Price Discrimination in the Digital Economy*

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ABSTRACT

With the developments in information technology firms have more detailed digital information about their prospective and previous customers, which provides new mechanisms for price discrimination. In particular, when firms have information about consumers' previous buying behavior, they may be able to use this information to offer different prices and/or products to consumers with different purchase histories. This article discusses the effects of price discrimination based on more detailed customer information under monopoly and competition.

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1. Introduction

With the developments in information technology firms have more detailed digital information about their prospective and previous customers, which provides new mechanisms for price discrimination. In particular, when firms have information about consumers' previous buying or search behavior, they may be able to use this information to charge different prices to consumers with different purchase histories. This form of price discrimination is present in several markets and it may become increasingly more important with greater digitalization of the market transactions. The development of the information technologies and web-browser cookies allows firms to collect, keep, and process more information about consumers, and can affect the prices and products offered by firms to different consumers.

This article discusses the effects of price discrimination based on information gained by sellers from consumer purchase histories under monopoly and competition. When price discrimination is based solely on purchase histories, it is called behavior-based price discrimination. This article also discusses the effect of finer information at the customer level on price discrimination practices. Having more information about the consumers' product valuation (through purchase histories or other methods) helps the firm extract more surplus from the consumers. However, consumers may anticipate this possibility, and therefore alter their initial purchases. Firms may also be proactive in sorting consumers that purchase in the early periods in order to gain more information on their preferences. With competition, more information about consumers may lead to pricing as there were less product differentiation as firms target each separate price to a less heterogeneous consumer pool. This effect can lead to lower equilibrium prices. Nevertheless, competing firms can potentially benefit from customer recognition in spite

of lower equilibrium prices if the information leads to changes in the products sold - either higher sales of same-cost products or a switch of sales to lower cost products - or to sales to consumers who are less costly to serve.

This article follows closely the results by Hart and Tirole (1988), Schmidt (1993), and Villas-Boas (2004) on monopoly, and the results by Villas-Boas (1999) and Fudenberg and Tirole (2000) for competition, while discussing the effects of switching costs considered in Chen (1997) and Taylor (2003). For a more extended survey of the behavior-based price discrimination literature see Fudenberg and Villas-Boas (2006).[1]

The article is organized in the following way. The next section considers the potential short-term market effects of firms having more information about their consumers. We consider both the case of monopoly and of competition, and for each case we consider the possibility of no information being tracked, the possibility of information being solely based on purchase histories (with either fixed consumer preferences, changing consumer preferences or entry of new generations of consumers), and the possibility of firms learning the preferences of their customers through other channels in addition to purchase choices. Section 3 looks at the strategic behavior of consumers when they foresee that their purchase decisions affect the market opportunities available to them in the future, because of the information gained by firms. Section 4 discusses the strategic actions of firms when gaining information about consumers through their purchases. Section 5 discusses several extensions, and Section 6 concludes.

[1]Fudenberg and Villas-Boas (2006) discusses in further detail the market forces described here, and also discusses the effects of long-term contracts (including the relationship to durable goods and bargaining), multiple products and product design, switching costs, privacy concerns and credit markets. One important aspect of price discrimination in the digital economy that is not discussed here is that of bundling of information goods; see Choi (2011) for a survey of this literature. For a textbook treatment of behavior-based price discrimination see Belleflamme and Peitz (2010).

2. Information about Consumers

Consider a firm selling a product to a set of heterogeneous consumers of mass one. Suppose consumers have a valuation for the product v with cumulative distribution function $F(v)$, density $f(v)$, with the property that $v[1-F(v)]$ is quasi-concave in v. Suppose marginal costs are zero, and consider the firm being able to know something about the valuation of some consumers, and being able to charge consumers differently depending on its information. Suppose also that there are no strategic issues about the firm learning more from consumers in this purchase occasion, and that consumers are not concerned about any effects on its future payoffs of their decisions to buy or not to buy at this purchase occasion. This can be seen as the ex-post situation after the firm learned something about the consumers in the previous periods. This can also be seen as the situation in the second period of a two-period model, where the firm learned something from the consumers that bought in the first period.

There are several modeling possibilities of what the firm knows about the valuation v of each consumer. One possibility is that the firm does not know anything about the valuation of each consumer and just knows that the cumulative distribution of v is $F(v)$. This could be the case when the firm is not able to keep track of which consumers bought the product in the previous period or there are no information technologies to keep track of the consumer purchase histories. This could also be the case if the valuations of each consumer were independent over time. In this "no information" case, as the firm does not know anything about v per consumer, the firm just charges a price p which is the same for all consumers. Since consumers are not concerned about the firm learning their valuation while purchasing the product, they buy the product as long as $v \geq p$. The profit-maximizing price p is then the optimal static monopoly price $p^* = \arg\max_p p[1-F(p)]$.

