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Second-period pricing in a duopoly with switching costs: the effect of size and composition of customer bases

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Abstract

Switching costs may facilitate monopoly pricing in a market with price competition between two suppliers of a homogenous good, provided the switching cost is above some critical level. It is also well known that asymmetric size of customer bases makes monopoly pricing more difficult. Adding consumer heterogeneity to the model we demonstrate that also composition of each firm's customer base affects pricing, and this composition may aggravate or ease the incentives to break out of the monoply pricing equilibrium.

JEL classi cation numbers: D44, D82, L10, L51

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1   Introduction

Firms often compete in markets for more or less homogeneous goods, with prices as the main strategic variable. A problem facing such firms is how to escape the Bertrand paradox. In many markets, the most compelling solution to the paradox is the existence of switching costs: the fact that even if consumers don't care about which product they start to buy, there may be costs associated with switching suppliers.[1] Such costs dampen competition in mature markets in a variety of settings, as shown by Paul Klemperer in numerous articles (see his 1995 survey). In particular, if all consumers have positive switching costs, the only possible price equilibrium in pure strategies is monopoly pricing, and such an equilibrium exists if and only if the switching costs exceed some critical level.

The aim of this paper is to shed light on the extent to which stability of monopoly pricing (i.e., the size of the critical switching cost) is affected by asymmetries between the firms. Already Klemperer (1987) noticed that the critical switching cost may depend on the relative size of the firms. In particular, size asymmetry make monopoly pricing less likely.[2] The critical switching cost may also be affected by heterogeneity of consumer preferences.[3] Moreover, heterogeneity among consumers also give rice to another possible asymmetry between the firms: they may have different compositions of their customer bases. In what follows we will study the effects of each kind of asymmetry and how they blend.

In addition to the already mentioned literature on switching costs, many scholars have studied non-linear pricing in more or less competitive settings. With the exception of Gabrielsen and Vagstad (2000), all these contributions model other sources of market power than switching costs. Wilson (1993, part 12.3) consider

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[1] Other proposed solutions include product differentiation (physically or informationally) and tacit collusion, as laid out in any modern treatments of Industrial Organization, e.g. Tirole (1988).

[2] In short, a price cut that is large enough to make the rival's start buying from you instead entails a gain (increased sales) but also a loss (lower profits from your "old" customers). Thus, a firm's incentives to undercut decreases in the firm's relative size. Consequently, unequal sizes call for larger switching costs to keep the smaller firm from undercutting.

[3] Gabrielsen and Vagstad (2000) finds that in a symmetric model consumer heterogeneity can be expected to aggravate problems of stability.

Cournot competition, while Stole (1995), Armstrong and Vickers (1999) and Rochet and Stole (1999) study situations with differentiated products.

To our knowledge, none has studied the joint effects of size and consumer type composition asymmetries on duopoly pricing. We conduct the analysis within a model allowing any kind of non-linear pricing. Our basic model entails two types of consumers, H (high-demand) and L (low-demand), and two firms who have split the market some way or another in a first period that is not modelled. All consumers have a common positive cost of switching supplier, implying that monopoly pricing is the only candidate for Nash equilibrium in pure strategies. Our first task is to characterize monopoly pricing. It turns out that absent any economies or diseconomies of scale, size does not matter for pricing, only the relative numbers of high vs. low-demand consumers within each firm's customer base. However, both size and composition matters for stability, i.e., the critical switching cost. Our main result is that each type of asymmetry tends to destabilize the market, but that one source of asymmetry may or may not counteract the effect of the other, depending on whether it is the smaller or larger firm who has the largest share of high-demand consumers in its customer base.

The paper proceeds as follows. The basic model is presented in Section 2. Under the assumption that there exists a pure-strategy equilibrium, equilibrium pricing is studied in Section 3. Section 4 gives a general discussion of issues related to the question of existence. In Section 5 the model is supplied with more structure and we solve the model explicitly and find the conditions under which a pure Nash equilibrium exist, while some concluding remarks are gathered in Section 6. All proofs are relegated to the appendix.

