above strategy of firm 1 ensures that no other firm wants to deviate, and firm 1 does not want to deviate, either. From the construction of the restricted equilibrium we know that firm 2 and firm 3's prices are already their best response, given that they are not posting price. The construction of the restricted equilibrium also tells us that firm 2 or firm 3's total discounted profit from posting a price slightly lower than $P_1(100)$ is no more than zero. So, firm 2 or firm 3 has no incentive to post price, either. $P_1(100)$ is either the best response to $P_2(100)$ and $P_3(100)$, or the highest price firm 1 can post to prevent firm 2 and firm 3 from undercutting it. So, firm 1 can not do any better than posting $P_1(100)$, either. So, this is an equilibrium.

Combining the above discussion, we have the statement in Theorem 3.3.

End of proof.

Proof of Theorem 3.4: Define Δ_{ij}^{p} as the posted price in the restricted equilibrium where firm i is the only price poster minus the posted price in the restricted equilibrium where firm j is the only price poster.

$$\Delta_{12}^{p} = P_1(100) - P_2(010). \tag{A.26}$$

$$\Delta_{13}^{p} = P_1(100) - P_3(001). \tag{A.27}$$

$$\Delta_{23}^{p} = P_2(010) - P_3(001). \tag{A.28}$$

From calculation on the same grid search, we find that at all these 2,500,000 points, $\Delta_{ij}^{p} < 0$ whenever $K_i < K_j$.

End of proof.

Chapter B

Instructions for The Experiment

Instructions-General

You are going to participate in a market experiment today. In this experiment, you will be a seller. You will be randomly matched with two other sellers. The three of you will produce the same good X and sell them in the same market. There are 100 computer-simulated buyers in this market. A buyer's valuation upon one unit of good X, denoted by v, is uniformly and independently distributed between 0 and 100. The computer will play their optimal strategies.

There will be multiple treatments in this experiment. The number of periods in each treatment will be randomly chosen by the computer. Each period lasts for 3 minutes. You remain in the group with the same sellers throughout the experiment.

In each treatment, you will see a special instruction at the beginning. Then, you start with a trial period and then the official periods begin. You only get paid for what you earn in the official periods, but the trial period can help you learn how to use the experimental interface. In each period, you can enter your strategies and click "OK". The computer will calculate your expected demand and profit. You can choose a strategy from your calculated list by clicking it, and then click "confirm". Your confirmed strategies will affect expected demands and profits of other sellers in your group, and vice versa.

After the experiment, you need to answer a questionnaire. After finishing the questionnaire, you will receive your payment. Then, you may leave. All costs, prices, and profits are shown in experimental dollars. When you get paid, 1000 experimental dollars equal to 3 U.S. dollars.

Please do not talk to other subjects in the experiment or use cell phone. If you do, the experimenter will ask you to leave. If you have questions, please raise your hand and the experimenter will come to you. Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. If you decide not to participate in this study or if you stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify. However, you will only get paid for your performance in the experiment if you finish the whole procedure.

Please click OK when you finish reading the instructions.

Instructions-Treatment 1

In this treatment, you can set your price for one unit of good X. The price is not publicly posted. You will not see other sellers' prices, and they can not see yours. But their prices will affect your expected demand and profit, and your price will affect theirs.

Buyers need to pay some search costs to find out your price. A buyer can always decide whether to exit the market without purchase, or to buy one unit of good X at the lowest price she has discovered, or to keep searching. A buyer has unit demand. So after purchasing one unit of good, she will exit the market for sure. If a buyer decides to search, she will randomly discover the prices of sellers. For each search, she needs to pay a search cost s*v, where s=0.05 and v is her valuation on the good, which is uniformly distributed on [0, 100]. She can decide to search more than once, each time at the search cost s*v. Once she has discovered the price of one seller, she will not go to this seller again in any future random search. (Please refer to the first graph.)

You only produce the goods when you get the demand. That means you only pay the production cost for units sold. Your profit = (your price - unit cost) * your demand.

On the active screen, you will see your subject ID, your asset, your unit cost and the other two sellers' unit costs. They will see your unit cost, too. You can input a price and click "OK". The price has to be an integer between your unit cost and 100. You can input as many different prices as you want. After you input your prices, the computer will calculate your expected demand and profit for a 3-minute-length, if this is your chosen price for the whole period and other sellers do not make new decisions. They will be shown on the upper-right box in the order of expected profit. You can choose a price from your calculated list by clicking it (it will turn blue), and then click "confirm". Once you have confirmed a price, you start earning profit. Every 5 seconds, 1/36 of your current expected profit will be added to your asset. Your confirmed price will affect expected demands and profits of other sellers in your group, and vice versa. After a seller in your group confirms a new price, the computer will automatically update your expected demand and profit. Before the period ends, you can always change your decision by confirming a new price. Remember, your profit inflow is always proportional to your current expected profit, which is determined by all the three sellers' most recently confirmed prices. After each period, you will see your realized demand and profit. After 10 seconds, the next period will start automatically.

Shortly, you will start with a trial period, where you can learn how to use the experimental interfaces.

Please click OK when you finish reading the instructions.

Instructions-Treatment 2

In this treatment, you can set your price for one unit of good X and also decide whether or not to post your price.

If you post your price, buyers will know them immediately without paying any search cost. Otherwise, they need to pay some search costs to find out your price.

A buyer can always decide whether to exit the market without purchase, or to buy one unit of good X at the lowest price she has discovered, or to keep searching. A buyer has unit demand. So after purchasing one unit of good, she will exit the market for sure.

If a buyer decides to search, she will randomly discover the price of one seller who is not posting price. For each search, she needs to pay a search cost s*v, where s=0.05 and v is her valuation on the good. She can decide to search more than once, each time at the search cost s*v. Once she has discovered the price of one seller, she will not go to this seller again in any future random search. (Please refer to all the graphs.)

You only produce the goods when you get the demand. That means you only pay the production cost for units sold.

In each period, you will receive an endowment which can be used to cover the cost of posting your prices. Each time you decide to post your price, you need to pay 100 experimental dollars. So, if you have made many entries on posting prices, your posting cost may exceed your endowment. But your profit from sales may cover this cost, if you are successful. Your profit = endowment + (your price - unit cost) * your demand - cost of posting price if you decide to post your price.

On the active screen, you will see your subject ID, your asset, your unit cost and the other two sellers' unit costs, and the cost of posting a price. You can input a price posting decision (1 for yes, 0 for no) and a price, then click "OK". You can input as many different strategies as you want. After you input your strategies, the computer will calculate your expected demand and profit in 5 minutes, if this is your chosen price for the whole period and other sellers do not make new decisions. You can choose a strategy from your calculated list and then click "confirm". Once confirmed, the posted prices in your group will be seen by all the sellers in your group.

Everything else remains the same as in the last treatment.

Shortly, you will start with a trial period.

Please click OK when you finish reading the instructions.

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