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Limited Memory Consumers and Price Dispersion

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Abstract We examine the effects of limited consumer memory on the pricing strategies of competing firms. We show that when the valuations of consumers are heterogeneous, it is possible to observe price dispersion even when each firm charges a single price.

Keywords Bounded rationality · Categorization · Limited memory · Price dispersion

1 Introduction

A traditional assumption in the literature on imperfect competition is that consumers have perfect information about available prices. Hence, the consumers are able to recall the prices that they encountered during the search process. In a variety of interesting cases this assumption can be strong.[1] Previous research suggests that many consumers do not remember the price of a product that they just bought and often claim that the price was not an important input in their purchase decision (Wakefield and Inman 1993). However, they can tell whether the price of a product is expensive or not. This suggests that, faced with memory constraints, consumers make their decisions using heuristics that help them to process the information on prices.

[1] See Alba et al. (1991) for a survey regarding the effect of memory on consumer choice. See also Dickson and Sawyer (1990) and Monroe and Lee (1999) for papers on the effects of imperfect short-term memory on prices.

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A potential heuristic to process the information is categorization based on perceived similarities (Rosch and Mervis 1975). In this scheme, which we follow in this study, the consumers do not necessarily remember the prices of products but rather remember the price group in which the product is assigned by the consumer.

We consider a duopoly market in which firms compete for limited-memory consumers with uniformly distributed valuations. Hence, the valuations of consumers are heterogeneous. The consumer with limited memory of the offered prices is able accurately to compare the offers to her valuation; and she can only remember whether the price of the product at a firm is above her valuation or not. One potential explanation is that the consumer faces a budget constraint and knows whether she can buy the product or not at check-out. It is as if the consumers are indifferent among any prices that are offered, given that the price is below their valuations. It turns out that the only pure strategy Nash equilibria are the ones where firms charge different prices.

In a similar framework where the valuations of the consumers are homogeneous, Chen et al. (2010) provide some evidence for price dispersion. However, in their framework only a mixed-strategy equilibrium exists. Hence, the price dispersion is a product of the randomized behavior of firms. Our paper shows that even when the firms play pure strategies, price dispersion may happen if the valuations of the consumers are heterogeneous.

A prominent example where price dispersion is present is that of search models. Generally, in these models price dispersion is constructed as a way to justify consumer search. In contrast to these models, our model does not involve much search and price dispersion occurs as a result of memory limitations of the consumers.

The rest of this paper is organized as follows. In the next section, we provide a brief literature review. Section 3 presents our model and result. Section 4 concludes and provides a summary. The appendix provides the technical details.

2 Related Literature

One way to model bounded rationality is to impose some limitations on the information processing of the decision makers. The decision makers might be making some optimization mistakes or might be making decisions in a restricted environment. In the stochastic frontier literature the managers make optimization mistakes, which is considered as firm inefficiency (Kumbhakar and Lovell 2000). Another example is that of consumers with limited memories. Our paper is related to this literature where the consumers receive a signal but can only recall the category to which such a signal belongs. Hence, the consumer's response is the same for any signal that belongs to the same category.

Dow (1991) investigates a scenario in which the consumers optimally choose the partitions. Rubinstein (1993) considers a model in which a price-discriminating monopolist faces consumers who have different memory capacities. Chen et al. (2010) examine a setting where price distributions are a result of competitive equilibrium, which contrasts with the fixed price distribution assumption of Dow

(1991). They also allow for several segments of consumers that differ in their memory recall abilities. In their model, the equilibrium structure for the consumer is so that the categorization is finer toward the bottom of the price distribution. Therefore, the consumers devote more memory resources to encoding lower prices in order to induce firms to charge lower prices.[2] Carvalho (2009) considers a model where the consumers' imperfect recall on prices is modelled as a random shock (with mean zero) added to the real price. Price dispersion becomes a possibility because the consumers do not fully react to price differences.

Other potential ways to model limited memory or bounded rationality are to: consider consumers who cannot perfectly recall past decisions (Hirshleifer and Welch 2002); consider a model in which the sellers have bounded rationality (Baye and Morgan 2004); and develop a model in which competing firms face consumers that round the prices that they observe to the nearest dollar (Basu 2006). Besides these models, it has been shown that price categorization may fail to be optimal when firms choose complex price schemes and thereby manipulate price formats to make them artificially complex (Spiegler and Piccione 2012).[3]

Price dispersion may happen when the consumers are not fully informed about prices and information-gathering is costly. Salop and Stiglitz (1977) and Varian (1980) suggest price dispersion models that are called "clearinghouse" models by Baye et al. (2004). Unlike sequential search models (Diamond 1971), these models assume that the consumers obtain price information at once. The model of Varian (1980) assumes different information costs[4] which results in equilibria with price dispersion. Burdett and Judd (1983) show that equilibria with price dispersion may exist even with identical agents on both sides of the market.[5]