2 The model

Consider two firms — A and B — setting prices in a market with two kinds of consumers — H ("high" demand) and L ("low" demand). The two firms offer functionally identical products, but each consumer has already bought from one of the firms, and if a consumer wants to switch to the other supplier, switching costs

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are incurred. We assume that all consumers have identical positive switching costs denoted s.[4] In particular, the costs of switching does not depend on a consumer's demand volume.[5]

Next, we assume that each firm offers a menu of two-part tariffs $M = \{(p_i, F_i)\}$, where tariff i consists of a fixed fee F_i and a marginal price p_i. That is, a consumer consuming q units pays $T_i(q) = F_i + p_i q$ under tariff i.[6] With two types of consumers it suffices to study menus with only two choices, one intended for each group of consumers: $M = \{(p_L, F_L), (p_H, F_H)\}$.

Consumer preferences over contracts are described by utility functions that are linear in money and quadratic in quantity:

$$u(\theta, q, T) = \theta q - \frac{1}{2}q^2 - T, \quad \text{for} \ \ \theta \in \{L, H\} \tag{1}$$

where θ is the consumer's "type", q is demand volume and T is monetary payment for the good in question. These preferences give rise to individual demand functions that are linear in prices with no income effects on demand:

$$q = q(p, \theta) = \theta - p, \quad \text{for} \ \ \theta \in \{L, H\} \tag{2}$$

Firms are allowed to be asymmetric as regards customer bases (from an unmodelled first period), while costs are symmetric. To obtain closed-form solutions to the

[4]This implies that the only candidate for equilibrium in pure strategies entails monopoly pricing (as specified below).

[5]This is obviously not the only way to model switching costs. Consider switching mobile telephone operator. This would entail some fixed costs, for instance the effort of contacting the operators and make them do what you want, possible penalties for terminating the relationship with your existing operator, and costs of opening a new relationship. Typically there are also volume-dependent switching costs, for instance the costs attached to lack of number portability which is presumably a larger problem for a pizza chain than from a typical private consumer, but may be substantial even for private consumers.

[6]Qualitatively similar results can be obtained if firms were allowed to use fully non-linear contracts. We have chosen to work with two-part tariffs partly because this corresponds to observed behaviour, and partly because the suboptimality of two-part tariffs in our particular model stems from our assumption of a two-point distribution of consumer characteristics — in a richer model the differences between two-part tariffs and optimal non-linear cotracts tend to vanish.

pricing problem we need marginal costs to be constant, for simplicity normalized to zero. Finally, to simplify notation we set $H = 1$ while $L \in (0, 1)$. This is without loss of generality as only their relative magnitudes are of importance.

3 Equilibrium prices

As long as all consumers have positive switching costs, Klemperer (1987) have argued — in a framework of linear pricing — that if there is a pricing equilibrium in pure strategies, this equilibrium must entail monopoly pricing. The argument goes as follows. Let p_M denote the monopoly price. At any lower common price, each firm has an incentive to slightly increase its price, which more fully exploits its own customers without losing any to its competitor. Note that even small switching costs suffices to make the (possible) equilibrium switch from competitive pricing to monopoly pricing. It should be clear that the logic of small deviations applies equally well to situations involving non-linear pricing: even if firm A uses linear prices, it would pay for firm B to price non-linearly, for instance using two-part tariffs.[7]

However, the proposed equilibrium may be vulnerable to non-marginal price changes: it is still the case that a sufficiently large price cut will make one firm corner the market, and if the switching costs are too small, cornering the market becomes so attractive that monopoly pricing is not an equilibrium either – implying that there is no equilibrium in pure strategies at all.[8] In this respect the magnitude of the switching cost is important.

In this section we simply assume that there exists an equilibrium in pure strate-

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[7] With linear pricing there is one single instrument — the price — serving two different purposes: efficiency and extraction of consumers' surplus. The virtue of two-part tariffs is that they separate these two aims: efficiency is achieved by marginal cost pricing, and consumers' surplus is extracted by the fixed term.