Another possibility is that consumers have the same valuation from period to period, and entered the market in the previous period, and the firm is able to identify which consumers bought the product in the previous period (with consumers being around for two consecutive periods).[2] Suppose that there was a demand x in the previous period and that the consumers who bought the product in the previous period are the ones with the highest valuation. Then, we know that all consumers who bought in the previous period have valuation greater or equal to some valuation v^* which is determined by $x = 1 - F(v^*)$.

The firm can then charge two prices, one price for the consumers who bought in the previous period, which the firm knows to have valuations above v^*, and another price for the consumers that did not buy in the previous period, which the firm knows to have valuation less than v^*. Let us denote the price to the consumers who bought in the previous period as p_o, and the price to the new consumers as p_n. For the price to the previous customers, if $v^* \geq p^*$ then the firm just charges $p_o = v^*$, as the optimal price for those consumers without any constraints on their valuations would have been p^*. For the same reason, if $v^* < p^*$ then the firm chooses to charge $p_o = p^*$. One can then write $p_o = \max[v^*, p^*]$, which considers both cases.

For the price to the new consumers the firm chooses to charge $p_n = \arg\max_p p[F(v^*) - F(p)]$, which accounts for the fact that the firm is only targeting the consumers with valuation below v^*. Considering both the price to the previous customers and the price to the new consumers, the firm is better off in this period with the ability to identify the consumers that bought in the previous period, as it is able to better extract the consumer surplus

[2] The previous period consumer decisions are considered in the next Section.

through price discrimination. This is a continuous setup of the two-type model considered in Hart and Tirole (1988) and Villas-Boas (2004).

One variation of this possibility is that consumers' valuations change through time. When this happens the firm may potentially want to charge a lower price to the consumers who purchased in the previous period, and a higher price to the new customers. One example of changing preferences is one where with some probability ρ consumer change preferences from one period to the next, and in the next period the consumer's valuation is an independent draw from the distribution $F(v)$. Consider the effect of this on the profit-maximizing price for the previous customers. If $v^* \geq p^*$, the firm's profit from the previous customers for a price $p_o \leq v^*$ is $p_o\{(1-\rho)[1-F(v^*)]+\rho[1-F(v^*)][1-F(p_o)]\}$. One can obtain that for sufficiently small ρ we have the optimal $p_o = v^*$. After a certain threshold value of ρ, the optimal price for the previous customers, p_o, starts decreasing from v^* with increases in ρ, and keeps on decreasing until it reaches p^* when $\rho = 1$. If $v^* < p^*$, the optimal price for the previous customers is always p^*, independent of ρ. Regarding the price for the new customers, the firm's profit from the new customers is $p_n\{(1-\rho)[F(v^*)-F(p_n)]+\rho F(v^*)[1-F(p_n)]\}$. One can then obtain that the optimal p_n is increasing in ρ, reaching p^* when $\rho = 1$. Note that a firm is still strictly better off with this possibility of identifying its past consumers as long as $\rho < 1$.

Another interesting variation is the case when a new generation of consumers comes into the market, so that the firm knows that some of their new consumers may have a high valuation for the product, and may be in the market for future periods. This case is considered in Villas-Boas (2004) with overlapping generations of consumers. In comparison to the model above, this

variation adds a force for the firm to raise the price charged to the new consumers, as some of the new potential consumers have a high valuation for the firm's product.

Finally, another possibility is that the firm is able to learn something about the valuations of the consumers that bought from it, and charge them differently because of their valuation. Note that this case is not "pure" behavior-based price discrimination as in the case above. In the case above, the firm only learns whether a consumer valuation is such that a consumer makes a certain choice (either buy or not buy). In some cases a firm may be able to learn something more about a consumer's valuation from a consumer that bought the product. For example, a consumer who chose to buy the product may reveal to the firm during the purchase process some information about her/his preferences and valuation, perhaps during the exchange of information with a salesperson, or the interaction of the consumer with a web site through the search process, or after the purchase during the servicing of the consumer.

In addition to learning about a consumer's valuation, the firm may learn about the cost of servicing the consumer. This can be particularly important in insurance or credit markets, where a firm may learn after purchase whether a customer is more or less likely to have an accident, or more or less likely to default on its debt. It can also be important in markets where customers can vary in the cost of servicing their purchases. For example, a cell telephone company knows how often each of its customers calls their service center while it does not have that information for non-customers. In these cases a firm can benefit even more in this period from having information on the consumers who bought in the previous period.