Finally, price dispersion maybe a result of price discrimination and heterogeneous producer costs.[6] Producers' costs maybe due to production costs, inefficiency, or shadow costs.[7] In general, price discrimination may be achieved when there is consumer heterogeneity. For example, in the airline context, the airlines price discriminate through a variety of means such as time of purchase or ticket restrictions. However, some part of the dispersion from these factors may be attributed to cost differences as well. While there is no consensus on the direction of the relationship between market power and price dispersion, it is widely accepted that there is a relationship between price dispersion and market power.[8]

[2] In the quantity setting price discrimination framework similar price dispersion patterns occur (Hazledine 2006; Kutlu 2009, 2012; Kumar and Kutlu 2015).

[3] Also, see Spiegler (2006).

[4] The low cost consumers obtain the information and high cost consumers remain uninformed.

[5] For a related survey see Hopkins (2008).

[6] Price discrimination refers to non-cost-related price dispersion. See Stole (2007) for a survey on price discrimination.

[7] See Kutlu and Sickles (2012) for a paper where all three of these factors are considered when modeling the costs of airlines.

[8] For example, Borenstein and Rose (1994) and Stavins (2001) suggest a negative relationship, Gerardi and Shapiro (2009) suggest a positive relationship, and Dai et al. (2014) and Chakrabarty and Kutlu (2014) suggest non-linear relationships.

3 The Model

In this section, we introduce our limited memory model. Consider two symmetric firms indexed by $j = 1, 2$ that sell a homogeneous product. The marginal cost is assumed to be constant and is set equal to zero. The market is composed of a unit mass of consumers with each consumer buying at most one unit of the product. The firms know the valuations of consumers and can prevent resale of the product. The valuations of consumers are uniformly distributed in the unit interval.

Consumers would like to buy from the firm that sets the lowest price. However, their memory is limited in the sense that they can only remember whether the price that is charged by a firm is below their valuations or not. Both firms and consumers are aware of consumers' memory limitations.

A consumer would know that she is not willing to buy the product from a firm if the price that is charged by this firm is above her valuation.[9] When the price is above the valuation of a consumer, this can be considered as the case where the consumer categorizes the price as "expensive." Similarly, if the price is below the valuation of the consumer, the consumer considers the product as "inexpensive."

The timing of the game is as follows: First, the consumer randomly picks a firm, say Firm 1, and checks the price that is charged by this firm, p_1. If the consumer goes to a second firm, say Firm 2, to check that firm's price, she only recalls whether p_1 was below or above her valuation, say v. Then, the consumer may check the price of the second firm, p_2.

If for both firms the prices are above the consumer's valuation, she does not buy the product. If for only one of the firms is the price below her valuation, the consumer buys the product from the cheaper firm. If for both firms the prices are below the consumer's valuation, she would perfectly observe p_2 and can only recall the fact that p_1 was below her valuation. We assume that the belief structure of the consumer is such that p_1, which she cannot recall, is the same as p_2. Hence, when at Firm 2 she would predict that $p_1 = p_2$.

Since the consumer is aware of her memory limitations, she realizes that she does not have to check the price of the second firm.[10] Therefore, the memory limitation leads to a model where the consumer buys from the first firm that she visits that charges a price that is below her valuation.[11] If the consumers' behavior is such that they consider any price below their valuation to be indifferent or they cannot distinguish among these prices, this would lead to the same equilibrium outcome.

When the firms charge prices that are less than 1, the profit depends on the relative magnitudes of the prices. If Firm 1 charges a price that is higher than Firm 2's price, the demand that corresponds to the consumers with valuation higher than p_1 is split. The firm with the lower price gets half of the consumers that are willing to buy from

[9] For more details about the demand structure and search mechanism see the "Appendix".

[10] Even if the search incurs a small cost, this improves the predicted payoff of the consumer. Hence, the consumer would prefer not searching.

[11] If the consumer is not forward looking, in the sense that she does not realize that checking the prices in another firm does not improve the outcome, the consumer buys from the last store that she visits that charges a price that is below her valuation. Hence, this leads to a model that involves some search by consumers. In any case, this does not affect the aggregate demand function and equilibrium prices.

anyone of the firms. It also gets the rest of the consumers who are not willing to buy from the high price firm but are willing to buy from the low price firm.

Our model is comparable to the no memory setting of Chen et al. (2010). In contrast to our model, they assume that the consumers' valuations are the same.[12] Hence, in their model, it is optimal for firms to price at the top of each price category. On the other hand, in our model the valuations of the individuals are heterogeneous. Therefore, a high price would result in a reduction in sales which may lead to a suboptimal profit.

