Consumer Search with Observational Learning*

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Abstract

This paper studies observational learning in a consumer search environment. In our model, consumers observe the purchasing decision of a predecessor before deciding which firm to visit. We show that if consumers *emulate* their predecessor and initiate their search at the firm she purchased from, a *social multiplier of demand* induces a lower equilibrium price. Further, as the search cost increases, firms compete fiercely to attract consumers and prices converge to the marginal cost. We show that the result can be extended to any number of firms, and the effect of emulation on prices is stronger as the number of firms increases. We also show that, as consumers observe more previous purchasing decisions, the downward pressure on prices grows to the degree that the pure strategy equilibrium may cease to exist. We then provide a rationale for emulation by introducing positive correlation in preferences across consumers. This correlation gives rise to *free-riding* which deters search, and as a result puts further downward pressure on prices for high search cost.

JEL Classification: D11, D83, L13

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1 Introduction

Observational learning has been the object of study of a large and important literature in economics since the seminal contributions of Banerjee (1992) and Bikhchandani et al. (1992). In the classical model, a sequence of individuals faces a simple decision problem under uncertainty and each individual observes the history of decisions of her predecessors. As argued by Banerjee (1992), this simple environment resembles the problem faced by consumers in markets where previous consumers' choices may be informative about the relative value of different products. Search markets, where consumers actively engage in costly activities to gather information about different alternatives, are prominent examples of such environments. Intuitively, consumers may *free ride* on the search effort of their predecessors, initiating their search in the firm their predecessor purchased from. In a sequential search environment, this form of *emulation* induces a *social multiplier of demand*, because consumers are more likely to purchase the good from the firm they visit first. It is *a priori* unclear whether, and to what extent, emulation and free-riding will play a role in firms' pricing decisions.

To the best of our knowledge, no paper has studied this issue. We attempt to bridge this gap with a simple oligopoly model of search with heterogenous products in the spirit of Wolinsky (1986) and Anderson and Renault (1999) (henceforth ARW). In the simplest version of the model, a large number of consumers derive utility from consuming a single unit of a given good that comes in two different varieties, each sold by a different firm. Consumers are initially uninformed about their valuation for each variety or the price charged by each firm, but may learn these after engaging in costly sequential search. The search procedure is particularly simple: consumers visit one firm at *random* and buy there without further search if their surplus exceeds a certain cutoff. Otherwise, they visit both firms and buy from the highest surplus-offering firm. Firms take consumers' behavior as given and choose prices simultaneously to maximize expected profits.

We depart from this model by informing each consumer of the purchasing decision of a single predecessor. Importantly, consumers do not observe whether their predecessor visited other firms nor the price they paid. We further assume that they visit first the firm offering the variety their predecessor bought. This behavioral modification, which we refer to as *emulation*, amounts to a change in the tie-breaking rule used in ARW and it is consistent with recent evidence in economics and marketing. For instance, Miller and Mobarak (ming) conduct a marketing intervention in Bangladesh to assess how stove adoption is affected by social learning. They show that some households are more likely to adopt the new technology if they are informed of the purchasing decision of an important member of their community. In another field experiment, Cai et al. (2009) show that restaurant-goers are more likely to order those goods that are presented to them as more popular. Similarly, Moretti (2011) analyzes the movie market where an unexpected increase in the first-week's box office revenue has a persistent and significant effect on future attendance. Finally, Zhang (2010) shows that patients waiting for a kidney draw negative quality inferences from earlier refusals in the queue, thus becoming more inclined towards refusal themselves.[1]

Strikingly, this small, yet realistic modification drastically changes equilibrium outcomes. An individual consumer is more likely to start her search in a given firm the higher its market share, linking individual demand to aggregate demand (conditional on the vector of prices.) Because of this *social multiplier*, firms lower prices not only to retain incoming consumers (as in ARW) but also to increase the number of consumers they attract through emulation. We show that the resulting (symmetric) equilibrium markup is a fraction of the price in ARW. We further show that this fraction depends on the magnitude of the social multiplier, it is decreasing in search costs and it converges to zero as the cost of search increases. Higher search cost exacerbates the impact of emulation because the share of *captive* consumers (those who never search) increases. In the ARW model, firms have monopoly power on this segment so that, as the proportion of these consumers increases, prices tend to increase. In our model, however, the likelihood that one such consumer visits a given firm depends on the firm's share among those consumers who actively search. Since firms cannot price-discriminate between the two groups, as the proportion of consumers who stop at the first firm increases, firms engage on increasingly fierce fight for searchers, leading to Bertrand-like competition and eventually to prices that can be as low as the marginal cost.

We then extend this result in two important dimensions. First, we consider the role of competition. Armstrong and Zhou (2011) show that, as long as it is exogenous, the order of visits has no effect on equilibrium prices as the number of firms grow. In our model, however, regardless of the number of firms, the equilibrium price decreases in the search cost and, whenever the latter is sufficiently high, it converges to the marginal cost. Furthermore, the ratio of the price in the ARW model to the price in our model increases with the number of firms, suggesting that the effect we uncover is stronger in more competitive markets. Second, we enrich the model by enlarging the set of predecessors that a new consumer observes. This has two main effects. First, it puts further downward pressure on prices since small price deviations trigger larger changes in the number of first visits, leading to a bigger social multiplier of demand. Thus, as long as pure strategy equilibria exist, prices

[1] For a recent discussion on the huge literature on social learning see Möbius and Rosenblat (2014).

are lower. Importantly, however, the only candidate to a pure-strategy equilibrium price converges to zero *before* the share of searchers vanishes. This is inconsistent with optimality since firms retain (some) monopoly power in the segment of those consumers who visit both firms. Therefore, pure strategy equilibrium fails to exist in environments with sufficiently rich observational learning.[2]

In light of these results, we then introduce 'proper' learning in the model. To do so, we assume that consumer valuations for each variety are positively correlated, but valuations across firms remain independent. More precisely, we assume that the valuations that consumers derive from the variety offered by each firm are drawn from one of two distributions, one of which (High) stochastically dominates the other (Low). Assuming that neither firms nor consumers observe which distribution is realized, we can focus on the effect of learning in consumer behavior and prices. [3] Note that observing a predecessor buying a given variety leads to an upwards update of its distribution of valuations and a downwards update in the rival's distribution. Hence, consumers are now willing to accept a lower surplus from their first visit, thus reducing search effort. We term this the *free-riding* effect of observational learning.

The total effect of learning on equilibrium prices is not straightforward. On the one hand, as explained above, less search leads to higher competition because the social multiplier becomes more important. On the other hand, a price deviation triggers a change of beliefs that may overcome this effect. If a firm deviates to a higher price, the proportion of sales in each demand state changes, thus changing the posterior belief that consumers hold about the other firm's distribution. Since the elasticity of demand is lower for the firm with a higher distribution of valuations, consumers become more pessimistic about its rival's distribution the higher the price of the firm they visit. Hence, the surplus (net of the price) they demand for buying right away decreases in the price, reducing the elasticity and increasing prices. We show that for uniform distribution the first effect is stronger for relatively small search costs while for sufficiently high search costs the second effect dominates and prices may be even lower than in the model without correlation of preferences. Indeed, we show that for any distribution function, as long as the likelihood ratio is unbounded at the lower bound, the equilibrium price converges to marginal cost for smaller search costs than in the baseline model.

[2]As we discuss in detail later, this result is closely related to the mixed strategy equilibrium described by Armstrong and Zhou (2011), who assume that consumers observe prices before they embark on their first search.

[3]This rules out signaling motives for prices. One possible interpretation of our model would then be a sub-market within a larger economy. Each sub-market draws its state independently and all social interactions occur within its limits.

Literature Review

Several recent papers have analyzed consumer search with observational learning, but they all assume that prices are fixed exogenously. Kircher and Postlewaite (2008) study consumers who differ in their willingness to search among that firms differ in quality. Although prices are fixed, firms may decide to offer a valuable service (an exogenously fixed discount) to any consumer who visits their store. Kircher and Postlewaite show that equilibria may arise where high-quality firms offer a discount to those consumers who search more actively and those who search less actively follow their advice. Hendricks et al. (2012) present a model of observational learning with multiple types in the spirit of Smith and Sørensen (2000), where each consumer has to decide between acquiring a costly signal about the quality of a single good, buying it right away, or not buying. They focus on the long-run dynamics of sales for high and low quality products and the possibility of bad herds arising.[4]

In the consumer search literature with price competition, the closest papers to ours are Armstrong et al. (2009) and Armstrong and Zhou (2011), who present a model of prominence in consumer search where one firm is sampled first by all consumers. In Armstrong et al. (2009) a given firm is made prominent exogenously. In the resulting equilibrium, the prominent firm charges a lower price than her rivals because her share of returning customers (who are typically less responsive to prices) is lower. One may view our framework as that of endogenous prominence, where the share of first visits depends on the price. Armstrong and Zhou (2011) study several different models that rationalize prominence. One such model is based on observable price competition where consumers rationally search the lowest-pricing firm first. Because demand is discontinuous in prices, the resulting equilibrium involves mixed strategies and has a property that higher search cost leads to (stochastically) lower prices. One may view observability of prices as an extreme example of observational learning where consumers observe market shares that are a sufficient statistic for the price ranking. We show that as long as this signal is sufficiently noisy, pure strategy equilibrium still exists. Finally, another closely related model can be found in Haan and Moraga-Gonzalez (2011), where prominence depends on advertising efforts and firm profits may decrease in search cost (although prices increase and consumer surplus decreases in the symmetric case).

Our paper is also related to the literature on pricing in the presence of social learning. Galeotti (2010) studies a model of non-sequential search with homogenous goods whereby consumers exchange price information in a network. In a mixed-strategy equilibrium, consumers free-ride on others' search efforts. As a result, when search costs are low, an increase in interpersonal communication leads to

[4]See also Ali (2014) and Mueller-Frank and Pai (Mueller-Frank and Pai) for related models.

higher rather than lower prices. Campbell (2013) and Chuhay (2010) analyze the impact of word-of-mouth communication on monopoly pricing and product design. Bose et al. (2006) study a dynamic interaction between a monopolist and a sequence of consumers with common valuation who observe each other's purchasing decisions. In a related effort, Kovac and Schmidt (2014) study a dynamic market where two firms offer a homogenous product and consumers learn prices from others. Since our focus is on competition and we abstract from dynamic issues, we view our work as complementary to this strand of the literature.

The recent literature on dynamic competition in the presence of switching costs is also closely related. Several authors (e.g. Doganoglu (2010); Cabral (2013); Rhodes (2014)) have shown that switching costs may have a pro-competitive effects because the incentive to "invest" in attracting consumers may prevail over the incentive to "harvest" profits from a locked-in consumer base. This is similar in spirit to our result that prices are lower with higher search cost, but unlike this literature our model does not allow for harvesting because the price is the same for all consumers.[5] Moreover, we show that the price can be as low as the marginal cost, an outcome that cannot be obtained with switching costs because the harvesting effect is never completely mute.

Finally, a number of papers have studied the relation between current market shares and future demand. Becker (1991) introduces aggregate demand as an argument of the individual demand function. Our model provides a simple microfoundation for such an assumption and derives novel implications. Caminal and Vives (1996) studies a dynamic signaling game where new cohorts of consumers observe past market shares of an experience good, but not prices and try to infer quality from this information. Firms use prices to manipulate market shares to attract consumers. While their setting is different in that consumers do not search, we also find that firms use prices to attract consumers, but here consumers free-ride on their predecessors' efforts and due to search cost, herds form, while in Caminal and Vives these effects are mute.

The reminder of the paper is organized as follows. Section 2 introduces the baseline duopoly model with simple emulation and characterizes the equilibrium. We then extend the model to oligopoly in Section 3, and to more complex emulation processes in Section 4. Section 5 introduces correlation in consumers' preferences, characterizes the equilibrium and derives comparative statics and welfare analysis. Section 6 concludes. All proofs are contained in the Appendix.

[5]If firms commit to serve all consumers at the same price, switching costs are irrelevant.

2 The Baseline Model

Consider a market populated by a countably infinite number of consumers interested in purchasing a single unit of a differentiated good that comes in two varieties, each sold by one firm, 1 and 2. Consumers are initially uncertain about their valuation of each firm's product, but may acquire this information through sequential search. We assume that the first visit is free, but the second has a cost of c in utility units and all consumers can recall their previously sampled varieties at no additional cost. For each firm utilities are drawn according to a cumulative distribution $G(u)$, with a strictly positive and continuously differentiable density $g(u)$ on a closed and finite support $[\underline{u}, \overline{u}]$.[6] Realizations are independent between consumers and firms. We assume that $1 - G(u)$ is Log-concave on $[\underline{u}, \overline{u}]$. The outside option is assumed to be sufficiently bad so that each consumer buys one unit regardless of prices.[7]

We assume that the market unfolds over time and consumers arrive to the market sequentially. In particular, we assume that consumer i arrives to the market in period i and leaves the market before the next consumer arrives. All consumers with the exception of the first one do not know their arrival times and hold a common prior $\nu(i)$ over it.[8] We introduce observational learning by allowing each individual consumer $i > 1$ to observe the purchasing decision of her predecessor $i-1$. Importantly, and in line with the literature on social learning, i does not observe her predecessor's search behavior, only the purchase. Given this information, the consumer decides which firm to visit first and finally decides where to buy. Consumer $i = 1$ has no predecessor and, thus, has no additional information. Following ARW, we assume that she chooses which firm to visit by flipping a coin.

Firms choose prices simultaneously at the beginning of the game in order to maximize average expected discounted profits. Let $x^i(p_1, p_2)$ be the probability that consumer i buys at firm 1 given the price pair (p_1, p_2). Then firm 1's expected discounted profit per consumer can be written as

$$\Pi_1(p_1, p_2) = p_1(1-\delta) \sum_{i=1}^{\infty} \delta^{i-1} x^i(p_1, p_2).$$

Notice that if $\delta = 0$, the pricing problem is the same as in ARW because the firm prices to the first consumer, who visits each firm with exogenous and equal probability.