An extreme version of learning about the previous customers' valuations is when the firm learns all the valuation of the consumers that bought the product, and can perfectly price discriminate between them. In this case, previous consumers with valuation $v \geq v^*$ would each

be charged a price $p_o(v) = v$, each ending up with zero surplus in this period. For consumers with valuation $v < v^*$, the ones that did not purchase in the previous period, the firm does not know the consumers' valuation, and therefore the price that they are charged is the same as obtained above, $p_n = \arg\max_p p[F(v^*) - F(p)]$. In this case, consumers end up with lower surplus after revealing their preference information, and the seller is better off, than in the case where the seller has only information about the consumer purchase histories.

Competition

Consider now a variation of the model where there is competition, as in Fudenberg and Tirole (2000) and Villas-Boas (1999). Suppose that we have a duopoly with Firms A and B competing in a market. A consumer with valuation v for Firm A has valuation $z - v$ for Firm B, where z is a constant, and such that $2v$ represents the relative preference of a consumer for good A over good B. Denoting the support of v as $[\underline{v}, \overline{v}]$, the two firms are symmetric if $z = \overline{v} + \underline{v}$, and $f(v)$ is symmetric around $\frac{\overline{v} + \underline{v}}{2}$, which we assume. Suppose also that $\underline{v}$ is high enough such that the full market is covered. Then, as above, suppose conditions under which (1) firms do not know anything about the consumers' valuations, (2) firms can identify the consumers that bought from them, or (3) consumers learn the valuations of the consumers that bought from them.

If firms do not know anything about consumers valuations they will just set one price for all consumers. For Firm A, charging price p_A, with the competitor charging the price p_B, the demand is $1 - F(\frac{z - p_B + p_A}{2})$. We can obtain similarly the demand for Firm B, and obtain that

in equilibrium, $p_A^* = p_B^* = \frac{1}{f(z/2)}$. For the case where $F(v)$ is the uniform distribution this reduces to $p_A^* = p_B^* = \overline{v} - \underline{v}$.

If firms are able to identify the consumers that bought from them in the previous period, consumer preferences remain unchanged, and there are no new consumers in the market, a firm may know that the consumers that bought from it have a relative preference for its product, and may then be able to charge one price to its previous customers, and another price to the previous customers of the competitor. Given the demand that a firm obtained in the previous period, it can identify that the threshold valuation of a consumer that bought from it in the previous periods. Denote this threshold valuation as v^*, the valuation for Firm A, such all consumers with valuation $v > v^*$ for Firm A chose Firm A, and all consumers with valuation $v < v^*$ for Firm A chose Firm B (as, by definition, their valuation is greater than $z - v^*$ for Firm B). We can then separate the problem in finding the equilibrium within the previous customers for Firm A, and within the previous customers for Firm B.

For the previous customers of Firm A, Firm A can charge price p_{oA} and Firm B can charge price p_{nB}. The price for Firm A of maximizing the profits from its previous customers is determined by $p_{oA} = \arg\max_p p[1 - F(\frac{z - p_{nB} + p}{2})]$ and the one for Firm B is determined by $p_{nB} = \arg\max_p p[F(\frac{z - p + p_{oA}}{2}) - F(v^*)]$. Solving these two equations together one can obtain the equilibrium prices. For example, for the uniform distribution example one can obtain $p_{oA} = \frac{4\overline{v} - z - 2v^*}{3}$ and $p_{nB} = \frac{2\overline{v} + z - 4v^*}{3}$. Under general conditions (for example, satisfied by the uniform distribution) one can obtain that in equilibrium p_{nB} is smaller than p_{oA}, and that

p_{oA} is smaller than the equilibrium price under no information, p_A^*. The intuition for the first result is that Firm B has to price lower because it is trying to attract consumers that have a higher preference for Firm A. The intuition for the second result is that Firm A's price has to respond to a lower price from Firm B, and given strategic complementarity in prices, Firm A's price is lower than the no information equilibrium prices. A similar analysis can be obtained for Firm B's previous customers. As the market is fully covered, we can then obtain that all consumers pay a lower price than in the no-information case, and that industry profits in the current period (second period of a two-period model) are now lower. That is, after learning the information about consumers, competition leads to lower profits, while the result was different under monopoly. This is for example the result in Fudenberg and Tirole (2000). This result is similar to the one in competition with third-degree price discrimination, where there is a market force leading to lower profits than in competition with uniform pricing, because there is now less differentiation across firms for the consumers being served for each pair of prices. An example of this is Thisse and Vives (1998), where firms know the exact location of the consumers and compete with location-based price discrimination. Note also that this result is for the industry profits after the information is revealed. It may still be possible in this setting that the present value of industry profits is greater when considered before information is obtained from consumers, if consumers foresee that their choices in the earlier periods affect the offers that they will get from the firms in future periods. This effect is studied in Section 4 below.