[8] There is always an equilibrium in mixed strategies, however, see Klemperer (1987). This equilibrium is rather complicated even in a model with linear pricing and homogeneous consumers, and it is beyond the scope of the present paper to analyze mixed-strategy equilibria of the current model.

gies and proceed to characterize this equilibrium, while the issue of existence is relegated to Section 4. Hence, consider a monopoly firm which have in its customer base from the first period a number l of low-demand customers, h of high-demand customers. Such a firm maximizes $\pi = l(p_L q_L + F_L) + h(p_H q_H + F_H)$ subject to standard participation and incentive constraints.[9] The solution is given in the following Proposition (proof in the appendix):

Proposition 1 *Let $\alpha \equiv \frac{h}{l}$. i) If $L \geq \frac{\alpha^2 + \sqrt{\alpha}}{1 + \alpha^2 + \alpha}$ then the monopolist offers*

$$p_H = 0, F_H = \frac{1}{2l}\left(2h(1 - 2L) + L^2(l + 2h)\right)$$

$$p_L = \frac{h}{l}(1 - L), F_L = \frac{1}{2}\left(L - \frac{h}{l}(1 - L)\right)^2$$

and earns $\pi = \frac{1}{2l}\left(L^2 l^2 + h^2 - 2h^2 L + h^2 L^2 + L^2 lh\right)$. ii) In contrast, if $L < \frac{\alpha^2 + \sqrt{\alpha}}{1 + \alpha^2 + \alpha}$ then the monopolist offers a single contract involving $p = 0$ and $F = \frac{1}{2}$ and earns $\pi = \frac{h}{2}$.

Clearly, for sufficiently low demand from the low-demand customers (low L) it is profitable to exclude them and focus on the high-demand customers. When low-demand customers are excluded, high-demand customers are offered efficient contracts and all rents are extracted with the fixed fee. When L is larger than a critical value, both types of consumers are served in equilibrium. The optimal contracts exhibit the well-known characteristics; no distortion of the high-demand

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[9]Let $q^*(\theta, p) \equiv \max\{\theta - p, 0\}$ denote the optimal demand of a customer of type θ when the marginal price is p. Moreover, let $v(\theta, p_j, F_j) \equiv u(\theta, q^*(\theta, p_j), F_j + p_j q^*(\theta, p_j))$ denote the utility of a consumer of type θ under a two-part tariff comprised of a marginal price p_j and a fixed fee F_j, where $j \in \{L, H\}$. Then the standard incentive and participation constraints can be written

$$v(L, p_L, F_L) \geq 0$$
$$v(H, p_H, F_H) \geq 0$$
$$v(L, p_L, F_L) \geq v(L, p_H, F_H)$$
$$v(H, p_H, F_H) \geq v(H, p_L, F_H)$$

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type and a marginal price above marginal cost is offered to the low-demand customers. Moreover, all rent is extracted from the low-demand customers whereas the high-demand customers earn an information rent. Note that the distortion imposed on the low-demand customers is increasing in the relative number of high-demand customers. The reason is that the more high-demand customers the more important they are, and to extract more rent from the high-demand customers you must distort the low-demand contract to make it unattractive for the high-demand customers.

4 Stability — the basic considerations

This section discusses the basic considerations related to the question of existence of a pure-strategy Nash equilibrium of the model outlined in the previous sections. To find the critical switching costs needed to sustain monopoly pricing, we need to derive optimal undercutting strategies for the firms. To attract your rival's customers, you must offer them a contract that compensate them for having to bear their switching cost s. Since consumers are of different types, there are two different ways to undercut the rival: one can either try to attract his high-demand customers (to be dubbed strategy 'high') or to go for all the competitor's customers (strategy 'all').[10]

The basic question is how asymmetries in either firm size or customer composition affect stability, i.e., the size of the critical switching costs needed to sustain a pure strategy equilibrium that involves monopoly pricing. First, consider size asymmetry. If firms are equal in size and composition, obviously both firms face the same incentive to undercut. Suppose then that the firms has identical composition of customers, but that one firm is larger than the other, where size is measured by a firm's total number of customers. Intuitively, the smaller firm now will have higher incentive to undercut than if firms are symmetric in every respect, simply because the potential gain from undercutting is larger the more customers you get when cutting prices. This intuition applies whichever undercutting strategy the small firm uses. Hence, size asymmetry should make the smaller firm more aggressive which

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[10]Formally, there is also a third strategy: going for the rival's low-demand customers only. However, as it turns out, this strategy is always dominated by strategy 'all'.