[6]Most of our results could be extended to infinite supports, provided that a regularity condition on the Hazard Rate holds.

[7]See Appendix C for an extension where we introduce a relevant outside option.

[8]This assumption is completely innocuous for the model of this section where consumer valuations are not correlated, thus consumers cannot learn anything about the two options from their position in the queue. It makes the model of Section 3 with correlated preferences far more tractable. See also Footnote 18.

In what follows we focus on the symmetric pure strategy (Perfect Bayesian) Equilibrium.

2.1 Consumer Behavior

We shall assume that consumers will always follow their predecessor for the first visit. This can be justified in three different ways. First, notice that in a symmetric equilibrium of this model, consumers are indifferent between following their predecessor or going to the other firm. Thus, ARW can be considered as a special case of our model whereby consumers ignore the actions of their predecessor and choose randomly. This behavior, however, fails to satisfy trembling-hand-perfection refinement because, if firms may make pricing mistakes, then following the predecessor is strictly preferable. Second, this model can be thought of as the limit of a more general model (provided in Section 5) where consumers' utilities are positively correlated, and so the predecessor's purchasing decision is informative about the distribution of utilities at both firms. Finally, following a predecessor could be supported as a social norm among consumers. As we shall show in this section, such social norms can plausibly emerge since consumers pay lower prices if they follow them.

Let p^* denote the symmetric equilibrium price. If firm 1 charges $p_1 \neq p^*$ while consumers expect the other firm to charge p^*, then a consumer who visits it first will search further if and only if her utility realization u_1 at firm 1 is below $\hat{w} - p^* + p_1$ where $\hat{w}$ solves

$$\int_{\hat{w}}^{\bar{u}} (u - \hat{w}) g(u) du = c. \tag{1}$$

If no solution exists, then set $\hat{w} = \underline{u}$. Notice that as c increases $\hat{w}$ decreases. Define $\bar{c}$ as

$$\bar{c} \equiv \int_{\underline{u}}^{\bar{u}} (u - \underline{u}) g(u) du, \tag{2}$$

which is the expected benefit from further search for a consumer who draws the lowest possible utility. Clearly if c exceeds $\bar{c}$ there is no search in equilibrium. Therefore, from now on, we assume that $c < \bar{c}$.

The consumer who arrives in period 1 has no a priori information to discriminate firms. She makes her first visit randomly and buys at the first firm if and only if $u_{i1} - p_1 > \hat{w} - p^*$ and searches the other firm otherwise. All remaining consumers observe a predecessor buying from firm $j \in \{1, 2\}$ and expect the same price p^* at both firms before embarking on their first search. Since predecessors' choices are not informative about unobserved prices or utilities, once at the first firm, consumers use the same reservation utility $\hat{w} - p + p^*$.

2.2 Equilibrium

In order to write firm 1's market share in period i (i.e the probability a consumer buys from firm 1 in the period) let us first introduce two objects, M_1 and M_2 as the probability that a consumer who makes her first visit to firm 1 and 2, respectively, purchases at firm 1. These probabilities can be written as

$$M_1(p_1, p^*) = (1 - G(\hat{w} + p_1 - p^*)) + \int_{\underline{u}}^{\hat{w}+p_1-p^*} G(u - p_1 + p^*)g(u)du \quad (3)$$

$$M_2(p_1, p^*) = G(\hat{w})(1 - G(\hat{w} + p_1 - p^*)) + \int_{\underline{u}}^{\hat{w}+p_1-p^*} G(u - p_1 + p^*)g(u)du. \quad (4)$$

The expression for $M_1(p_1, p^*)$ includes consumers who buy outright after a utility draw above $\hat{w}+p_1-p^*$ (the first term) and consumers who continue to firm 2 but come back (the second term). $M_2(p_1, p^*)$ is composed of those consumers who visit firm 2, draw a utility below $\hat{w}$ and go on to firm 1. Of these, consumers with utility draws at firm 1 above $\hat{w}+p_1-p^*$ all buy from firm 1 (the first term), whereas all remaining consumers have to compare prices and utility levels (the second term). First visits are valuable because some consumers buy outright, i.e., $M_1(p_1, p^*) \geq M_2(p_1, p^*)$.

Using this notation, and suppressing terms in brackets while noting that x_i and M_j depend on prices, the probability that consumer i (who observes the purchasing decision of consumer $i-1$) purchases from firm 1 can be written as

$$x^i = x^{i-1}M_1 + (1 - x^{i-1})M_2 = M_2 + x^{i-1}\big(M_1 - M_2\big), \quad (5)$$

with a convention that $x^0 = 1/2$.[9] Consumer i first visits firm 1 with probability x^{i-1} and buys there with probability M_1. She may also buy at firm 1 after having visited firm 2 first, which happens with probability M_2. The last expression clearly shows the value of being the first to be visited. Firm 1's market share is M_2 plus the extra consumers it gains because they have visited it first, and thus bought with an increased probability $M_1 - M_2 > 0$.

We use the recursion in (5) to obtain the closed form expression for x_i for $i \geq 2$ as

$$x^i = \frac{(1 - M_1 - M_2)(M_1 - M_2)^i + 2M_2}{2(1 - (M_1 - M_2))}. \quad (6)$$

We can now use (6) to compute the discounted per consumer market share

[9]The first consumer visits either firm with equal probability.

(demand) of firm 1 that can be written as

$$Q_1(p_1) = (1-\delta)\sum_{i=0}^{\infty}\delta^{i-1}x_i = \frac{M_1+M_2-\delta(M_1-M_2)}{2(1-\delta(M_1-M_2)).} \tag{7}$$

The expected discounted demand is a combination of the demand of early consumers (whose visiting probabilities are closer to random) and the demand of all the later arriving consumers, who are allocated according to the stationary market shares. The difference between these groups stems from those consumers whose utility realizations are such that, regardless of the firm they visit first, they buy there. If these consumers do not observe previous purchases, they buy in each firm with probability 1/2. If they observe a predecessor, however, they buy at each firm with the probability that a searcher buys at that firm (since they are following them, or following others who follow them, etc.) Thus, their price elasticity is higher the later they arrive in the queue.

Notice also that this profit function includes the demand function of Anderson and Renault (1999) as a special case. In particular, when $\delta \to 0$, this becomes

$$Q_1(p_1) = \frac{1}{2}(M_1+M_2), \tag{8}$$

the familiar demand equation in the ARW model. Recall that in ARW each firm is equally likely to be visited first by a consumer. Half of them make the first visit to firm 1 and purchase with probability M_1, while the other half make the first visit to firm 2, and purchase from firm 1 with probability M_2.

At the other extreme where $\delta \to 1$, initial individuals whose visiting probabilities are not equal to the stationary ones are no longer relevant and we obtain

$$Q_1(p_1) = \frac{M_2}{1-(M_1-M_2)}. \tag{9}$$

To gain some intuition for this expression, notice that in this model there are two types of consumers: those who buy in the store they visit first (captives) and those who buy in the store that offers them the highest surplus (searchers). The demand of the first group is driven by the choice of the most recent searcher in the queue. Thus, demand of both searchers and captives is entirely determined by the firm's share of searchers. This share is the probability that a consumer buys from that firm if she does not visit it first (M_2) divided by the total mass of searchers, which is given by $1-(M_1-M_2)$. To see this, recall that $M_1 - M_2$ captures those consumers who buy in firm 1 only if they visit it first, i.e. consumers who always buy in the first store they visit. Notice also that in a symmetric equilibrium we have $M_1 + M_2 = 1$ and thus the demand is 1/2 regardless of δ.

The following definition, inspired by the literature on social interactions (e.g. Manski (1993), Glaeser et al. (2003)) turns out to play a crucial role in our analysis.

Definition 1. *The social spillover, η, is the increase in the probability that consumer i buys in a firm given that her predecessor bought there. Therefore, $\gamma = \frac{\eta}{1-\eta}$ is the social multiplier of demand and captures the total additional demand obtained from one extra purchase.*

In this baseline model, $\eta = M_1 - M_2$, which represents the change in the probability that consumer i purchases at firm 1, given that she visited it first rather than second. Because each consumer's increased purchasing probability at firm 1 leads to an increase in the probability of a first visit (and thus purchase) by her successor, the total additional demand, or the social multiplier of demand, is $\gamma = \sum_{i=1}^{\infty} \eta^i = \frac{\eta}{1-\eta}$. Since M_1 and M_2 are probabilities and $M_1 \geq M_2$, η ranges from 0 to 1, whereas γ ranges from 0 to infinity.

Before we provide the equilibrium characterization, it is convenient to define $\hat{p}$ as the symmetric equilibrium price in the ARW model ($\delta \to 0$ in our model) which can be obtained by taking the derivative of $Q_1(p_1)$ given by (8) with respect to p_1, imposing full symmetry ($p_1 = p^*$ and $Q_1(p^*) = 1/2$) and noting that $p^* = -Q_1(p^*)/Q_1'(p^*)$. This gives the familiar

$$\hat{p} = \frac{1}{2\int_{\underline{u}}^{\hat{w}} g(u)^2\,du + (1 - G(\hat{w}))g(\hat{w})}. \tag{10}$$

As shown in Anderson and Renault (1999), $\hat{p}$ is increasing in c for all $c < \bar{c}$.

We shall assume that $G(u)$ is well-behaved so that $\Pi_1(p_1, p^*)$ is concave in p_1. This is not guaranteed by the log-concavity of $g(u)$ as is the case in the ARW model.[10] We shall go back to this issue later in the section.

Now we are ready to characterize the symmetric equilibrium price for any δ ($\hat{p}$ is the price for $\delta = 0$).

Proposition 1. *In equilibrium, both firms charge*

$$\tilde{p} = (1 - \delta\eta^*) \cdot \hat{p},$$

where $\eta^* = (1 - G(\hat{w}))^2 \leq 1$ is the social spillover in equilibrium. Thus, for any $\delta > 0$ and $c > 0$ we have $\tilde{p} < \hat{p}$.

[10] In Section 4, where we study more general observational learning models, we show that the profit function is not concave if consumers observe more than 1 predecessor for sufficiently high c and regardless of $G(u)$. While we are able to show that the profit function is concave for the uniform F, we were unable to formulate the condition in general because the profit function includes fractions of $G(u)$ and thus is not easily characterized by methods used in this literature. For example, Armstrong et al. (2009) solve their prominence model for a finite number of firms only for the uniform distribution.

Proof. All proofs are provided in the Appendix. $\square$

As δ increases, the weight of the initial batch of individuals in the discounted expected demand decreases and demand is increasingly dependent on the stationary market shares. As already mentioned, the latter depends only on the behavior of searchers. Since searchers are more price-elastic, prices decrease in δ. Intuitively, a price reduction leads to a sequence of demand increases through emulation that, when discounted to present, result in $\frac{1}{1-\delta\eta^*}$ extra demand, thus the price in the model with emulation is $(1-\delta\eta^*)$ times the price in ARW.

The comparative statics of the equilibrium price with respect to search costs is, perhaps, more surprising.

Proposition 2 (Comparative Statics)**.** *In the symmetric equilibrium, the following holds:*

(i) *$\tilde{p}$ is increasing in c when c is is sufficiently low.*

(ii) *There exists a threshold $\bar{\bar{\delta}} < 1$ such that for all $\delta \in (\bar{\bar{\delta}}, 1)$, $\tilde{p}$ decreases in c when c is sufficiently high.*

(iii) *As $\delta \to 1$ and $c \to \bar{c}$, $\tilde{p}$ converges to zero.*

As the search cost increases, first visits become more attractive, but the mass of searchers, consumers who compare both prices and thus react to price differences, decreases. Moreover, searchers have very low valuations relative to prices, so small price reductions attract their large share. The net effect on equilibrium prices depends on the weight that searchers have on total profits. As δ increases, searchers become more and more important and price elasticity increases, inducing lower prices. Indeed, as $c \to \bar{c}$ and $\delta \to 1$ prices approach zero (i.e. the marginal cost). Intuitively, when almost no consumers search, the fact that consumers follow each other induces a Bertrand-like competition for the few consumers who do search and react to prices. These consumers are extremely price sensitive (they have very low utility realizations in both firms), and their successors are unlikely to search giving further advantage to the firm that retains them. Indeed, recall that the (total) social multiplier of demand, γ, converges to infinity as $c \to \bar{c}$, leading to the marginal cost pricing for $\delta \to 1$.

This is a rather surprising result. In the ARW model without observational learning, a higher search cost relaxes price competition and results in a higher price, whereas in the model with observational learning (δ sufficiently high), exactly the opposite is true. The result is related to Armstrong and Zhou (2011) where the average equilibrium price is decreasing in search cost. The main difference is that in their model consumers observe prices, whereas here they observe each-other's purchasing behavior. Thus our contribution here is to show that observational learning is qualitatively similar to price advertising.

For illustration, consider Figure 1 that depicts equilibrium prices as a function of the search cost for uniformly distributed valuations in the baseline model with $\delta \to 1$ and $\delta \to 0$. As per Proposition 2, the price is increasing in the search cost starting at zero for both levels of δ. For $\delta \to 0$ (ARW model) prices continue to increase for the whole range of the search cost. In the model with emulation, however, as $\delta \to 1$ the price eventually decreases in c, and in the limit goes to zero as $c \to \bar{c}$.[11]

It remains to be shown that $\tilde{p}$ is indeed an equilibrium. In the Proof of Proposition 1 we establish that the profit function is locally concave for any log-concave distribution and globally concave for the uniform distribution. We also show that, in any symmetric equilibrium, and for any distribution function, the lower bound of the price distribution converges to zero as $c \to \bar{c}$. This implies that expected profits vanish as search costs grow large.