One particular characteristic of the framework above is that firms know as much about their previous customers as about the previous customers of the competitors. That is, if a new consumer approaches a firm the firm knows that the consumer was a customer of the competitor in the previous period. One way to take out this characteristic from the model is to allow new

generations of consumers to come into the market as considered in Villas-Boas (1999). In that case, a firm knows that a pool of new consumers is composed of old consumers that do not have a high valuation for its product (and a high valuation for the competitor), and by a new generation of consumers, where several of them may have a high valuation for the firm's product. This is then a force for the firm to charge a higher price to its new customers (as some of them may have a high valuation), which then, by strategic complementarity of prices, leads the competitor's price to its previous customers to be higher.

Another variation, as considered above for the monopoly case, is that a fraction of consumers change preferences from the previous period to the new period (e.g., Chen and Pearcy, 2010). That is, some of a firm's previous customers may now have a lower valuation for the firm's product than in the previous period, and some of the competitor's previous customers may now have a higher valuation for the firm's product. This will then lead the firm, in comparison to the case when the preferences do not change, to lower the price for its previous customers, and raise the price to its new customers.

Another possibility for a firm to learn about its previous customers' valuations, also as discussed above for the monopoly case, is to learn something about the valuation of each consumer during the purchase process or when servicing the consumer post-purchase, for the consumers that bought from the firm. An extreme version of this case is when the firm learns perfectly the valuation of its previous customers. For Firm A, the price for a previous customer with a valuation v would then be the price (if greater than its marginal costs) that it would lead that consumer to be just indifferent between purchasing the product from Firm A at that price, and purchasing the product from Firm B at its price for the new customers. That is, $v - p_{oA}(v) = z - v - p_{nB}$. Note that if $v^* < \frac{\overline{v} + \underline{v}}{2}$, the competitor would find it profitable to attract

some of the previous customers of Firm A, as Firm A does not charge a price below its marginal cost. If we have $v^* = \frac{\overline{v} + \underline{v}}{2}$, then the equilibrium involves $p_{nB} = 0$ (as marginal costs are assumed equal to zero) and $p_{oA}(v) = 2v - z$. For the uniform distribution case one can still obtain that in this case profits are lower than in the no information case. One can however consider variations of this model where the firms' learn the profitability of their previous customers (e.g., insurance markets, credit markets), which can potentially lead to more information leading to ex-post greater profits, as the informed firm may be able to extract more surplus from the different consumers (see, for example, Shin and Sudhir, 2010, for a study along these lines).

3. Strategic Behavior of Consumers

The activities of the firms considered in the previous section, namely using information gained from consumers through their purchase decisions, are contingent on those decisions, which raises the possibility that consumers may understand that the decisions that they take may affect the options that they will have available in the future periods. In this section we assume that the firm does not have any information about any individual consumer prior to that consumer's decision, and further assume that the firm only uses this information for one more period after this consumer's decision (as in the analysis in the previous section). This could be seen as the consumer entering the market in this period and staying in the market for only two periods. The consumers discount the next period payoff with the discount factor $\delta_C \leq 1$.

A consumer considers whether to buy the product now at a price p_f and be offered a price p_o in the next period, or not to buy it this period, and be offered the product in the next

period at the price p_n. If a consumer with valuation v buys the product in this period and next period, he gets a surplus $v - p_f + \delta_C(v - p_o)$. If the consumer decides not to buy this period, he will get a surplus $\delta_C \max[v - p_n, 0]$. As noted in the Section above, the marginal consumer who is indifferent between buying and not buying in the current period, v^*, ends up with zero surplus in the next period, because it faces a price $p_o \geq v^*$. Then the valuation v^* of a consumer indifferent between buying and not buying in the current period is determined by

$$v^* - p_f = \delta_C \max[v^* - p_n, 0].$$

From this it is clear that if, for some reason, the price to the new consumers is expected to increase in the next period, $p_n \geq p_f$, then all consumers with valuation greater than the current price charged, p_f, should buy the product. Therefore, in this case we have $v^* = p_f$. This can occur, for example, when there is entry of new consumers in the next period, such that the firm chooses to raise its price to the new consumers. Villas-Boas (2004) shows that in such a setting the equilibrium involves price cycles, where in some periods the price to the new consumers is indeed higher than the price to new consumers in the previous period.