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will destabilize the market; higher switching costs is needed to sustain monopoly prices than in a perfectly symmetric setting.

Now consider composition asymmetries. The first thing to notice regarding composition asymmetries is that, given that a pure strategy equilibrium exists, more asymmetry tends to increase industry profit. The intuition is that composition asymmetries enable firms to specialize in rent extraction from the group of customers that is most important to each firm. A firm that has relatively many low-demand customers will distort low-demand contracts relatively less, and in this way extract more rent from low-demand customers at the expense of leaving more rent to high-demand customers. Similarly, the firm who has relatively more high-demand customers will distort low-demand contracts relatively more in order to extract more rent from high-demand customers. Thinking about complete asymmetry - full specialization - makes the argument obvious. This will allow for efficient contracts and full rent extraction of all customers.

>From a situation where firms are symmetric in every sense, assume that firm A swaps low-demand customers for a number of high-demand customers in a way that leaves his profit unchanged. After the swap firm A with more high-demand customers will be less eager to undercut the rival's high-demand customers for two reasons. First, because the rival firm has fewer high-demand customers than before and second because the rival's high-demand customers will earn more information rent in an asymmetric equilibrium than in the symmetric situation. For the firm with less high-demand customers the effect is the opposite. For this firm the value of the rival's stock of high-demand customers has increased due to the swap; they are more numerous and will earn less rent when staying with firm A. A similar logic applies to strategy 'all', hence basic intuition tells us that such a swap from a symmetric situation tends to increase the critical switching costs.

Then consider a similar swap, but now from a situation where the firms may be of unequal size. Because the firms have symmetric composition before the swap, we need only consider the incentives of the smaller firm. As before assume that the smaller firm (firm A) receives high-demand customers in exchange for low-demand customers in way that leaves his profit unchanged. This swap reduces the value of the

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larger firm's stock of high-demand customers, and the smaller firm will be less eager to undercut to steal firm B's high-demand customers. Hence, a redistribution of customers in this way tends to counteract instability stemming from size asymmetry. Similarly, if undercutting all is the optimal undercutting strategy, giving the smaller firm more high-demand customers in exchange for low-demand customers will reduce the smaller firm's incentive to undercut the bigger firm. What if the swap is the other way around, i.e. that the smaller firm receives low-demand customers in exchange for high-demand customers in a way that leaves his profit unchanged? If so, undercutting the bigger firm's high-demand customers becomes more tempting because high-demand customers are more numerous and receive less rent. Hence such a swap will work to destabilize the market. However, a similar swap will not affect the incentive to undercut all. The intuition is that....

To illustrate the basic considerations presented above the next section present some numerical examples where we derive the results we intuitively have discussed in this section. We use specific parametrizations in our examples. However, our results could also be obtained for more general specifications of our model, but then at a substantial cost of loss of tractability.

5 Some numerical examples

In all subsequent examples we have fixed L and restricted attention to compositions of customers yielding interior equilibrium solutions. Suppose $L = \frac{2}{3}$. Restricting attention to interior solutions then means that both firms have more low-demand than high-demand consumers, i.e. that $l_i > h_i$. Let $\alpha_i = \frac{h_i}{l_i}$ denote firm i's number of high-demand customers relative to the number of low-demand customers, $i = A, B$. Moreover, suppose $l_A + l_B \equiv l = 10$ and $h_A + h_B \equiv h = 5$. Then monopoly pricing for firm i yields (from Proposition 1) $p_H = 0$ and $p_L = \frac{1}{3}\alpha_i$. Demand at these prices are given by

$$q_L = L - p_L = \frac{2}{3} - \frac{1}{3}\alpha_i \quad \text{and} \quad q_H = 1 - p_H = 1$$

The accompanying payments and profit can be written

$$F_L = \frac{1}{18}\left(2 - \alpha_i\right)^2, \; F_H = \frac{1}{9}\left(2 + \alpha_i\right) \quad \text{and} \quad \pi = \frac{l_i}{18}(2 + \alpha_i)^2$$

We now proceed by analyzing how asymmetries in firm size and customer composition affect the stability of a pure strategy equilibrium involving monopoly pricing. We start by looking at the case where customer composition is symmetric, but firms may be of different size.