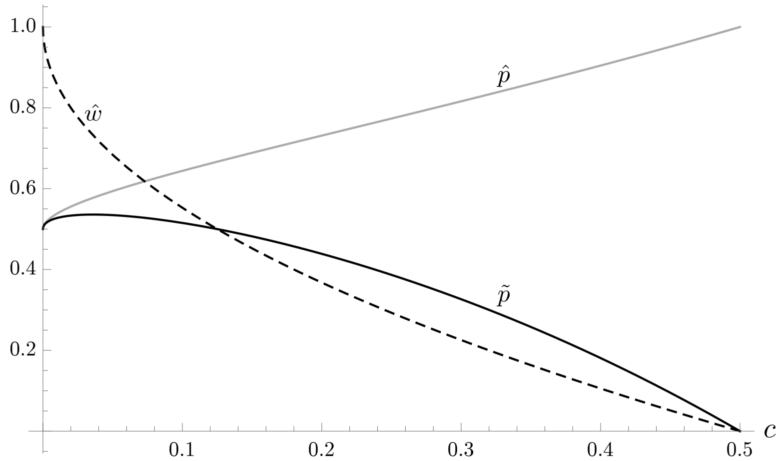

Figure 1: The equilibrium price in the baseline model for $\delta \to 1$ ($\tilde{p}$, black) and for $\delta \to 0$ ($\hat{p}$, gray). The dashed curve depicts the reservation utility $\hat{w}$.

Before we proceed, two points should be noted. First, we have assumed that firms commit to serve all consumers at the same price. In models of social learning, firms may use dynamic or stochastic pricing schemes in order to maximize inter-temporal profits. This assumption, however, can be justified if price-adjustment is *slow* when compared to the speed of learning among consumers. Indeed, in this baseline model, cumulative demand affects current demand only through the purchasing decision of the last individual. Therefore, even if firms were able to adjust prices every N cohorts, as N grows, marginal cost pricing obtains. Moreover, as shown in Campbell (2013), dynamic considerations would reinforce some of our results since firms would be willing to offer low prices to newcomers in order to attract future demand.

[11]For $G(\cdot) \sim U[0,1]$, $\bar{c} = 0.5$.

Second, in this simple model, total welfare is unaffected by the introduction of emulation. In a symmetric pure strategy equilibrium, consumers extract no useful information from the purchasing decision of their predecessor and prices are irrelevant since the market is fully covered.[12] Nevertheless, consumers are better off (and firms are worse off) in the presence of emulation, the higher the discount factor. Therefore, emulation may emerge as a beneficial social norm through a process of social experimentation.

3 The Effect of Competition

We now extend the model of the previous section to the case of an oligopoly with n firms. The aim is to understand whether the social multiplier of demand is still relevant in more competitive markets. For the sake of comparison, the reader should keep in mind that in the model where the order of first visits is exogenously determined (e.g. Armstrong et al. (2009)), the effect of prominence completely disappears as the number of firms in the market grows.

For ease of exposition, we focus in the remainder of the paper on the two polar cases where $\delta \to 0$ and $\delta \to 1$. In the latter case, profits depend on the stationary market shares, while the former case is identical to ARW and serves as a useful benchmark.

We now proceed in a similar fashion as before. We first define M_1 and M_2 for this more general model. Recall that M_1 and M_2 are the probabilities that a consumer buys from firm 1 if she makes her first visit to firm 1 and any other firm, respectively. These are given by

$$M_1(p_1, p^*) = (1 - G(\hat{w} + p_1 - p^*)) + \int_{\underline{u}}^{\hat{w}+p_1-p^*} G(u - p_1 + p^*)^{n-1} g(u) du \quad (11)$$

$$M_2(p_1, p^*) = \frac{(1-G(\hat{w}+p_1-p^*))}{n-1} \sum_{j=1}^{n-1} G(\hat{w})^j + \int_{\underline{u}}^{\hat{w}+p-p^*} G(u - p_1 + p^*)^{n-1} g(u) du. \quad (12)$$

M_1 is similar to the one from duopoly. M_2 accounts for the fact that a consumer may arrive at firm 1 after having visited 1 to $n-1$ other firms.

Consider $\delta \to 1$. If firm 1 sets price p_1 and if all of its rivals set p^*, the firm's stationary market share $x(p_1, p^*)$ can be computed as

$$x(p_1, p^*) = \frac{M_2(p_1, p^*)}{1 - (M_1(p_1, p^*) - M_2(p_1, p^*))},$$

which is analogous to (9).

[12]This is not true in the model of Appendix C, where we consider an extension of our model where consumers have a zero outside option.

For $\delta \to 0$, as before,

$$x(p_1, p^*) = \frac{M_1(p_1, p^*) + M_2(p_1, p^*)}{2},$$

and the equilibrium price can be computed by equating marginal revenue to zero and imposing symmetry. This yields the familiar ARW price in oligopoly

$$\hat{p}_n = \frac{1}{n\big(\int_{\underline{u}}^{\hat{w}} (n-1)G(u)^{n-2} g(u)^2\, du - G(\hat{w})^{n-1} g(\hat{w})\big) + \frac{(1-G(\hat{w})^n)g(\hat{w})}{1-G(\hat{w})}}. \tag{13}$$

Before we solve for the price for $\delta \to 1$, we compute the social spillover of demand for oligopoly as follows

$$\eta_n^* = M_1(p^*, p^*) - M_2(p^*, p^*) = 1 - \frac{nG(\hat{w}) - G(\hat{w})^n}{n-1}. \tag{14}$$

That is, the social spillover is now the difference between the probability that a consumer purchases in store 1 if she visits it first rather than later. We can therefore extend Proposition 1 to the oligopolistic competition for the special case where $\delta \to 1$.

Proposition 3. *In the symmetric equilibrium, all firms charge*

$$\tilde{p}_n = (1 - \eta_n^*) \cdot \hat{p}_n,$$

where $\eta_n^* = 1 - \frac{nG(\hat{w}) - G(\hat{w})^n}{n-1} \leq 1$, *thus for any* $c > 0$ *we have* $\tilde{p}_n < \hat{p}_n$. *Further, both* $\tilde{p}_n$ *and* $\hat{p}_n$, *but also* $\tilde{p}_n/\hat{p}_n$ *are decreasing in* n.

Notice, therefore, that, as the number of firms grows, the relative gap between prices in the model with and without emulation also grows, so that competition strengthens its effect.

It is instructive to look at both models in the limit case where $n \to \infty$. One immediate implication of large n is that the share of returning consumers vanishes. This greatly simplifies pricing in both models. As shown in Anderson and Renault (1999), the ARW model with an infinite number of firms is effectively a model of price competition with differentiated goods and so the price can be computed using the following formula

$$\hat{p}_\infty = \frac{1 - G(\hat{w})}{g(\hat{w})}. \tag{15}$$

Here a firm optimally trades off the exploitation of the captives (represented by $1 - G(\hat{w})$) and the retention of searchers ($g(\hat{w})$). In our model with emulation, however, for $n \to \infty$ the price is

$$\tilde{p}_\infty = (1 - \eta^*_\infty) \cdot \hat{p}_\infty = G(\hat{w}) \cdot \hat{p}_\infty, \tag{16}$$

and is strictly lower for any $c > 0$ since $G(\hat{w}) < 1$.

To better understand this pricing rule, note that in the ARW model with a large number of firms, a unit price increase leads to a unit increase in the reservation utility, resulting in $g(\hat{w})$ consumers leaving (and never returning). This trade-off is resolved using the price in (15). In our model, a unit increase in price induces a loss of $g(\hat{w})$ searchers, each of whom diverts an incoming consumer away from the firm, never to return. Therefore, $\eta_\infty = 1 - G(\hat{w})$. As search cost increases, by log-concavity of $1 - G(w)$, $\frac{1-G(\hat{w})}{g(\hat{w})}$ grows initially but eventually falls, leading to a bell-shaped pattern in prices.

Figure 2 illustrates equilibrium prices for $n = 2, 4$, and ∞. As shown in Proposition 3, prices decrease in n for a given search cost. Interestingly, in the limit case where $n \to \infty$, the market is perfectly competitive both when the search cost is very low and when it is very high. In the former case, this reflects the fact that consumers are willing to visit a large number of firms to find a suitable product and, therefore, each of them has negligible market power. In the latter case, however, very few consumers visit more than one firm, and thus, firms compete fiercely to attract first visits. In other words, the equilibrium price in our model is the same whether consumers make fully informed decisions (buying from the firm that offers the highest surplus) or fully uninformed decisions (buying from the first firm they visit).

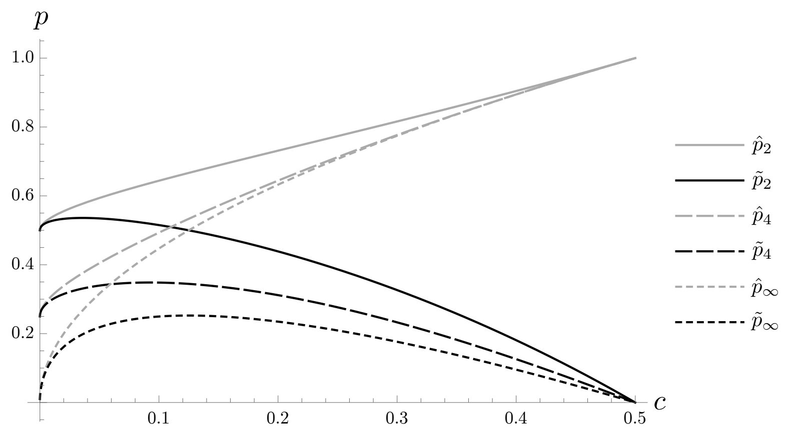

Figure 2: Equilibrium prices as a function of search cost for our model (black) and the ARW model (gray) for n equal to two (solid), four (long dash) and infinity (short dash). $G(\cdot) \sim U[0, 1]$.

To close this section, we note that the oligopoly model highlights how observational learning differs from prominence, where search order is exogenously given. In prominence models, prices differ across firms because they face different shares of returning and incoming consumers and, therefore, different demand elasticities. As shown in Armstrong et al. (2009), this difference vanishes as the number of firms grows because the share of returning consumers goes to zero.[13] As a result, the (exogenously) determined order or prominence is irrelevant for prices (although it is important for profits) with sufficiently many firms. In contrast, in our setting, even when the number of firms grows large, the model with emulation features a lower equilibrium price. This is because while firms do not price to returning consumers, they do internalize the social multiplier of demand that arises through emulation.

4 The Strength of Social Interaction

We now relax the assumption that every consumer has access to the purchasing decision of a single predecessor. In order to do so, we start with a reduced-form model of social interaction. We simply assume that firm 1's market share x determines its share of first visits, denoted by $z(x)$. For example, in the baseline model, each consumer observes a single predecessor, so the firm's market share and its share of first visits are equal, hence $z(x) = x$.

Using $z(x)$, firm 1's demand can be written as

$$x(p_1, p^*) = z(x(p_1, p^*))M_1(p_1, p^*) + (1 - z(x(p_1, p^*)))M_2(p_1, p^*). \tag{17}$$

Assuming that $z(x)$ is a well-behaved and differentiable function of x, we can use implicit differentiation to solve for a candidate symmetric equilibrium. First, notice that the social spillover is now defined as

$$\eta = z'(x)(M_1 - M_2).$$

The social spillover may be decomposed in two distinct terms. First, $z'(x)$ captures the marginal increase in the probability that a random consumer visits a given firm as a function of cumulative demand. This term depends only on the structure of the social interaction. Second, $M_1 - M_2$ captures the increase in demand accruing to a firm with an additional first visit. This term depends on the distribution of valuations and the search cost but it is independent of the structure of social interactions. Notice finally, that in the baseline model, $z'(x) = 1$ so that $\eta = M_1 - M_2$.

To find the putative equilibrium price, we equate firm 1's marginal revenue to

[13] In this class of models, consumer go back to a firm they have visited only after they visit all firms, which becomes very unlikely as n grows.

zero and impose symmetry to write

$$\tilde{p} = (1 - \left(M_1^* - M_2^*\right) z'(1/2))\hat{p} = (1 - \eta^*)\hat{p}. \tag{18}$$

Again, the equilibrium price is a fraction of the ARW price. This fraction is smaller, the larger the measure of non-shoppers, i.e. those who do not search regardless of the firm they visit first, as represented by $M_1^* - M_2^* = (1 - G(\hat{w}))^2$, and the larger the marginal change in the probability of attracting one of them by increasing the market share above half, $z'(1/2)$. Given this, it is easy to see that the equilibrium price derived in Section 2 for $\delta \to 1$ obtains for $z'(1/2) = 1$. The ARW price obtains when $z'(1/2) = 0$, i.e. when the social multiplier of demand is zero.

The strength of social interactions as measured by $z'(1/2)$ has a clear threshold. If $z'(1/2)$ exceeds unity, i.e. a share of first visits increases at least one for one with the market share, then there exists sufficiently high search cost c, and thus sufficiently low $\hat{w}$, such that the putative symmetric equilibrium price is equal to the marginal cost. For learning models where $z'(1/2) < 1$, even for c so hight that $G(\hat{w}) = 0$, the marginal cost pricing does not obtain. This is because the stationary market share is never fully determined by the share of first visits, so that price elasticities are always positive and, therefore, prices exceed marginal cost.