If, on the other hand, the consumers expect the price to the new consumers to be lower next period, $p_n < p_f$ (which, as shown in the section above, happens when there is no entry of more consumers next period), then consumers will be strategic, and there are some consumers with valuation above the current price p_f who prefer to wait for the next period, because they get a better deal next period. In this case the valuation of the marginal consumer indifferent between buying and not buying in the current period can be obtained as $v^* = \frac{p_f - \delta_C p_n}{1 - \delta_C} > p_f$. Consumers with valuation $v \in [p_f, v^*]$ would buy the product if they were myopic, but do not

buy if they are strategic. This effect may hurt the firm, as fewer consumers buy in this period when the firm is able to practice behavior-based price discrimination, than when the firm does not keep information of the consumers that bought from it. This is known as the "ratchet effect" of the consumers loosing surplus (i.e., being charged a higher price) by revealing some information about their valuations (Freixas et al., 1985).

If the firm is able to learn something about the valuation of each consumer during the purchase process, then the marginal consumer if buying in the current period also ends up getting zero surplus in the next period, and therefore, the valuation of the marginal consumer buying in the current period is obtained in the same way.

In another variation of the model mentioned above, if preferences change through time, then a marginal consumer buying in the current may have a positive surplus in the next period if his preferences change to higher valuation than the price to the previous customers. Because some of the previous customers may lower their valuation the firm may also lower its price to the previous customers. These two effects are a force for more consumers to be willing to buy at a given price in the current period (lower price and consumers are less likely to have zero surplus in the next period of buying in the current period). In the extreme case where valuations are completely independent from period to period, the problem of the seller ends up being like a static problem in every period, and all consumers with valuation above the price charged in a current period buy the product in that period.

Competition

Under competition, if the firms are not able to identify their previous customers, then customers make choices in each period as if there are no future effects, and the market equilibrium is as characterized above for the no information case.

If the firms are able to identify their previous customers, then in the competition model of the section above, a marginal consumer has to decide between buying from Firm A and getting the competitors' product in the next period at the price for its new customers, getting a surplus of $v - p_{fA} + \delta_C(z - v - p_{nB})$, and buying from Firm B and getting product A in the next period at the price of its new customers, getting a surplus of $z - v - p_{fB} + \delta_C(v - p_{nA})$. The valuation v^* for product A of the consumer indifferent between buying either product in the current period has then to satisfy making these two surpluses equal, leading to $(2v^* - z)(1-\delta_C) = p_{fA} - p_{fB} + \delta_C(p_{nB} - p_{nA})$ where p_{nA} and p_{nB} are also a function of v^*, given the analysis in the Section above. From above, if the marginal consumers decide to buy product A in the current period instead of product B, then they know that Firm B will charge a higher price to new consumers in the next period (as those new consumers have now a greater preference for Firm B). That means that a price cut by Firm A in the current period leads to fewer consumers switching to product A than if the next period prices were fixed, as consumers realize that by switching they will be charged a higher price in the next period from the product that they will buy, product B. That is, the possibility of behavior price-discrimination in the future makes the consumers less price sensitive in the current period. For the uniform distribution example we can obtain $2v^* - z = \frac{p_{fA} - p_{fB}}{1 + \delta_C / 3}$, where the demand for product A is composed of consumers with a valuation for product A of $v \geq v^*$. This lower price sensitivity may lead then to higher prices in the first period, as discussed in the next Section.

When some of the consumers' preferences change from period to period the results above continue to hold, but we get closer to the no information case.

When there is entry of new consumers, as described in the Section above, the effect of current demand realization on future prices for new consumers is reduced. In that case, demand may become more price sensitive when firms can identify their previous customers. This is because the consumers at the margin know that they switch products from period to period. Then, their problem is the one in which order to get the products: product A in the current period followed by product B in the next period, or the reverse order. In the steady state of a symmetric equilibrium in an overlapping generations model, consumers become less concerned about this order as their discount factor δ_C increases, so they become more and more price sensitive (Villas-Boas, 1999). This effect is also present in the case where there is no entry of new consumers, but in that case the effect mentioned above of greater prices in the next period for switching consumers dominates.

When firms learn the consumers' exact valuations from their previous customers, the marginal consumers in a symmetric equilibrium end up with a surplus equal to $v^* = \frac{\overline{v} + \underline{v}}{2}$, as the poaching price is zero and a firm charges a price equal to $2v - z$ to its previous customers in the next period, as presented in Section 2 above. In this case, for the symmetric market, the marginal consumers who switch to product A know that they will be able to buy product B at a price that is below what they would get if they stayed with product B. This means that in this case the demand is more price sensitive when charging a lower price in the current period than in the case when firms did not learn about the valuations of their previous customers. For the uniform example, if $p_{fA} < p_{fB}$, we have the marginal valuation for product A that buys product A in the

current period defined as $z - 2v^* = \frac{p_{fB} - p_{fA}}{1 - \delta_C / 2}$. This shows for the uniform case that demand is more price sensitive than when firms do not learn about the valuations of their previous customers.