We now provide our main result in Proposition 1: The proposition states that when the valuations of the consumers are heterogeneous, the only pure strategy Nash equilibria are such that the prices that are charged by the firms are different. Therefore, there would be price dispersion even when each of the firms charges a single price. Moreover, the profits of the firms are not the same.

Proposition 1 *If the consumers can recall only their valuations, then the equilibria prices and profits are given by:*

$$(p_1, p_2) = \left(\frac{1}{2}, \frac{3}{8}\right) \quad \textit{and} \quad (\pi_1, \pi_2) = \left(\frac{1}{8}, \frac{9}{64}\right)$$
$$(p_1, p_2) = \left(\frac{3}{8}, \frac{1}{2}\right) \quad \textit{and} \quad (\pi_1, \pi_2) = \left(\frac{9}{64}, \frac{1}{8}\right).$$

The reason for the presence of price dispersion is as follows: First, let the uniform price that maximizes the profit for a monopoly be p^M. For our linear demand model $p^M = 1/2$. If both firms charge a price of p^M, they will split the monopoly profit. Assume that there is an equilibrium without price dispersion so that the single price that is charged by the firms is p^S (i.e., $p_1 = p_2 = p^S$). We will illustrate that such an equilibrium does not exist. If the common price is greater than the monopoly price (i.e., $p^S > p^M$), one firm (say, Firm 1) would increase its profit by reducing its price to p^M. It continues to sell to half of the consumer mass that has a valuation of $v \geq p^S$, and it sells to all of the consumers whose valuation is below p^S but is at or above p^M. Hence, the profits of Firm 1 for different prices are summarized by $\pi_1(p^M, p^S) > \pi_1(p^M, p^M) > \pi_1(p^S, p^S)$. Indeed, for our linear demand setting, as long as at least one of the firms' price is above $1/2$, any firm with a price above $1/2$ would find that a reduction of its price to $1/2$ would increase its profits. Therefore, there does not exist an equilibrium such that $p_1 = p_2 > p^M$.

If both firms' prices are at p^M (i.e., $p^S = p^M$), then one firm (say, Firm 1) may find that a small decrease in its price would increase its profit. It continues to sell to half of the consumer mass that has a valuation of $v \geq p^M$ (albeit at a slightly lower price), and it sells to all of the consumers whose valuation is below p^M but is at or above the lower price. For our linear model, this price reduction yields a maximum

[12] They, however, extend their model by allowing heterogeneity in the memory capacities and adding uninformed (loyal) consumers.

profit at $p_1 = 3/8$, where this firm's profit is 9/64 $(= (3/8)(1/2)(1/2) + (3/8)(1/8))$. Therefore, there does not exist a single-price equilibrium such that this common price is the monopoly price, i.e., $p_1 = p_2 = p^M$.

Now, we argue that if the common price is lower than the monopoly price (i.e., $p^S < p^M$), then one firm (say, Firm 1) would find it profitable to increase the price. For any price $p_1 \geq p^S$, Firm 1 sells to half of the consumer mass that has a valuation of $v \geq p_1$. Hence, Firm 1 would get a higher profit by increasing its price to p^M.

Therefore, whenever the firms set a common price, one of the firms would be better off by deviating from this common price. This results in equilibria with price dispersion.

In particular, for our linear model, when $p_2 = 3/8$, the profit-maximizing price for Firm 1 is $p_1 = 1/2$. If both firms' prices are at levels that are below 1/2 but above 3/8, then the lower-price firm would find a price reduction to 3/8 to be profitable, while the higher-price firm would find a price increase to 1/2 to be profitable. The equilibrium prices for the two firms turn out to be 3/8 and 1/2, and the equilibrium profits are 9/64 and 1/8, respectively.

Finally, the line of reasoning that we have followed illustrates that price dispersion is not an artifact of the linear demand assumption. That is, price dispersion may occur even when the valuations of the consumers are not uniformly distributed.

4 Summary and Discussion

We examined the effects of limited-memory consumers on the pricing behavior of firms when the consumers have heterogeneous valuations. In our model a consumer can only recall whether the price of the product in a particular firm is above or below her valuation. The market is a duopoly where the firms know the valuations of the consumers.

Based on this information firms play a price choice game. It turns out that, at the equilibrium the firms charge different prices and have different profits. Chen et al. (2010) found a similar result when the valuations of the consumers are homogenous but in their setting a pure-strategy Nash equilibrium does not exist. Hence, price dispersion is achieved through randomized pricing.

One of the interesting properties of our model is that the consumers buy from the first firm that charges a price that is below their valuation. Hence, although the consumers can check the price that is charged by the other firm, they simply prefer not to do so. This property of our model contrasts with the dynamics of conventional search models.