The flexibility of the $z(x)$ formulation also allows for consumers to behave as contrarians - i.e. they may go to the store where the predecessor has not purchased. For instance, assume that each consumer observes one predecessor, and that consumers always visit first the other firm. Then $z(x) = 1 - x$, so that $z'(x) = -1$. This means that $\tilde{p} = (1 + (1 - G(w))^2)\ \hat{p}$, which is higher than $\hat{p}$, and $\tilde{p}$, but also $\tilde{p}/\hat{p}$, is increasing in c. In the limit where $c \to \bar{c}$, $\tilde{p} = 2\hat{p}$. As expected, contrarian behavior increases prices by discouraging price reductions with a negative multiplier of demand. This is more so when search cost is high, because losing first visits is particularly damaging with high search cost, so firms are deterred from reducing prices. This suggests that in a generalization of our model where consumer preferences are negatively correlated, prices will be higher with than without observational learning.[14]

We now proceed to rationalize $z(x)$ as the outcome of a micro-founded model of social interaction. We assume that every consumer (except the first few) observe an odd number $(2k + 1)$ of randomly drawn predecessors, where k is a nonnegative integer.[15] We interpret k as a measure of the strength of social interactions in the

[14]Negative correlation results in free-riding in search, as in Section 5 where we study positive correlation of preferences. Both the contrarian search behavior and the fact that consumers search less due to free-riding lead to higher prices. Although we do not study a model with negative correlation preferences, it can be developed in the same spirit as the model of Section 5.

[15]Similar results obtain when the number of observed predecessors is even. In that case there are possibilities of a tie, that result in random search as in ARW. For instance, the model where

market. The baseline model where each consumer observes a single predecessor obtains when $k = 0$. We still assume that consumers emulate their predecessors, so that they start their search in the firm where $k + 1$ of their predecessors bought. Given that x is firm 1's market share,[16]

$$z(x) = \sum_{j=k+1}^{2k+1} \binom{2k+1}{j} x^j (1-x)^{2k+1-j}$$

Taking the derivative with respect to x and evaluating it at $x = 1/2$ yields

$$z'(1/2) = \frac{(1+2k)!}{2^{2k}(k!)^2} \equiv \zeta(k),$$

which is equal to 1 for $k = 0$ and increasing in k since

$$\zeta(k+1) = \frac{3+2k}{2(1+k)}\zeta(k) > \zeta(k).$$

As k grows, the sample of previous observations becomes more precise and, therefore, the probability that one of the firms is more popular in a given sample becomes increasingly large the larger is its market share (as captured by $\zeta(k)$.) Therefore, the price elasticity in a symmetric equilibrium explodes for a given $c > 0$. Intuitively, as consumers observe many others, the firm's share of first visits becomes increasingly sensitive to its market share, leading to an ever higher social multiplier of demand and ever lower price.

For every k there exists a measure of captive consumers $(1-G(\hat{w}))^2$ corresponding to a search cost $\bar{c}_k$ such that the only candidate for a symmetric equilibrium price is zero, i.e. $\bar{c}_k$ solves $1 = \zeta(k)(1 - G(\hat{w}))^2$. Because $\zeta(k)$ is increasing in k and goes to infinity, $\bar{c}_k$ is decreasing in k and converges to zero as k goes to infinity. This putative outcome, however, cannot be supported as an equilibrium for any $k \geq 1$ because, in that case $\bar{c}_k < \bar{c}$, and thus even though the putative symmetric price is zero, a positive measure of consumers search. Because of the product differentiation, a deviation to a higher price yields positive profits for any search cost $c < \bar{c}$. Hence, we have the following result.

Proposition 4. *If a symmetric pure strategy equilibrium exists, both firms charge*

$$\tilde{p}_k = (1 - \eta_k^*) \cdot \hat{p},$$

consumers observe two predecessors has exactly the same equilibrium as our baseline model where they observe one predecessor.

[16]This probability is computed assuming that all draws are independent. The probability that a randomly drawn predecessor shares a predecessor with one of her successors equals the clustering coefficient of the resulting random network. This coefficient converges to zero as the number of consumers grows.

where $\eta_k^* = \zeta(k)(1 - G(\hat{w}))^2 \leq 1$*, which is decreasing in* k *for any* $c > 0$*. For all* $c \in [\bar{c}_k, \bar{c})$ *no pure strategy equilibrium exists.*

Notice then that the model presented in Section 2 exhibits the weakest social interactions conducive to marginal cost pricing. Models with weaker interactions result in positive profits for any level of search cost, while models with stronger interactions result in lower prices and possibly mixed strategy equilibria. Indeed, we have the following corollary of Proposition 4 using the fact that $\lim_{k\to\infty} \bar{c}_k = 0$.

Corollary 1. *For any* $c > 0$*, there exists* K_c *sufficiently large such that for any* $k \geq K_c$*, no pure strategy equilibrium exists.*

Whenever $z'(1/2) > 1$, the putative equilibrium price becomes zero for a search cost well below the level where no consumers search. This immediately implies no pure strategy equilibrium. We are unable to characterize the mixed strategy equilibrium, but it is clear that as $c \to \bar{c}$, the equilibrium distribution of prices will converge to the marginal cost because,then, a price deviation above the marginal cost leads to zero demand, and thus zero profit.

Figure 3 illustrates our results. It shows $\tilde{p}$ for the uniform distribution and various levels of k. Solid black lines depict the equilibrium price, whereas dashed gray lines show the putative equilibrium price that is not an equilibrium because an upward price deviation exists. For $k = 0$, which corresponds to our baseline model, the putative equilibrium price actually constitutes an equilibrium for all $c < \bar{c}$. This is not the case for sufficiently high c and any $k \geq 1$. As per Proposition 4, for a given c, whenever a symmetric pure strategy equilibrium exists, $\tilde{p}$ is decreasing in k.

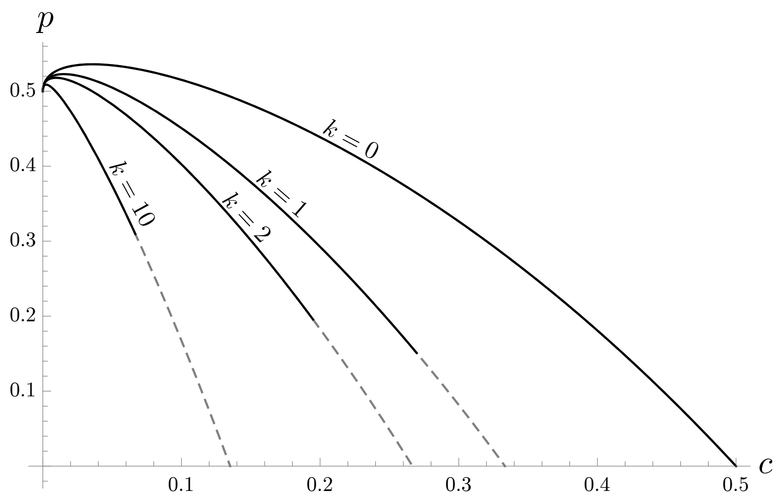

Figure 3: The symmetric equilibrium price, putative (dashed gray) and actual (solid black), for various sample sizes.

This result is closely related to Armstrong and Zhou (2011) who show that in a search model if consumers observe prices prior to search, there is no pure strategy equilibrium in prices. The intuition stems from the fact that first visits are valuable ($M_1 > M_2$) and, as a result, firms are willing to infinitesimally undercut each other to get all of the first visits. But since some consumers search beyond the first firm, firms have some monopoly power and thus a Bertrand outcome cannot constitute an equilibrium. Corollary 1 describes a qualitatively similar result. As k grows, each consumer observes an increasingly large sample of purchases, thus even an infinitesimal price reduction leads to a large increase in first visits because a very large sample of purchasing decisions serves as a precise statistic for the lowest price. As a a result, for a sufficiently high search cost, the only candidate for a symmetric pure strategy equilibrium requires prices to be close to zero, but due to the monopoly power firms cannot converge on a Bertrand outcome. This is not the case with $k = 0$ because, in that case, zero prices obtain for $c \to \bar{c}$ where the measure of searchers vanishes and so firms' monopoly power is fully erode

We conclude this section with a brief remark over the empirical content of these results. In our model, prices depend on the size of the social multiplier which is composed of two different terms. The first term, $z'(x)$, measures the response of the share of first visits to a marginal increase in current demand. As we have shown, this effect can be directly linked to the strength of social interactions as captured by k, and can be approximated by the average degree of a social network. The second term, $M_1 - M_2$, measures the "conversion rate" of first visits into sales. In a search model, its magnitude is inversely related to the search cost. As a result, prices are decreasing in the average degree of the network and hump-shaped in search cost. This yields a novel implication of the effect of the Internet on prices in horizontally-differentiated markets: the expansion of online social networks should have resulted in stronger price competition while the use of search engines should have an ambiguous effect on prices.

5 Correlated Preferences

The empirical literature suggests that consumers follow others because they believe that, had they had the same information, they would have decided similarly. That is, their preferences are similar. A positive correlation in valuations across consumers introduces a new channel through which social learning may influence prices. Whereas in the model with "pure" emulation considered so far, observational learning leads to a higher price elasticity, with positively correlated valuations, this need not be true. In particular, consumers will free-ride on each other's efforts and search less than in the model where their preferences are independent. If free-riding leads to less search, firms may increase their market power and, as a result, prices may be higher.

We now introduce these considerations into the baseline model. We assume that all consumers draw their valuations for each firm's product from one of two potential distributions, a High distribution (denoted by $G_H(u)$) and a Low distribution ($G_L(u)$).[17] Both distributions are equally likely to realize at each firm, and these realizations are independent across firms. We assume that both distributions have the same (finite) support $[\underline{u}, \bar{u}]$. Let g_H and g_L be the corresponding continuously differentiable densities. As standard in the economics literature, we assume that the Monotone Likelihood Ratio property holds so that $\frac{g_H(x)}{g_L(x)}$ is an increasing function of x. Let $\lambda(u) = \frac{g_H(u)}{g_H(u)+g_L(u)}$ be the conditional probability of H given u. Let $G(u) = \frac{1}{2}G_H(u) + \frac{1}{2}G_L(u)$ be the unconditional distribution of valuations of a random consumer. As in the baseline model, we shall assume that $G(u)$ is log-concave. Preferences are correlated across consumers because they are drawn from the same distribution (G_H or G_L). Finally let $(S_1, S_2) \in \{H, L\}^2$ be the realized state. Even though consumers do not know the utility that their predecessor derived from her chosen variety, her purchasing decision is informative about which state (S_1, S_2) has realized. Clearly, when $G_H \to G_L$, our baseline model obtains.

5.1 Consumer Behavior

The consumer who arrives in period 1 lacks any information to discriminate between firms, and, therefore, makes her first visit randomly. She buys outright if and only if $u_i - p_i > \hat{w} - p^*$, where $\hat{w}$ is computed as in the baseline model without learning. All remaining consumers hold a common prior $\nu(j)$ over the distribution of their arrival time. Therefore, all consumers use the same search rule, except the first one.[18] They observe their predecessor buying from firm $j \in \{1, 2\}$ and expect the same price p^* at both firms before embarking on their first search. Since valuations are positively correlated, the expected surplus from visiting firm j is larger than that from visiting firm $-j$ and so the consumer should visit that firm. Upon visit, a consumer learns her utility realization for good j, u_{ij}, and the price set by firm j. The consumer will search further if and only if $u_{ij} < \tilde{w}(p_j)$, where $\tilde{w}(p_j)$ solves

$$\int_{\tilde{w}-p_j+p^*}^{\bar{u}} (u - \tilde{w} + p_j - p^*)(q(\tilde{w}; p_j)g_H(u) + (1 - q(\tilde{w}; p_j))g_L(u))du = c. \tag{19}$$

[17] This simple structure ensures that the model remains tractable. Often used "truth-or-noise" cannot be used because the optimal search rule does not satisfy the reservation property. This is because when the posterior belief that a consumer holds about the probability that her predecessor searched is discontinuous in her own realization, search rules become exceedingly complex. If one looks at the extreme case of perfectly correlated preferences, then the model is the same as ARW because only the first consumer searches, and all others follow him.

[18] Monzón and Rapp (2014) show that the classical results in herding models survive even if consumers are uncertain about their arrival time.

Here, $q(u;p)$ is the (posterior) probability that the distribution is High at the other firm. This probability will, in general, depend on the valuation drawn from firm j (because preferences are correlated) and firm j's price, because the price affects firm j's market share, and thus the probability of an arrival there. In principle, $q(u;p)$ is a complicated object, since each consumer may infer from u not only how likely it is that a given distribution is realized but also her cohort, which is potentially informative about the purchasing decision of the predecessor.

In order to understand $q(u;p)$, we first look at the probability that consumer i buys from firm 1 if the state is $(SS') \in \{H, L\}^2$. Since the probability she starts her search in that firm is equal to the probability that her predecessor bought there, $x^{i-1}_{SS'}$, we have that consumer i buys with the probability

$$x^i_{SS'} = x^{i-1}_{SS'} M_1^{SS'} + (1 - x^{i-1}_{SS'}) M_2^{SS'}, \tag{20}$$

where

$$\begin{aligned} M_1^{SS'} &= (1 - G_S(\tilde{w}(p))) + \int_{\underline{u}}^{\tilde{w}(p)} G_{S'}(u - p + p^*) g_S(u) du \\ M_2^{SS'} &= G_{S'}(w^*)(1 - G_S(w^* + p - p^*)) + \int_{\underline{u}}^{w^*+p-p^*} G_{S'}(u - p + p^*) g_S(u) du, \end{aligned}$$

where $w^* = \tilde{w}(p^*)$. It is straightforward to see that if $\tilde{w}(p) > \underline{u}$, this mapping has a fixed point where market shares are stationary. In Appendix 2 we show that, provided that the number of consumers is sufficiently large, consumers' optimal search strategy is arbitrarily close to the one computed for a stationary market share distribution. In this case, dropping the time subscript, we can write a firm's market share in state SS' when it charges p while the other firm charges the equilibrium price p^* as the solution to (20) where we impose $x^i_{SS'} = x^{i-1}_{SS'} = x_{SS'}$. This gives

$$x_{SS'} = \frac{M_2^{SS'}}{1 - (M_1^{SS'} - M_2^{SS'})}.$$

Once we have market shares in every state (which depend on p and p^*, but also on $w(p)$ that is yet to be determined) we find $q(u;p)$ as

$$q(u;p) = \frac{x_{HH}(p)\lambda(u) + x_{LH}(p)(1 - \lambda(u))}{(x_{HH}(p) + x_{HL}(p))\lambda(u) + (x_{LH}(p) + x_{LL}(p))(1 - \lambda(u))} \tag{21}$$

The above formula uses market shares in every state and weights the conditional probability of H given u by these market shares using Bayes rule.