4. Firms Gaining Information About Consumers

Now we consider the strategic decisions of the firms when their decisions change the information that firms gain in the current period. In order to focus exclusively on the strategic effects of gaining information, suppose that the firm does not currently know anything about the consumers' valuations, and that it will only use the information obtained now for the next period, where payoffs will be discounted with discount factor δ_F. Note that if no information is gained by the consumers' choices, there are no dynamic effects and the firm's decision is exactly as considered in Section 2 above for the no information case.

Monopoly

We will first examine the impact of various information structures under monopoly.

Consider the case where the seller in the next period is able to recognize its previous customers so that it knows that their valuation for the product is above a certain threshold, and that the valuation of the other consumers is below that threshold. The problem of the seller (if the price to the new consumers falls in the next period, which can be shown to hold) is then

$$Max_{p_f} \, p_f [1 - F(\frac{p_f - \delta_C p_n(p_f)}{1 - \delta_C})] + \delta_F \pi_2(p_f)$$

where $p_n(p_f)$ is obtained as described in Section 2 as $\arg\max\, p[F(\frac{p_f - \delta_C p_n(p_f)}{1-\delta_C}) - F(p)]$, and $\pi_2(p_f)$ is the profit in the next period, which, given the analysis in the Sections above, can be presented as

$$\pi_2(p_f) = \max_p\, p[1 - F(\max[p, \frac{p_f - \delta_C p_n(p_f)}{1-\delta_C}])] + \max_p\, p[F(\frac{p_f - \delta_C p_n(p_f)}{1-\delta_C}) - F(p)]$$

where the first term represents the profit next period from the consumers that purchased the product also in the current period, and the second term represents the profit next period from the consumers that did not purchase the product in the current period.

For the case when firms and consumers discount the future in the same way, $\delta_C = \delta_F = \delta$, one can show that at the optimum the valuation of the marginal consumers choosing to purchase in the current period, v^*, is strictly greater than the valuation of the marginal consumers. As discussed above, this is because consumers are aware that prices may fall in the future, and therefore prefer to wait for the lower prices rather than buy now and also be charged a high price in the next period. It can also be shown under these conditions, and for the same reason, that the present value of profits is lower in this case than when the firm does not keep information about who are its previous customers. That is, in a monopoly setting, a firm knowing whom its previous customers are can have lower profits.

As noted above, a variation of this possibility is when some consumers' preferences change from this period to the next. In this case, the results above continue to go through, but we now get closer to the no information case.

Another possibility is that there is entry of new consumers in the next period and the firm faces a market consisting of overlapping generations of consumers with each generation coming

into the market in each period. In such a setting, a low price for new consumers satisfies all the existing low valuation consumers and may be followed in the next period by a high price for new consumers to take advantage of the new high valuation consumers coming into the market in the next period. Villas-Boas (2004) shows that this is indeed the case and that the equilibrium involves price cycles in both the prices to the new and previous customers. In periods when the firm charges low prices to new consumers, they know that the next period price is higher, and then they all buy in that period as long as their valuation is above the price charged. In periods when the firm charges high prices, consumers know that the next period prices to new consumers will be low, and therefore some consumers with valuation above the price charged decide not to buy.

Another interesting issue to consider is what happens when consumers live as long as firms. Hart and Tirole (1988) consider this case when consumers can be of only two types. They find that if the discount factor $\delta > 1/2$ there is no price discrimination when the horizon tends to infinity, with the firm charging always the low price. The intuition is that if the high valuation consumer ever reveals his valuation he will get zero surplus forever, and if there were an equilibrium where the high valuation consumer would buy at a price above the lowest price, he would gain from deviating and being seen as a low valuation consumer forever. Schmidt (1993) considers a variation of this setting where the seller is the one with private information (on its costs), with a discrete number of consumer types (possibly more than two types), and focusing on the Markov-perfect equilibria. The results there can also be presented in terms of private information by the consumers. In that case, the result is as in Hart and Tirole - there is no price discrimination as the horizon tends to infinity. The intuition is that if consumers are given a

chance to build a reputation that they have a low valuation they will do so (see also Fudenberg and Levine 1989).

Another interesting variation of randomly changing preferences is considered in Kennan (2001). There, a positive serial correlation leads to stochastic price cycles as purchases reveal a high consumer valuation, which is followed by a high price, while no purchases reveal low consumer valuation, which is followed by low prices.

Another possibility discussed in the Sections above was the case where a firm when serving the customers that choose to purchase also learns their valuation. In that case consumers are also strategic in the current period, and the firm is hurt by the reduced number of consumers that decide to buy in the current period. However, because now the firm is able to extract in the next period all the valuation from the consumers that purchase in the current period, the present value of profits can actually be higher with this ability to learn the valuation of its previous customers.