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Appendix

Before proving our proposition, we provide the profit functions of the two firms. Let p_i be the price for Firm $i = 1, 2$. The profit of Firm 1 is characterized as follows (the profit of Firm 2 is specified in an analogous way):

$$\pi_1(p_1, p_2) = \begin{cases} \frac{1}{2}(1-p_1)p_1 & \text{if} \quad p_2 \leq p_1 \leq 1 \\ \left(\frac{1}{2}(1-p_2) + (p_2 - p_1)\right)p_1 & \text{if} \quad p_1 < p_2 \leq 1 \\ (1-p_1)p_1 & \text{if} \quad p_1 \leq 1 < p_2 \\ 0 & \text{if} \quad 1 \leq p_1 \end{cases}.$$

If Firm 2 charges a price that is too high, then the demand for Firm 1 would be equivalent to that of a monopoly: $\max\{(1-p_1)p_1, 0\}$. When firms charge prices that are lower than 1, the profit of each firm depends on the relative magnitudes of the prices.

If Firm 1 charges a price that is higher than Firm 2's price, then the demand that corresponds to the consumers with valuations that are higher than p_1 is split so that the demand for Firm 1 would be equal to $\frac{1}{2}(1-p_1)$. If Firm 1 charges lower than Firm 2, then it gets half of the consumers that are willing to buy from either of the firms – $\frac{1}{2}(1-p_2)$ – as well as the rest of the consumers who are not willing to buy from high price firm but are willing to buy from the low price firm, $p_2 - p_1$.

For the $p_1 < p_2$ case, $p_2 - p_1$ portion of the demand for Firm 1 comes from the consumers that are certain that they would not buy from Firm 2. On the other hand, $\frac{1}{2}(1-p_2)$ portion of the demand comes from the consumers that do not know which price is higher.

Proof *(Proposition 1)* Assume that the consumers are indifferent between all prices below their valuations. Hence, as long as the price of the product is below their valuations, the consumers buy the product. The equilibrium outcome would be equivalent to the case where the consumers are ignorant about the market so that each consumer randomly picks a firm and buys the product if the price is below her valuation. If the price is above the consumer's valuation, she checks the price that is charged by the other firm. Given p_2, Firm 1 can either set a price higher than (or equal to) p_2 and get $\pi_1 = \frac{1}{2}(1-p_1)p_1$ or set a price smaller than p_2 and get $\pi_1 = \left(\frac{1}{2}(1-p_2) + (p_2 - p_1)\right)p_1$. We refer to these strategies as up (U) and down (D), respectively. The optimal prices for up and down strategies are $p_1 = \max\left\{\frac{1}{2}, p_2\right\}$ and $p_1 = \min\left\{\frac{1+p_2}{4}, p_2\right\}$, respectively. When presenting the profits, we mention whether the relevant prices correspond to up or down strategies. There are three cases to consider.

Case 1:

$$p_2 \geq \frac{1}{2} \Rightarrow \pi_1\left(\frac{1+p_2}{4}, p_2; D\right) - \pi_1(p_2, p_2; U) = \frac{1}{16}(3p_2 - 1)^2 > 0.$$

Hence, firm 1 plays $p_1 = \frac{1+p_2}{4}$.

Case 2:

$$p_2 \leq \frac{1}{3} \Rightarrow \pi_1\left(\frac{1}{2}, p_2; U\right) - \pi_1(p_2, p_2; D) = \frac{1}{8}(1-2p_2)^2 > 0.$$

Hence, firm 1 plays $p_1 = \frac{1}{2}$.

Case 3:

$$\frac{1}{3} < p_2 < \frac{1}{2} \Rightarrow \pi_1\left(\frac{1}{2}, p_2; U\right) - \pi_1\left(\frac{1+p_2}{4}, p_2; D\right)$$
$$= \frac{1}{16}\left(-p_2^2 - 2p_2 + 1\right) > 0 \Leftrightarrow p_2 < \sqrt{2} - 1.$$

Therefore, if $p_2 < \sqrt{2} - 1$, firm 1 plays $p_1 = \frac{1}{2}$; and if $p_2 > \sqrt{2} - 1$, firm plays $p_1 = \frac{1+p_2}{4}$. The best response function of Firm 2 is similar. These findings indicate that the pure strategy equilibria are asymmetric and such that $(p_1, p_2) = \left(\frac{1}{2}, \frac{3}{8}\right)$ and $(p_1, p_2) = \left(\frac{3}{8}, \frac{1}{2}\right)$. Hence, one of the firms plays the up strategy and the other plays the down strategy. The profit for the firm that plays the up strategy is $\frac{1}{8}$ and the profit for the firm that plays the down strategy is $\frac{9}{64}$.

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