This completes the characterization of the consumer search rule. In particular, $w(p)$ is implicitly defined in (19) where $q(u;p)$ is given by (21) where $x_{SS'}$ is given in (20).

5.2 Equilibrium Conditions

In equilibrium, both firms charge the same price. Therefore, consumers' search rule in (19) can be rewritten as

$$\int_{\tilde{w}}^{\bar{u}} (u - \tilde{w})(q(\hat{w})g_H(u) + (1 - q(\hat{w}))g_L(u))du = c \tag{22}$$

where $q(\tilde{w}) = q(\tilde{w}; p^*)$ is the equilibrium probability that the rival firm has a High distribution given the reservation utility. Notice that $q(u) \leq q(\bar{u}) \leq \frac{1}{2}$ since observing the predecessor buying at a firm is bad news about the prospects at the rival. Hence, we have the following observation.

Proposition 5. *In a symmetric equilibrium, $\tilde{w} < \hat{w}$, and, hence, consumers free-ride on others' effort relative to the model without correlations.*

Firms' profits depend on the search rule used by consumers both on and off the equilibrium path. In particular, let $\tilde{w}'(p)$ be the implicit derivative of the reservation utility with respect to p. In the baseline model without learning, as well as in the ARW model, $\tilde{w}'(p) = 1$ so that a unit increase in the price is compensated with a unit increase in required utility. This is no longer the case with correlated preferences and observational learning. Consumers who visit a firm with a different price adjust their beliefs about the distribution of valuations in the rival firm, while keeping their beliefs about its price constant.[19] In particular, the higher the price, the less likely it is that a consumer ends up in that firm if its rival has a High realization of valuations. Thus, in general, $\tilde{w}'(p) < 1$.

Firm 1's expected demand when it charges p_1 while its competitor charges p^* and consumers use reservation utility function $\tilde{w}(p)$ is the average of demands over all possible states. Because states between firms are independent, and equally likely, the demand is given by:

$$x(p_1, p^*) = \frac{1}{4} \sum_{SS'} x_{SS'}(p_1, p^*).$$

Here $x(p_1, p^*)$ implicitly depends on $w(p)$ and thus on consumer search rule. In the symmetric equilibrium, the price satisfies

$$\sum_{SS'} x_{SS'}(p^*, p^*) + p^* \sum_{SS'} \frac{\partial x_{SS'}(p^*, p^*)}{\partial p_1} = 0.$$

[19] The assumption of passive beliefs is common in the literature. For a discussion see Janssen and Shelegia (2014).

Once we impose $\sum_{SS'} x_{SS'}(p^*, p^*) = \frac{1}{2}$ because of symmetry, the equilibrium pricing rule simplifies to

$$\frac{1}{2} + p^* \sum_{SS'} \frac{\partial x_{SS'}(p, p^*)}{\partial p_1} = 0. \tag{23}$$

In order to solve the model, then, we need to characterize the derivative of demand with respect to the price in every state. This derivative crucially depends on the response of consumers to a marginal change in price by one firm. In turn, this response depends on the poster estimate of state H at the other firm, which in turn depends on the demand in each state. No closed form solutions exist, but one can obtain a numerical solution by finding $\tilde{w}'(p)$ using the implicit function theorem, and imposing symmetry everywhere. In what follows we provide the numerical solution for the Uniform distribution and analytically characterize the limit when the mass of searchers vanishes for any distribution.

5.3 Equilibrium Characterization

If $\lambda(\underline{u}) = 0$, upon drawing $\underline{u}$ at firm j, the probability that the rival firm has a High distribution is arbitrarily small and so $x_{L,H}(p^*, p^*) = 0$. Thus, $q(\underline{u}) = 0$ and we define

$$\bar{c}_L = \int_{\underline{u}}^{\bar{u}} u g_L(u) du$$

to be the largest search cost such that there is search in equilibrium. For every $c < \bar{c}_L$, a firm offering its product for a price $p^* - (\bar{c}_L - c)$ retains all its incoming consumers and, therefore, obtains a stationary market share equal to one. This puts an upper bound on the equilibrium price. The following proposition establishes that this upper bound converges to zero as $c \to \bar{c}_L$.

Proposition 6. *As $c \to \bar{c_L}$, $p^* \to 0$ for every (G_H, G_L) such that $\lambda u = 0$.*

As the search cost increases, retaining consumers becomes increasingly cheap. Market shares are fully determined by the relative proportion of searchers who buy in each store, so that a deviating firm can attract all consumers by offering an increasingly small discount, leading to Bertrand competition and marginal-cost pricing.

5.4 Comparative Statics

We discuss now the effects of learning on prices. In order to do so, we shall compare the equilibrium prices if consumers' preferences are correlated ($G_H \neq G_L$) with the case where consumer preferences are independent ($G_H = G_L = G$). Let, as before, $\tilde{p}$ be the price with uncorrelated preferences and $\tilde{p}_{cor}$ be the equilibrium price if preferences are correlated. The following corollary shows that learning may put even further pressure on prices.

Corollary 2. *Take an (unconditional) distribution G with associated distributions G_H and G_L. There exists $\epsilon > 0$, such that for $c \in (\bar{c}_L - \epsilon, \bar{c}_L)$, $\tilde{p}_{cor} < \tilde{p}$.*

That is, if the purchasing decision of a predecessor is informative about the distribution of utilities of her successor, the equilibrium price elasticity increases and, thus, prices decrease. This is because consumers whose valuation for the variety they sample first is low become increasingly pessimistic about their prospects at the other firm, the higher is the correlation across consumers, and, therefore, they are less inclined to search. Since the elasticity of demand decreases in the proportion of searchers when the latter is sufficiently high, the result follows.

The following figures illustrate our results for $G(\cdot) \sim U[0,1]$. In this example G_L is a triangular distribution on $[0,1]$ with mode 0 while G_H is a triangular distribution on $[0,1]$ with mode 1. As required, the mixture of the two is uniform on $[0,1]$ and G_H FOSD G_L. Also, $\lambda(\underline{u}) = 0$.

Figures 1 and 2 show prices and reservation utilities in various models. As

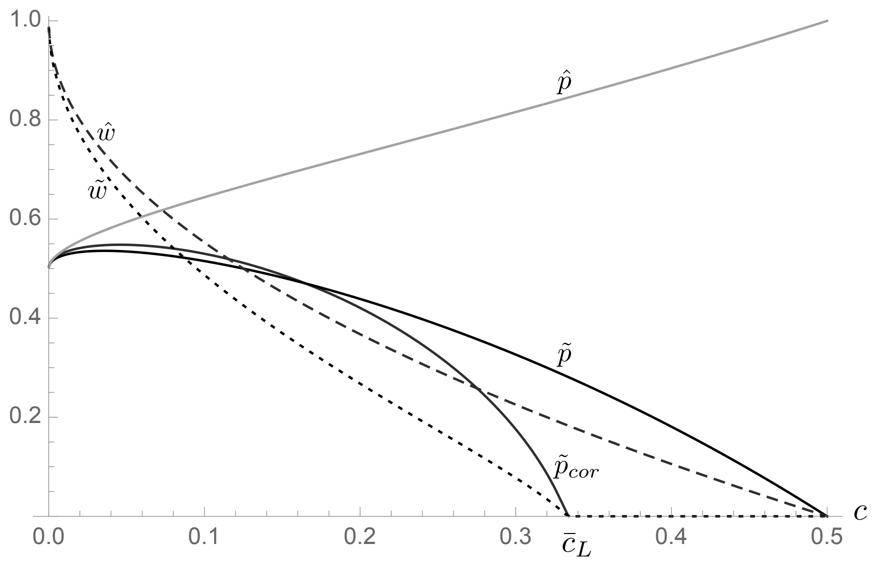

Figure 4: Prices in our model with correlated ($\tilde{p}_{cor}$), uncorrelated ($\tilde{p}$) and the ARW ($\hat{p}$, gray) for triangular distributions.

expected, the price is lower in the model with pure emulation ($\tilde{p}$) than in the ARW model ($\hat{p}$). The equilibrium price in the ARW model is increasing in c and reaches 1 at $c = 1/2$. This is where even a consumer who draws 0 at the first firm refuses to search further. In our model with correlation of preferences, as predicted by Proposition 6, because $\lambda(0) = 0$, the price converges to zero when $c \to \bar{c}_L = 1/3$. In our model with pure emulation and the same unconditional distribution, the price converges to zero at $c = 1/2$, as implied by Proposition 2. Intuition for both results is simple. When $c = 1/3$ in the model with learning, a consumer who is sure that utilities from the other firm are drawn from G_L will not search. But this is what happens in equilibrium when a consumer draws utility close to 0 - she reasons that because the distribution at the current firm is almost surely G_L, the fact that she came here indicates that the distribution is also G_L at the other firm, or otherwise she would have almost surely ended up at the other firm for the first visit. Thus even though u close to $\underline{u}$ is bad news about the current firm, it is also bad news about the next firm. Because the search cost at the current firm is sunk, no consumer searches beyond the first firm.

Figure 5 shows $\tilde{w}'(\tilde{p}_{cor})$ as a function of c. For $c \to 0$, the derivative of reservation utility approaches 1. This is because when almost all consumers search, the price contains almost no information and so the reservation utility matches it one for one. For all $c \in (0, \underline{c}_L)$, $\tilde{w}'(\tilde{p}_{cor})$ is less than 1, reflecting the informational content of price deviations.

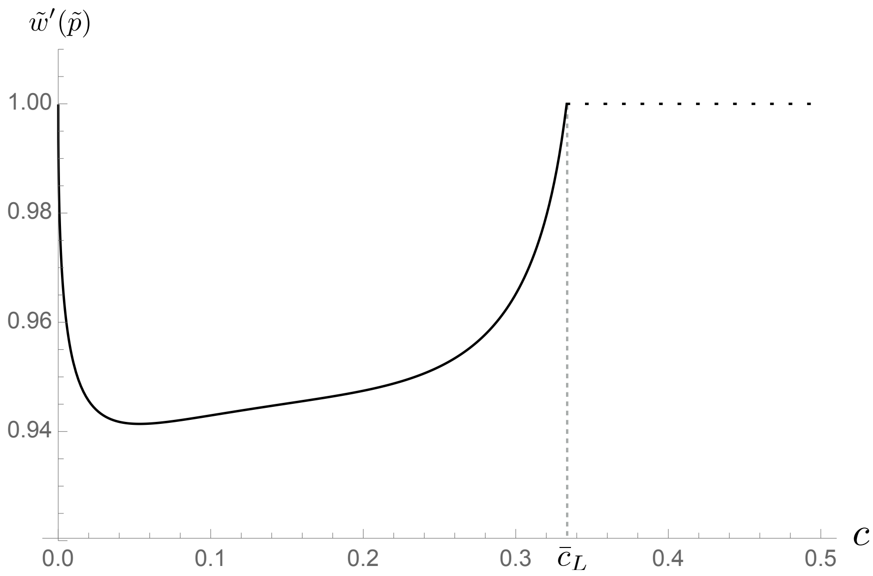

Figure 5: The derivative of reservation utility with respect to p in our model for triangular distributions.

Finally, Figure 6 illustrates equilibrium demands in various states as a function of c. In symmetric states (LL and HH), demand for both firms is equal to 0.5 and is independent of the search cost. Matters are more interesting in asymmetric states. As the search cost increases, demand for a firm with low distribution facing a firm with high distribution shrinks (the opposite is true for high distribution vs low distribution). Naturally, when search cost is low some consumers buy at the firm where utility is drawn from G_L, and so the same proportion of consumers visits this firm first. As $c \to 1/3$, search vanishes and almost all consumers are steered toward and stay at the firm with the high distribution. Thus, a *herd* forms whenever (almost) all consumers make the first visit to a given firm and buy outright.[20]

These results can be linked to those obtained in Bar-Isaac et al. (2011) who show that a reduction in search costs leads to an increase in demand for "superstars" (accompanied by a simultaneous increase in the demand for niche products.) In contrast, with observational learning the superstar effect increases in search costs because individual experimentation becomes increasingly costly.

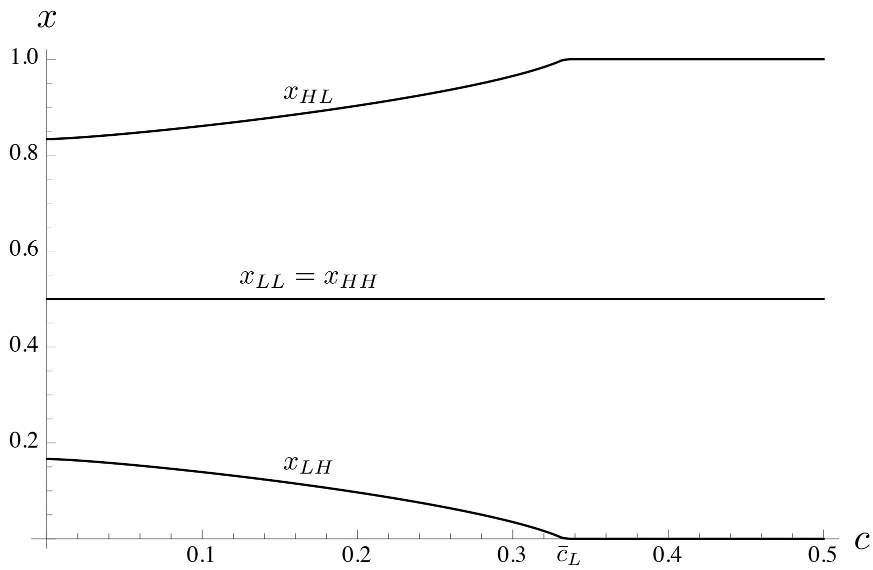

Figure 6: Equilibrium demand in various states for triangular distributions.