Competition

We discuss now the effect of competition within the competition framework described in Section 2. When the firms are not able to recognize their previous consumers we are back to the no information case, and the market equilibrium is as characterized in Section 2 for that case.

If firms are able to recognize their previous customers while noting that consumers that choose their product have a valuation above a certain threshold, we can use the analysis in the two Sections above to set up the problem of each firm. In order to present sharper results let us focus on the case of the uniform distribution of consumer valuations. The problem for Firm A can then be set as

$$Max_{p_{fA}} p_{fA}[1-F(v^*(p_{fA}, p_{fB}))]+\delta_F \pi_2^A(p_{fA}, p_{fB})$$

where $v^*(p_{fA}, p_{fB})$ is the valuation for product A of the marginal consumer choosing product A in the current period, as computed in Section 3 above, and $\pi_2^A(p_{fA}, p_{fB})$ represents the next period profit for Firm A given the current period prices. For the uniform distribution, as we obtained in Section 3, we have $v^*(p_{fA}, p_{fB}) = \frac{z}{2} + \frac{p_{fA} - p_{fB}}{2(1+\delta_C/3)}$. Given this we can then write $\pi_2^A(p_{fA}, p_{fB})$ given the analysis of Section 2 of the equilibrium in the next period given v^*. Note that $\pi_2^A(p_{fA}, p_{fB})$ is composed of both the profits from Firm A's previous customers and the profits from Firm B's previous customers.

In such a setting one can then show that the first period prices are higher than in the no information case. This is because the current period demand is less elastic than when there is no behavior-based price discrimination, as discussed in Section 3, because consumers know that if they do not switch the firm will offer them in the next period a lower price (a price to the new consumers in the next period). Note also that in this setting, and in relation to the symmetric outcome, if firms had more or fewer customers they would be better off in the next period. For the uniform distribution these two effects cancel out in the two-period model, and the first-period prices end up being independent of the firms' discount factor (Fudenberg and Tirole 2000).

If some of the consumer preferences can change from this period to the next, the results presented here would go through, but now the equilibrium prices would be lower and closer to the case where there cannot be behavior-based price discrimination.

Another interesting possibility is when there is entry of new consumers in each period in a set-up with overlapping generations of consumers, such that in each period new consumers for a firm could be either previous customers from the competitor or new consumers to the market.

In this situation one has to fully consider the dynamic effects over several periods of the pricing decisions in the current period (Villas-Boas 1999). One result is that the prices to the new consumers end up being below the ones in the case with no behavior-based price discrimination if the consumers care enough about the future. This is because the demand from the new consumers is more elastic than in the case when no information is collected because the marginal consumers are just deciding the order in which they buy the different products, given that the marginal consumers switch products in equilibrium.

Another possibility, along the lines discussed in the Sections above, is when firms are able to learn the valuation of their previous consumers during the purchase process. In this case competing firms can potentially gain more from learning the valuation of consumers than not learning, which could be a force for greater competition for consumers.

5. Discussion and Related Topics

The results above concentrate on the case where the firms can only offer short term contracts. In some cases firms may be able to attract consumers with the promise of guaranteed future prices. Hart and Tirole (1988) consider this situation in a monopoly setting, and show that with such contracts the seller is able to sell to the high valuation consumers at a price above the valuation of low valuation consumers, because it is able to commit to an average price in future periods that does not extract all the surplus from the high valuation consumers. Hart and Tirole also show that the outcome obtained is the same as if the seller were selling a durable good.[3] This also shows that behavior-based price discrimination in a monopoly setting leads to a lower present value of profits than in the case of a monopolist selling a durable good. Battaglini (2005)

[3] Hart and Tirole also discuss what happens under commitment. See also Acquisti and Varian (2005) on the comparison of commitment with non-commitment. Acquisti and Varian consider also the effect of the seller offering enhanced services.

considers the case of long-term contracts with two types of infinitely lived consumers with preferences changing over time (as in Kennan 2001) and continuous consumption. He shows that in the optimal contract the efficient quantity is supplied in finite time (after the type of the consumer is the high valuation type).

Fudenberg and Tirole (2000) consider the effect of long-term contracts in competition in a two-period model. They show that long-term and short term contracts co-exist in equilibrium, with some consumers taking short-term contracts, and that there is less switching in equilibrium when long-term contracts are possible. The intuition for this last result is that the existence of long-term contracts (purchased by consumers with more extreme preferences) leads firms to be more aggressive (lower prices) in their short-term contracts, which yields less switching.