5.5 Welfare

What are the welfare consequences of introducing correlation of preferences into the model? Consumers observe the purchasing decisions of their predecessors and thus visit the store offering higher utility realizations with higher probability. Since the search rule is a cutoff rule, we have that total Surplus can be written as:

$$\begin{aligned}
W &= \sum_{S,S'} \int_{\underline{u}}^{\hat{w}} \big(uG_S(u)g_{S'}(u) + uG_{S'}(u)g_S(u)\big)du \\
&+ \sum_{S,S'} \bigg[x_{SS'} \left(\int_{\hat{w}}^{\bar{u}} ug_S(u)du + G_S(\hat{w}) \int_{\hat{w}}^{\bar{u}} ug_{S'}(u)du \right) \\
&+ (1 - x_{SS'}) \left(\int_{\hat{w}}^{\bar{u}} ug_{S'}(u)du + G_{S'}(\hat{w}) \int_{\hat{w}}^{\bar{u}} ug_S(u)du \right) \bigg] \bigg) \\
&- c \sum_{S,S'} \big(x_{S,S'}G_S(\tilde{w}) + (1 - x_{S,S'})G_{S'}(\tilde{w})\big)
\end{aligned}$$

The first term represents the expected utility of a consumer whose utility draws

[20]In the classical definition, a herd occurs when individuals disregard their private information and follow the crowd. In our simple model, individuals do not possess prior information.

in both stores are below the cutoff and, therefore, is independent of market shares because such a consumer searches regardless of where she makes her first visit. The remaining terms increase in the difference between the market share of a firm offering a High and a Low distribution $(x_{HL} - x_{LH})$, and, therefore, it is higher in our model as compared to ARW. This means that

Proposition 7. *Welfare is higher if consumers observe others.*

Perhaps the more interesting result concerns the comparative statics of welfare with respect to search costs. Information about predecessors and search constitute substitute sources of information. As the search cost vanishes, search is a more efficient signal and so the prior information becomes irrelevant. On the other hand, as search cost increases, information about predecessors becomes increasingly important. This substitution effect is at the core of the following result.

Proposition 8. *Increasing the search cost may have a non monotone effect on welfare. For arbitrarily low search costs, welfare decreases in the search cost. On the other hand, for high enough search cost there are distributions G_H and G_L such that welfare increases in the search cost.*

The first part is rather trivial. If the search cost is sufficiently low, almost every consumer searches and an increase of the search cost induces a first order, direct and negative effect on welfare. Since consumers do not stick to their first option, prior information is not valuable and, thus, welfare is reduced. The second part, however, is less intuitive. When almost every consumer buys at the first store she visits, an increase of the search cost has a negligible effect on total search expenditure. Marginal consumers are discouraged from searching but those do not matter for welfare because their utility loss is negligible (their cutoff rule being optimal). Importantly, however, these marginal consumers fail to internalize the information externality they originate when searching. Naive intuition would suggest that this externality is positive, since consumers who search acquire valuable information and pass it on to their successors. Importantly, however, their successors obtain only a biased signal since they do not learn their search pattern, only their purchasing decision. As it turns out, when search costs are very high, a searcher is more likely to buy in a store with a Low distribution than in a store with a High distribution and thus passes on *bad* information to her successor. Since successors deem it unlikely that their predecessor searched, they follow them to the store with a Low distribution. Therefore, the net effect of an increase in search cost depends on the relative magnitude of the direct negative effect and the indirect effect on information aggregation. In the proof we show that for Triangular distributions it is indeed the case that social welfare is non-monotone in the search cost.

6 Conclusion

In this paper, our aim was to introduce observational learning into a standard consumer search model with horizontally differentiated products. We have developed a simple and tractable extension of the ARW framework, whereby consumers observe others and visit first the firm where their predecessor has purchased. In the simplest version of this model, this amounts to a behavioral modification of the standard framework that, nonetheless, has strong implications for the equilibrium prices. We further developed a rationale for such behavior through correlated preferences and showed that the qualitative implications of the original model remain unchanged.

In order to highlight the core mechanism through the social multiplier of demand, we have abstracted from a number of important issues. First, firms are restricted to serve all incoming consumers at the same price. This assumption, however, can be justified if price-adjustment is *slow* when compared to the speed of learning among consumers. Second, in our model firms choose only prices, so we have abstracted from such important choice variables as product design or advertising.[21] For instance, niche products induce a different learning process than mass products and this is likely to have implications for prices (see Chen et al. (2011)). Similarly, advertising spurs consumer awareness for new products and, therefore, may soften the price-elasticity of the residual demand. On the other hand, many advertising decisions are intrinsically linked to consumers' interactions. For instance, most products have a recognizable logo stamped on them so that other consumers may identify it. Thus, firms may actively affect the speed of learning about new products by advertising and branding. We believe that these features can be incorporated within our basic framework.

Finally, our model provides a simple framework to evaluate the effect of the Internet on consumer search markets. On the one hand, online platforms facilitate the comparison of different products and, thus, reduce search costs. On the other hand, online social networks foster social interactions. As it turns out, these two features have opposite effects on the size of the social spillover and, therefore, provide different implications for equilibrium prices. Therefore, a potential avenue for future research is to empirically separate the effects of these two sources of information on prices and demand elasticities in consumer search markets.

[21] See Bar-Isaac et al. (2011) and Haan and Moraga-Gonzalez (2011) who build on the ARW model to endogenize product design and study informative advertising, respectively.

Appendix A: Proofs

Proof of Proposition 1

Using the demand in (7), the FOC for firm 1's profit maximization after imposing that in equilibrium $M_1^* + M_2^* = 1$ is

$$\frac{1}{2} + p\frac{(\partial M_1/\partial p_1 + \partial M_2/\partial p_1)}{2(1-\delta(M_1 - M_2))} = 0.$$

In the symmetric equilibrium $M_1 + M_2 = 1$, $Q_1 = 1/2$, $\partial M_1/\partial p_1 = -\int_{\underline{u}}^{\hat{w}} g(u)^2\,du - (1-G(\hat{w}))g(\hat{w})$ and $\partial M_2/\partial p_1 = -\int_{\underline{u}}^{\hat{w}} g(u)^2\,du$. So we can solve for $\tilde{p}$ from the above to obtain

$$\tilde{p} = \frac{1-\delta\eta^*}{2\int_{\underline{u}}^{\hat{w}} g(u)^2\,du + (1-G(\hat{w}))g(\hat{w})}.$$

It is well known that in the ARW model the price is

$$\hat{p} = \frac{1}{2\int_{\underline{u}}^{\hat{w}} g(u)^2\,du + (1-G(\hat{w}))g(\hat{w})},$$

thus $\tilde{p} = (1-\delta\eta^*)\hat{p}$.

Even though the candidate equilibrium price is clearly unique, it still remains to be shown that no firm wants to deviate from the candidate equilibrium. We shall first show that the SOC is satisfied locally for any $G(\cdot)$ that satisfies log-concavity of $1-G(u)$. Then we show that the profit function is globally concave for the special case where $G(u)$ is uniform.

We take the SOC for firm 1 and evaluate it at $p_1 = \tilde{p} = (1-\delta(1-G(\hat{w})))\hat{p}$.

$$\begin{aligned}
\frac{\partial^2\Pi_1(p_1,\tilde{p})}{\partial p_1^2}\Big|_{p_1=\tilde{p}} &= \Big[(1-G(\hat{w}))(\delta+\delta(G(\hat{w})-2)G(\hat{w})-1)g(\hat{w}) \\
&- 4(\delta-2)(G(\hat{w})-1)g(\hat{w})\int_{\hat{w}}^{\hat{w}} g(u)^2\,du - 8\left(\int_{\hat{w}}^{\hat{w}} g(u)^2\,du\right)^2 \\
&+ g(\hat{w})^2(\delta+\delta(G(\hat{w})-2)G(\hat{w})-1) + (3(\delta-1) \\
&+ (3\delta-2)(G(\hat{w})-2)G(\hat{w}))g(\hat{w})^2\Big] \Big/ \Big[2(1-\delta+\delta(2-G(\hat{w}))G(\hat{w}))\times \\
&\times \left(2\int_{\underline{u}}^{\hat{w}} g(u)^2\,du + (1-G(\hat{w}))g(\hat{w})\right)\Big].
\end{aligned}$$

The denominator is positive. The derivative of the numerator with respect to δ is

$$(1-G(\hat{w}))\left(4g(\hat{w})\left(\int_{\underline{u}}^{\hat{w}} g(u)^2\,du\right) + (1-G(\hat{w}))g(\underline{u})^2 + (1-G(\hat{w}))\left((1-G(\hat{w}))g(\hat{w}) + 3g(\hat{w})^2\right)\right),$$

which is positive because $(1-G(\hat{w}))g(\hat{w})+3g(\hat{w})^2>0$ by the log-concavity of $1-G(u)$. Thus the SOC is increasing in δ. We then consider the numerator of SOC for $\delta=1$ to obtain

$$-8\left(\int_{\underline{u}}^{\hat{w}} g(u)^2\,du\right)^2-4(1-G(\hat{w}))g(\hat{w})\int_{\underline{u}}^{\hat{w}} g(u)^2\,du-(2-G(\hat{w}))G(\hat{w})\times \\ \times\left[g(\underline{u})^2+g(\hat{w})^2+(1-G(\hat{w}))g'(\hat{w})\right].$$

This is negative by the log-concavity of $1-G(u)$ which implies that the expression in square brackets is positive. This proves that $\frac{\partial^2\Pi_1(p_1,\tilde{p})}{\partial p_1^2}\Big|_{p_1=\tilde{p}}<0$, thus $p_1=\tilde{p}$ is the local maximizer of firm 1's profits.

Now we show that $\tilde{p}$ is the global maximizer for the special case where $G(\cdot)\sim U(0,1)$. In that case $\tilde{p}=\frac{1-\delta(1-\hat{w})^2}{1+\hat{w}}$.

There are three cases depending on p_1. For $p_1\in[\tilde{p},1+\tilde{p}-\hat{w})$, after some manipulations, the second derivative of profits can be written as

$$\frac{\partial^2\Pi_1(p_1,\tilde{p})}{\partial p_1^2}=-\frac{(\hat{w}+1)^3(\delta(\hat{w}-1)+\hat{w}+1)\left(\delta(\hat{w}-1)^2-1\right)^2}{\left(\delta(1-\hat{w})\left(p\hat{w}+p+\hat{w}^2-2\right)+\delta^2(1-\hat{w})^3+\hat{w}+1\right)^3}.$$

The denominator is clearly positive since $1+\hat{w}-\delta(1-\hat{w})>0$. The numerator is increasing in p_1, thus it reaches its minimum at $p_1=\tilde{p}=\frac{1-\delta(1-\hat{w})^2}{1+\hat{w}}$. Plugging this value into the numerator, and simplifying yields $(1+\hat{w})^3\left(1-\delta(1-\hat{w})^2\right)^3$, which is positive, therefore the numerator is positive for all p_1 in the interval. Thus, the second derivative of firm 1's profit is negative for all p_1 in this interval.

Now consider $p_1\geq 1+\tilde{p}-\hat{w}$, which means that p_1 is so high that all consumers who visit firm 1 first go on to search firm 2. In this case,

$$\frac{\partial^2\Pi_1(p_1,\tilde{p})}{\partial p_1^2}=-2.$$

Now consider $\tilde{p}-\hat{w}<p_1<\tilde{p}$. It can be shown that in this case the second derivative of profits has the opposite sign of

$$f=\delta^2p_1^3(\hat{w}-1)^2(\hat{w}+1)^3+3\delta p_1^2(\hat{w}-1)(\hat{w}+1)^2(\delta(\hat{w}-1)+\hat{w}+1)\left(\delta(\hat{w}-1)^2-1\right) \\ +3p_1(\hat{w}+1)(\delta(\hat{w}-1)+\hat{w}+1)^2\left(\delta(\hat{w}-1)^2-1\right)^2+\left(\delta(\hat{w}-1)^2-1\right)^2 \\ \times\left(4\delta+\delta^2\left(3\hat{w}^2-4\right)(\hat{w}-1)^2+\hat{w}^2(\hat{w}+2)^2+\delta^3(\hat{w}-1)^4+\delta\hat{w}(\hat{w}(\hat{w}(3\hat{w}+2)-7)-2)-1\right),$$

which is increasing in p_1, thus its minimum is reached at the lower bound of p_1. There are two cases depending on δ. For $\delta<\frac{1-\hat{w}(1+\hat{w})}{(1-\hat{w})^2}$ (in which case the $\tilde{p}-\hat{w}>0$)

so that the lower bound on p_1 is $\tilde{p} - \hat{w}$. Plugging it in simplifies f as

$$\begin{aligned} f &= \delta^2(\hat{w}-2)\left(\hat{w}^2-1\right)^2\left(\hat{w}(2\hat{w}+3)-3\right)-(\hat{w}+1)^2\left(2\hat{w}^2+\hat{w}-2\right)+2\delta^3(\hat{w}+1)^2(\hat{w}-1)^5 \\ &+ \delta(\hat{w}+1)^2((\hat{w}-6)\hat{w}(\hat{w}+1)+6)(\hat{w}-1). \end{aligned}$$

The above is minimized at $\hat{w} = 0$ and $\delta = 1$ where it is equal to 0, thus it is negative for all other cases.

The second case is where $\delta \geq \frac{1-\hat{w}(1+\hat{w})}{(1-\hat{w})^2}$, so that the lower bound on p_1 is 0. Plugging 0 into the expression for f gives

$$\begin{aligned} f &= \left(4\delta+\delta^2\left(3\hat{w}^2-4\right)(\hat{w}-1)^2+\hat{w}^2(\hat{w}+2)^2+\delta^3(\hat{w}-1)^4+\delta\hat{w}(\hat{w}(\hat{w}(3\hat{w}+2)-7)-2)-1\right) \\ &\times \left(1-\delta(1-\hat{w})^2\right)^2. \end{aligned}$$

The term on the second line is positive. The term on the first line is minimized at $\hat{w} = 0$ and $\delta = 0$, where it equals zero, thus otherwise it is positive. This proves that f is positive in both cases, thus the second derivative of profits is negative for $\tilde{p} - \hat{w} < p_1 < \tilde{p}$

Finally, consider $p_1 < \tilde{p} - \hat{w}$, in which case p_1 is so low that all consumer who arrives to firm 1 buy from it. In this case

$$\frac{\partial^2 \Pi_1(p_1, \tilde{p})}{\partial p_1^2} = 0,$$

but the profit function is linear and increasing in p_1, thus the maximizer can never be in this interval.

This establishes that for the uniform distribution of valuations, firm 1's profit is concave in p_1 and so $\tilde{p}$ is its global maximizer. Thus $p_i = \tilde{p}$ for $i = 1, 2$ constitutes the unique symmetric pure strategy equilibrium.

We finally prove that for any distribution, prices converge to zero as $\delta \to 1$ and $c \to \bar{c}$ in any symmetric equilibrium. Let $\underline{p}$ be the lowest price in the support. A firm charging $\underline{p}$ obtains an expected market share $x(\underline{p})$. First, if the lowest upper bound of $x(\underline{p})$ is 1, then, it must be that $x(\underline{p}) \to 1$ for $c \to \bar{c}$, since firms retain market power for smaller search costs. If indeed $x(\underline{p}) \to 1$ as $c \to \bar{c}$, randomization implies that either $\underline{p} \to 0$ proving the result or the price distribution becomes degenerate. But the preceding argument shows that if a pure-strategy equilibrium exists it must have zero prices. Thus, $\underline{p} \to 0$ also in that case. Finally, assume that $x(\underline{p}) \leq \bar{x} < 1$ and consider a deviation to a price $\underline{p} - (\bar{c} - c)$. Clearly $w(p) = \underline{u}$ and, therefore, $x(p) = 1$. Hence, if $x(\underline{p})\underline{p} < \underline{p} - (\bar{c} - c)$, this deviation is profitable. Hence, in any equilibrium $\underline{p}(1 - \bar{x}) \leq \bar{c} - c$. Since $\bar{x}$ is independent of c, it must be that $\underline{p}$ converges to zero, and randomization implies that the expected price also converges to zero.

Proof of Proposition 2

The last part follows directly from $\eta^* = (1 - G(\hat{w}))^*$ which is positive and less than 1 for all $c > 0$. To see that the price increases in the search cost for low enough c, notice that the derivative of $\tilde{p}$ with respect to $\hat{w}$ (which is decreasing in c) at $\hat{w} = \bar{u}$ is

$$\frac{\partial p}{\partial \hat{\omega}}\bigg|_{\hat{\omega}=\bar{u}} = -\left(\frac{g(\bar{u})}{2\int_{\underline{u}}^{\bar{u}} g(u)du}\right)^2$$

which is negative for any distribution and any δ. On the other hand, at the lower bound, the derivative is

$$\frac{\partial p}{\partial \hat{\omega}}\bigg|_{\hat{\omega}=\underline{u}} = 3\delta - 1 - \frac{(1-\delta)g(\underline{u})}{g(\underline{u})^2},$$

which is equal to 2 at $\delta = 1$. It follows directly that there exists $\bar{\delta} < 1$ such that for all $\delta > \bar{\delta}$ the derivative is positive, thus the price is decreasing in c.

Proof of Proposition 3

In order to show that the price is lower with emulation we need that $\frac{nG(\hat{w})-G(\hat{w})^n}{(n-1)} < 1$. To see this notice that $\frac{nG(\hat{w})-G(\hat{w})^n}{n-1} < 1$ is equivalent to

$$n > \frac{1 - G^n(\hat{w})}{1 - G(\hat{w})}.$$

This always holds for $c > 0$ because $\frac{1-G^n(\hat{w})}{1-G(\hat{w})} = \sum_{j=0}^{n-1} G^j(\hat{w}) < \sum_{j=0}^{n-1} 1 = n$.

To prove that the ratio $\tilde{p}_n/\hat{p}_n$ is decreasing in n note that $\tilde{p}_n/\hat{p}_n = \frac{nG(\hat{w})-G(\hat{w})^n}{n-1}$, which is decreasing in n if for any $n \geq 2$ we have

$$\frac{nG(\hat{w}) - G(\hat{w})^n}{n-1} < \frac{(n-1)G(\hat{w}) - G(\hat{w})^{n-1}}{n-2},$$

which can be rewritten as

$$G(\hat{w})^{n-2}(n - 1 - (n-2)G(\hat{w})) < 1.$$

The LHS of the above is strictly increasing in $G(\hat{w})$ for $G(\hat{w}) < 1$, thus the LHS reaches its maximum at $G(\hat{w}) = 1$, where it is equal to 1. It follows that $\frac{nG(\hat{w})-G(\hat{w})^n}{n-1}$ is decreasing in n for $c > 0 (G(\hat{w}) < 1)$.

To prove that $\tilde{p}_n$ is decreasing in n we note that Anderson and Renault (1999) show that $\hat{p}_n$ is decreasing in n, which given that $\tilde{p}_n/\hat{p}_n$ is also decreasing immediately implies that $\tilde{p}_n$ is also decreasing in n.

Finally, we show that the limit of $\tilde{p}_n$ when $c \to \bar{c}$ is 0. This follows from $\lim_{c\to\bar{c}} \eta_n^* = 1 - \frac{n-1^n}{n-1} = 0$. A simple modification of the argument presented in the Proof of Proposition 2 shows that this must hold in any equilibrium.

Proof of Proposition 4

The implicit derivative of x with respect to p_1 can be found from (17) as

$$\frac{\partial x}{\partial p_1} = \frac{z(x)(\partial M_1/\partial p_1 - \partial M_2/\partial p_1) + \partial M_2/\partial p_1}{1 - z'(x)(M_1 - M_2)}.$$

If we now impose symmetry, then $x = 1/2$ and $z(1/2) = 1/2$ so that the necessary condition for the symmetric pure strategy equilibrium price becomes

$$\tilde{p} = \frac{1 - (M_1^* - M_2^*)z'(1/2)}{\partial M_1/\partial p_1 + \partial M_2/\partial p_1} = \frac{(1 - G(\hat{w})^2\zeta(k))}{2\int_{\underline{u}}^{\hat{w}} g(u)^2 du + (1 - G(\hat{w}))g(\hat{w})} = (1 - \eta_k^*)\hat{p},$$

where in the last transformation we used the well-known expression for the ARW price

$$\hat{p} = \frac{1}{2\int_{\underline{u}}^{\hat{w}} g(u)^2 du + (1 - G(\hat{w}))g(\hat{w})}.$$

As shown in the text, $\zeta(k)$ is increasing in k, therefore, if the equilibrium exists, $\tilde{p}$ is decreasing in k.

As for the non-existence of the pure strategy equilibrium, note that for $c = \bar{c}_k$, $\tilde{p} = 0$ because, by definition, $1 - \eta_k^* = 1$. At the same time, $G(\hat{w}) > 0$, thus a positive fraction of consumers searches, thus firm 1 can earn strictly positive profit by a deviation to $p_1 > 0 = p^*$. In fact, there exists $c' < \bar{c}_k$, such that no pure strategy equilibrium exists for any $c > c'$.

Finally, notice that the same argument used in the Proof of Proposition 2 extends for any $z'(1/2) \leq 1$ and, therefore, the mixed strategy equilibrium becomes degenerate at $c \to \bar{c}$.

Appendix B: Correlated Preferences

The following lemma shows that the stationary equilibrium we study can be reached as the limit of the dynamic economy of the model for T large enough provided that $G(\hat{w}(p^*)) > 0$.

Lemma 1. *Suppose there is a unique cutoff $\tilde{w}(p_1) > \underline{u}$ solving equation (19) and let $w(p_1)$ be the optimal cutoff rule. Then, for every $\epsilon > 0$, there exists a $T^* < \infty$ such that for all (non-negative) prices $\|\tilde{w}(p_1) - w(p_1)\| < \epsilon$.*

Proof of Lemma 1

We first establish that market shares converge for any pair of non-negative prices. To see this, notice first that $M_1(p_1, p^*)$ and $M_2(p_1, p^*)$ are independent of t. The evolution of market shares can be readily computed as

$$|x^t - x^{t-1}| = |x^{t-1} - x^{t-2}|(M_1(p_1, p^*) - M_2(p_1, p^*)) \tag{24}$$

Notice that that $M_1 - M_2 \leq \max_S(1 - G_S(\tilde{w}(p^*))$.[22] If p^* is such that $\tilde{w}(p_1) = \bar{u}$, then market shares are independent of time because all consumers go through firm 2. If $\tilde{w}(p_1) = \underline{u}$, firm 1 is an absorbing state of the process independently of p_2 and the state S'. Hence, assume that p_1 is such that $G_S(\tilde{w}(p_1)) \in (0, 1)$

$$|x^t - x^{t-1}| \leq [\max_S(1 - G_S(\tilde{w}(p^*)))]^t |x^1 - x^0| \tag{25}$$

or

$$|x^t - x^{t-1}| \leq [\max_S(1 - G_S(\tilde{w}(p^*)))]^t |x^W - \frac{1}{2}| \tag{26}$$

where x^W is the share of firm 1 in ARW (i.e. the first consumer). Clearly, this Fixed Point converges to the stationary market shares by Blackwell's Theorem and the parameter of convergence is $\{\max_S(1 - G_S(\hat{w}(p^*))\}$ which is strictly less than one. For every $\epsilon > 0$ and for every $p \geq 0$, there exists $T_1 < \infty$ such that $T_1 = \frac{\ln(\phi * \epsilon)}{\ln((1 - G_L(\tilde{w}(0))))}$ and

$$|x^t - x^{t-1}| \leq \phi\epsilon$$

for every $t > T_1$ and some $\phi > 0$. Now we can compute the optimal cutoff rule for a consumer who knew his own arrival time. Indeed, since $\lambda(u)$ and $x_{S,S'}(p_1)$ are continuous functions, the conditional probabilities of the different states given some (u, p_1) realization can be written as

$$q_{T_1}(u; p_1) = \frac{x_{HH}^{T_1}(p_1)\lambda(u) + x_{LH}^{T_1}(p_1)(1 - \lambda(u))}{(x_{HH}^{T_1}(p_1) + x_{HL}^{T_1}(p_1))\lambda(u) + (x_{LH}^{T_1}(p) + x_{LL}^{T_1}(p_1))(1 - \lambda(u))}. \tag{27}$$

which differs from q^* as computed from Equation (21) because it depends on t. The remainder of the proof establishes that this difference is arbitrarily small. Notice that $x_{S,S'}^{T_1} \in [x_{S,S'} - \phi\epsilon, x_{S,S'} + \phi\epsilon]$, we can write

$$sup \parallel q_{T_1}, q^* \parallel \leq \frac{\phi\epsilon}{\lambda(x_{HH} + x_{HL}) + (1 - \lambda)(x_{LH} + x_{LL})} < \frac{\phi\epsilon}{G_L(\hat{w}(0))(1 - G_L(\hat{w}(p_1))} \tag{28}$$

Let $T^* = RT_1$, for R large enough we have that

$$\sup \parallel \sum_{t=1}^{T^*} \frac{1}{T^*} q_t(u, p_1), \sum_{t=1}^{T^*} \frac{1}{T^*} q_t^*(u, p) \parallel < \frac{(R-1)\frac{\phi\epsilon}{G_L(\hat{w}(0))(1 - G_L(\hat{w}(p_1))} + 1}{R}$$

$$< \frac{2\phi\epsilon}{G_L(\hat{w}(0))(1 - G_L(\hat{w}(p_1))}$$

[22]Here M_1 is at most 1, and M_2 is at least $G_S(\tilde{w}(p^*))$.

and now let $\phi = \sup_{p:\bar{u}>\hat{w}(p!)>\underline{u}} \frac{1}{2} G_L(\hat{w}(0))(1-G_L(\hat{w}(p_1)))\underline{g}(u)$, so that the difference between the stationary probability measure and the actual probability measure that almost everyone observes is smaller than $\epsilon \underline{g}(u)$. Using Equation (19), it is easy to verify that $G(\hat{w}(p))$ is a continuous contraction in the probability measure q. Since G is strictly increasing, G^{-1} is uniformly continuous with parameter $\frac{1}{\underline{g}(u)} \geq 0$, and this implies that $\|\tilde{w}(p_1) - w(p_1)\| < \epsilon$ as required.

Proof of Proposition 5

In equilibrium $x_{HH} = x_{LL} = 1/2$ and $x_{HL} > 1/2 > x_{LH}$, thus $\lambda(u) < 1/2$ for all u. From (19) it follows that its LHS is higher than the LHS of (1) for the same w. This immediately implies that $\tilde{w} < \hat{w}$.