Under competition and short-term contracts, Esteves (2004) and Chen and Zhang (2009) consider the case when the distribution of valuations is in discrete types. In this case, the equilibrium involves mixed strategies. Esteves considers the case with two consumer types, each having a preference for one of the competing firms, and myopic consumers, and finds that first period prices tend to fall when the discount factor increases. Chen and Zhang consider the case with three consumer types, with one type that has the same valuation for both firms, and two other types that have extreme preferences for each firm. In this set-up expected prices in the first period are higher even when consumers are myopic, as a firm that sells more in the first period is not able to discriminate in the next period between the consumer types that can consider buying from that firm.

Another interesting issue to consider under competition is that in some markets where firms can practice behavior-based price discrimination, consumers have also switching costs of changing supplier. Note that switching costs alone can lead to dynamic effects in the market as

studied in the literature.[4] The effects of the interaction of switching costs with behavior-based price discrimination are studied in Chen (1997) and Taylor (2003). Chen considers a two-period model and shows that with switching costs, behavior-based pricing leads to rising prices over time. Taylor considers the case of multiple periods and shows that prices are constant over time until the last period, and shows that moving from two firms to three firms, there is aggressive competition for the switcher consumers. In addition, Taylor considers the case when the firms may have some prior information about the switching costs of different consumers.[5]

On a related topic, firms could also offer different products depending on the purchase history of consumers. Some results on these effects are presented in Fudenberg and Tirole (1998), Ellison and Fudenberg (2000), and Zhang (2010).

When studying the effects of price discrimination based on purchase history, one can also think of the implications for privacy concerns. For studies on the effects on privacy along these and related dimensions see, for example, Taylor (2004a, 2004b), Calzolari and Pavan (2006), and Ben-Shoham (2005).[6]

In some markets, firms also learn consumer characteristics that directly affect cost of servicing them. This is for example the case in credit markets, insurance markets, and labor markets. It is also the case when the costs of servicing customers are heterogeneous across consumers, and are learned through interaction with them. In the digital economy these aspects can become important with after-purchase service and the possibility of returns.

[4] See, for example, Farrell and Klemperer (2007) for a survey of the switching costs literature.
[5] For the analysis of the second period of a model with switching costs see Schaffer and Zhang (2000). Dobos (2004) considers the case of horizontal differentiation, switching costs, and network externalities. See also Villanueva et al. (2007) on the effect of customer loyalty, and Pazgal and Soberman (2008) on the incentives for firms in investing on technologies to track purchase histories.
[6] For related studies on privacy matters see also Hirshleifer (1971), Hermalin and Katz (2006), and Wathieu (2007). See also Acquisti (2011) for a survey on the economics of privacy. For a recent survey on privacy issues related to information technology see Hui and Png (2006).

The effects of these issues in credit markets are considered, for example, in Pagano and Jappelli (1993), Padilla and Pagano (1997, 2000), Dell'Ariccia et al. (1999), and Dell'Ariccia and Marquez (2004).[7]

Another important recent practice of firms with the digital economy is to make offers to consumers based on their search behavior. Armstrong and Zhou (2010) look at this case under competition and find that firms may have an incentive of offer a lower price on a first visit by a consumer than a return visit. This possibility can then lead to higher equilibrium prices in the market. For a recent survey of related effects of product and price comparison sites see Moraga and Wildenbeest (2011).

Finally, another interesting issue to study would be the effect of purchase history on the advertising messages that consumers may receive.[8]

6. Conclusion

This paper presents a summary of the effects of price discrimination based on purchase history. With the digital economy this type of information became more available for firms, and consequently they are engaging more frequently in this type of price discrimination in markets such as telecommunications, magazine or newspaper subscriptions, banking services credit cards.[9] For situations where firms have substantial market power (monopoly) we found that firms benefit after the information is gained, but that this may lead consumers to be more careful when revealing information, which could potentially hurt the firm's profits. For situations with

[7] See also Engelbrecht-Wiggans et al. (1983), Sharpe (1990), Morgan and Stocken (1998), and Bouckaert and Degryse (2004).
[8] For studies of targeted advertising see, for example, Stegeman (1991), Roy (2000), and Iyer et al. (2005). Also related is the literature on competition with price discrimination such as Thisse and Vives (1988), Borenstein (1985), Holmes (1989), Corts (1998), Chen et al. (2001), Chen and Iyer (2002), and Ulph and Vulkan (2007).
[9] See for example, "Publications are Trying New Techniques to Win over Loyal Readers." *The New York Times*, January 4, 1999, p. C20.

competition, if the competitors are aware that firms have purchase history information, more information may actually lead to more intense competition after the information is gained. However, before information is gained, consumers may become less price sensitive as the marginal consumers may get a better price offer in the next period if they do not switch brands in response to a price cut. This may then lead to softer competition prior to firms gaining information. With new consumers coming into the market this effect is attenuated, as the prices for the new customers are now less affected by the fact that these new customers have a lower valuation for the firm.

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