Proof of Proposition 6

Fix c and let p^* be the conjectured price of the rival firm. We prove that for any price $p^* > \bar{p}(c)$ there is a profitable deviation to $p^* - (\bar{c}_L - c)$ that captures the full demand.[23] Indeed, notice that

$$\int_{\underline{u}}^{\bar{u}} (u - \underline{u} - (\bar{c}_L - c)) dG_L(u) = c$$

by definition of c_L. Since $\lambda(\underline{u}) = 0$ a firm charging $p^* - (\bar{c}_L - c)$ retains all its incoming consumers. Because of the social multiplier of demand, this implies that its long-run market share is 1. This yields a profit of $p^* - (\bar{c}_L - c)$. Therefore, every price p^* such that

$$\frac{1}{2} p^* \leq p^* - (\bar{c}_L - c)$$

is inconsistent with an equilibrium. Thus, $p^* \leq p(c) = 2(\bar{c}_L - c)$. Clearly, as $c \to \bar{c}_L$, $p(c) \to 0$ and the result follows.

Proof of Proposition 8

By the Envelope Theorem, since $\tilde{w}$ is chosen optimally given c, a marginal change in c affects W only through the direct effect of savings in search expenditures and the indirect effect of information aggregation via $x_{SS'}$. When $c \to 0$, there is no value of information since search is free, and, thus, the only value comes from savings. On the other hand, if $c \to \bar{c}$, there is a (small) direct effect on savings since the measure of searchers is $\frac{1}{4} \sum x_{SS'} G_S(u)$. Information is useful since search is costly so that the only question is whether more or less information is aggregated. Since $x_{HH} = x_{LL} = \frac{1}{2}$, the only question is the sign of $\frac{\partial x_{HL}}{\partial \tilde{w}}$.

$$\frac{\partial x_{HL}}{\partial \tilde{w}} = \frac{G_L(\tilde{w}) g_H(\tilde{w}) - G_H(\tilde{w}) g_L(\tilde{w})}{(G_H(\tilde{w}) + G_L(\tilde{w}))^2} > 0 \tag{29}$$

[23] The argument can be extended to mixed strategies by choosing p^* to be the lower bound of the support of the price distribution.

where the first equality comes from the definition of market shares at $\tilde{w} \to \underline{u}$ and the last inequality comes from the MLRP, but $\tilde{w}$ is decreasing in c. In particular,

$$\frac{\partial \tilde{w}}{\partial c} = -\frac{1}{1 - \frac{1}{4}\sum x_{SS'} G_{S'}(\tilde{w})} < -\frac{1}{1 - G_H(\tilde{w})}$$

Thus, welfare increases in search costs if

$$\frac{G_L(\tilde{w})g_H(\tilde{w}) - G_H(\tilde{w})g_L(\tilde{w})}{(G_H(\tilde{w}) + G_L(\tilde{w}))^2} \frac{1}{1 - G_H(\tilde{w})}(V_H(\tilde{w}) - V_L(\tilde{w}))\frac{1}{2} \geq \frac{1}{4}\sum \frac{G_S(\tilde{w})G_{S'}(\tilde{w})}{G_S(\tilde{w}) + G_{S'}(\tilde{w})}$$

which yields

$$(G_L(\tilde{w})g_H(\tilde{w}) - G_H(\tilde{w})g_L(\tilde{w}))(V_H(\tilde{w}) - V_L(\tilde{w})) \geq 2(G_H(\tilde{w}) + G_L(\tilde{w}))^2)(1 - G_H(\tilde{w}))\sum \frac{G_j(\tilde{w})G_i(\tilde{w})}{G_i(\tilde{w}) + G_j(\tilde{w})}.$$

For the case of the triangular distribution this becomes

$$(\tilde{w})^2\frac{1}{3} > (\tilde{w})^2(1 - (\tilde{w})^2)\{\tilde{w} + (\tilde{w})(2\tilde{w} - (\tilde{w})^2)\} = (\tilde{w})^3(1 - (\tilde{w})^2)(1 + 2\tilde{w} - (\tilde{w})^2)$$

which holds for $\tilde{w}$ small enough.

Appendix C : Finite Outside Option

We have followed Anderson and Renault (1999) and assumed that consumers have to buy from one of the firms because their outside option is arbitrarily bad. This assumption greatly simplifies the analysis but it is not without loss. The main consideration is that when there is a sufficiently good outside option, for high enough search costs consumer do not search, and firms charge monopoly prices. This means that there is a limit to how low prices can be when search costs are high, because eventually consumers stop searching and prices jump up.

In this Appendix we extend the model to incorporate a zero outside option using the baseline model presented in Section 4. This is the Wolinsky's version of the ARW model. In order to deal with the issue that some consumers do not buy, we assume that every consumer observes the close predecessors who *purchased* one of the two goods. As before we focus on the case where $\delta \to 1$. Firm 1's share of first visits is now $z(x) = x/X$, where x is the demand of firm 1 and X is total market demand. We have

$$\begin{aligned} x(p_1, p^*) &= \frac{x(p_1, p^*)}{X}(1 - G(\hat{w} + p_1 - p^*)) + \Big(1 - \frac{x(p_1, p^*)}{X}\Big)G(\hat{w})(1 - G(\hat{w} + p_1 - p^*)) \\ &+ \int_{p_1}^{\hat{w}+p_1-p^*} G(u - p_1 + p^*)g(u)du, \end{aligned}$$

where p_1 is the price charged by firm 1 and p^* the equilibrium price. This expression is similar to (5) except for the usage of stationary market shares x/X and the fact that only consumers with valuations above p_1 purchase the product (notice that the integral runs from p_1 instead of $\underline{u}$).

Total demand can be readily computed since those consumers who do not purchase in any of the two firms is $G(p_1)G(p^*)$, which gives the total demand $X = 1 - G(p_1)G(p^*)$. One can now solve for $x(p_1, p^*)$, maximize firm 1's profit given firm 1's demand, and impose that in equilibrium $p_1 = p^*$.

Before we fully characterize the above equilibrium, we should note that with a zero outside option consumers may stop searching, which is the case when $p^* > \hat{w}$. Thus when search cost is sufficiently large, consumers do not search and firms charge monopoly prices.

Proposition 9. *Under suitable conditions on $G(w)$, there exist two thresholds, c_1 and c_2 with $\bar{c}_1 < \bar{c}_2$, such that*
(i) with observational learning equilibrium price is $\tilde{p}$ for $c \leq \bar{c}_1$ and p^m otherwise;
(ii) without observational learning equilibrium price is $\hat{p}$ for $c \leq \bar{c}_2$ and p^m otherwise.
(iii) for $c \leq \bar{c}_2$ the price in the model with emulation is lower than in the model without it.

Proof. Solving for x from (30), taking derivative with respect to p_1 and imposing $p_1 = p^*$ gives the following pricing rule

$$\tilde{p} = \frac{\big(1-G(\tilde{p})^2\big)\big((2-G(\hat{w}))G(\hat{w})-G(\tilde{p})^2\big)}{2(1-G(\tilde{p})^2)\int_p^{\hat{w}} g(v)^2\,dv+G(\tilde{p})(1-2G(\tilde{p})^2+(2-G(\hat{w}))G(\hat{w}))g(\tilde{p})+(1-G(\tilde{p})^2)(1-G(\hat{w}))g(\hat{w})}. \tag{30}$$

The above only holds for $p \leq \hat{w}$, which gives the threshold on c, denoted by $\bar{c}_2$ From (30), $\bar{c}_2$ is such that the corresponding w solves

$$w = \frac{2G(w)\,(1 - G(w)^2)}{(2G(w)^2 + G(w) + 1)\,g(w)}. \tag{31}$$

Now consider the Wolinsky pricing rule derived under the assumption that half of consumers make first visits to firm 1.

$$\hat{p} = \frac{1-G(\hat{p})^2}{2\Big(\int_{\hat{p}}^{\hat{w}} g(v)^2\,dv+G(\hat{p})g(\hat{p})+\frac{1}{2}(1-G(\hat{w}))g(\hat{w})\Big)}. \tag{32}$$

As before, the above only holds for c below a threshold, denoted by $\bar{c}_1$. $\bar{c}_1$ is such that $p = w$, and corresponds to w that solves

$$w = \frac{1 - G(w)}{g(w)}.$$

It is easy to show that $\frac{2G(w)\left(1-G(w)^2\right)}{(2G(w)^2+G(w)+1)g(w)} < \frac{1-G(w)^2}{2g(w)G(w)}$ in the relevant range of $\hat{w}$, therefore $\bar{c}_1 < \bar{c}_2$.

We still have to show the uniqueness and the existence of $\bar{c}_1$ and $\bar{c}_2$. For $\bar{c}_1$ see Janssen and Shelegia (2014) for the proof. For our model, note that $\bar{c}_2$ is defined as c such that $\tilde{p} = \hat{w}$. Given that $G(\bar{u}) = 1$, which makes the RHS of (31) equal to 0, such a solution always exits, but might not be unique. Thus we require that $G(w)$ is such that (31) has a unique solution.[24] If it is indeed unique, it is trivial to show that $p^M > w$, so that indeed once $c > \bar{c}_1$, firms charge $p^M > \hat{w}$ and no consumer searches.[25]

In both cases, for $c > \bar{c}_i$, firms charge p^M and consumers stop at the first firm. This implies that in the model with emulation all consumers follow the first consumer, who is allocated at random. Thus for c above the corresponding threshold, both models are identical.

Finally, to show (iii) notice for $c \in [\bar{c}_1, \bar{c}_2)$ the price with emulation is $\tilde{p}$ and is strictly below p^M, the price in the ARW model. Now we need to show that $\tilde{p} < \hat{p}$ for $c < \bar{c}_1$. To do so, we show that the ratio of the LHS of (30) to the LHS of (32) for the same p is less than 1. After some rearrangement one can write this condition to be the same as

$$2 \int_p^{\hat{w}} g(v)^2 \, dv + G(p)g(p) + (1 - G(\hat{w}))g(\hat{w}) > 0,$$

which holds for any $p < \hat{w}$. Thus for any $c \leq \bar{c}_1$, the solution to (30) is higher than the solution to (32), therefore $\tilde{p} < \hat{p}$. □

In Figure 7 below we depict equilibrium prices for $G(\cdot) \sim U[0, 1]$. The gray curve depicts standard Wolinsky price as a function of c. For relatively low c, the price is below the reservation utility and increasing in c. Once c reaches the threshold $\bar{c}_1$, the price is at the monopoly level, and stays there for all higher c. As shown above, the price with emulation is lower (the black curve). It is also non-monotone, and never reaches zero because once $c > \bar{c}_2$, search stops and the price jumps to the monopoly

[24] It is unique for the uniform distribution.

[25] In principle, it is possible that at the threshold, $\hat{w} > p^M$, in which case no pure strategy equilibrium exists for c immediately above $\bar{c}_2$ because conditional on consumers not searching, firms charge p^M and induce search, but conditional on consumers searching, they charge $p > \hat{w}$, precluding search.

level (1/2 for the uniform distribution). Note that in both models, when c exceeds the respective threshold, a version of the Diamond Paradox occurs - consumers do not search, and firms charge the monopoly price. Because, $\bar{c}_2 > \bar{c}_1$, with emulation the Diamond Paradox appears for higher search cost than in the Wolinsky model. Thus emulation allows consumers to collectively escape the paradox by putting sufficient downward pressure on prices. Moreover, once the search cost exceeds $\bar{c}_2$, prices jump up discontinuously, leading to a stark contrast between markets with small and large search costs. Markets with $c \leq \bar{c}_2$ are characterized by low prices, whereas markets with $c > \bar{c}_2$ are characterized by monopoly prices, In contrast, in the baseline model the transition is smooth.

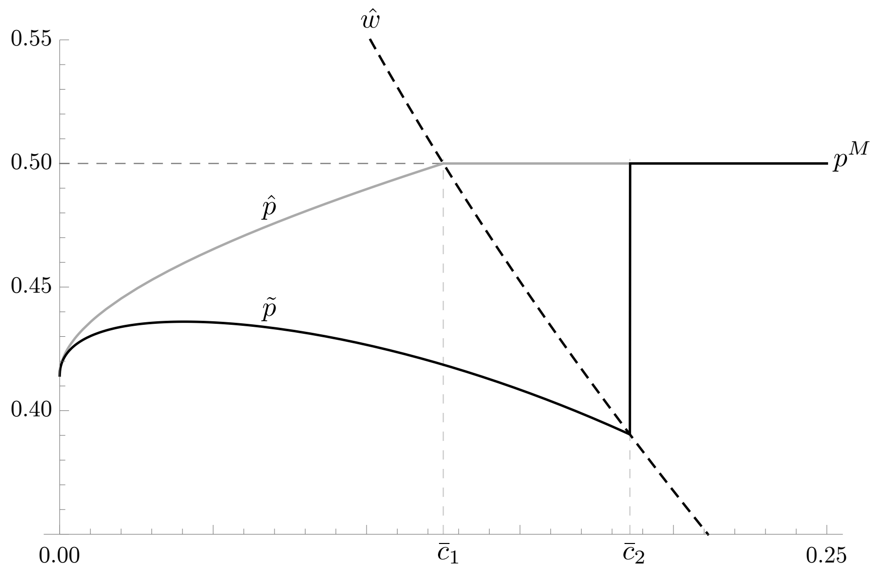

Figure 7: Equilibrium prices in the model with zero outside option for $G \sim U[0, 1]$.

To conclude, note that prices are never close to marginal cost because consumers stop searching when search cost is high, the reason for zero price in the model without outside option. As a result, whether the price is decreasing in search cost depends on the shape of the distribution G. This occurs, for instance, if the price with $c = 0$ is higher than the price when $c = \bar{c}_2$. It is easily verified that for the uniform case this holds.

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