5.1 Composition symmetry

Suppose that both firms have symmetric composition $l_A = k(l_A + l_B)$ and $h_A = k(h_A + h_B)$. For natural reasons $k \in [0,1]$ will be referred to as firm A's market share. Note that $\alpha_A = \alpha_B = \frac{h}{l}$, hence composition is indeed symmetric. Then the following Proposition holds (proof in the appendix):

Proposition 2 *With symmetric composition, the following is a necessary and sufficient condition to deter a firm with market share of k from undercutting:*

$$s \geq s^*(k) = \max\left\{\frac{1}{36}\frac{8k^2 - 5k + 10}{2k + 1}, \frac{25}{108}\left(1 - k\right)\right\}$$

The first expression within the braces is the switching cost necessary to keep the firm from using strategy "high," while the second expression corresponds to strategy "all." Clearly, to prevent any kind of undercutting, the switching cost must not be smaller than any of those two numbers. It turns out that when $k \in (0.20, 0.34)$, it suffices to prevent strategy "all", while if $k \notin (0.20, 0.34)$ it suffices to prevent strategy "high."

What remains is to put together both firms' incentives to undercut its rival. By symmetry, to prevent firm B having market share $1 - k$ from undercutting, the following must hold:

$$s \geq s^*(1 - k)$$

It is easily verified that s^* is a decreasing function. This implies that the switching cost needed to keep *both* firms from undercutting, i.e., $\min\left\{s^*(k), s^*(1 - k)\right\}$ is minimized when the market is split equally between the two firms, that is, for $k = \frac{1}{2}$.

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This proves the following Proposition (Klemperer, 1987, proves the same result in a model without consumer heterogeneity):

Proposition 3 *Size asymmetry reduces the scope for stable monopoly pricing.*

The critical switching costs from Proposition 2 are plotted in the figure below. On the vertical axis we have the critical switching cost, and on the horizontal axis we have firm A's market share. The straight lines correspond to strategy 'all' for both firms, and the other lines to strategy 'high'. The downward sloping lines refer to firm A and the upward sloping ones to firm B. The figure clearly demonstrates that the more symmetric the firms are in terms of market shares, the smaller switching cost is needed to support monopoly pricing as the equilibrium outcome. Size asymmetries destabilize the market.
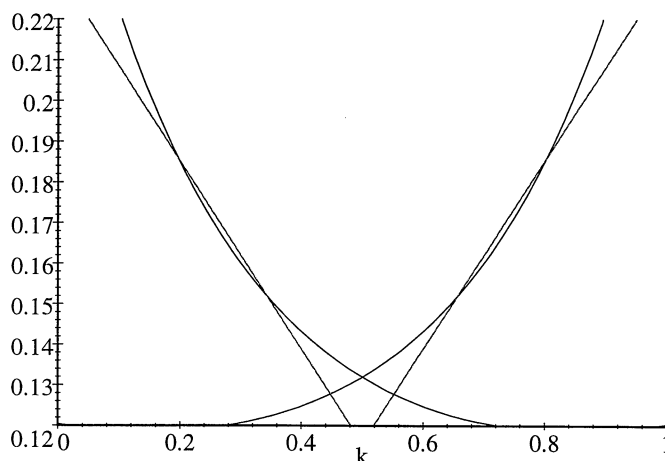
5.2   Composition asymmetry

Suppose we are in a situation with symmetric composition (with or without size asymmetries). Then consider the effect of a change in customer composition that leaves firm A's profit unchanged. In the initial situation, we denote firm A the smaller firm as far as number of customers is concerned, i.e., $l_A + h_A \leq l_B + h_B$. As before, let k denote firm A's market share.

Our first result is just an observation about the connection between composition asymmetries and industry profits (proof in the appendix):

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Proposition 4 *Industry profits are always higher with asymmetric composition than with symmetric composition.*

This result may at first glance seem surprising. The intuition is that asymmetric composition involves some degree of specialization. Some degree of specialization leads each firm to focus more on rent extraction from consumer types that are relatively numerous compared to the symmetric case. If one thinks of the extremely asymmetric composition case, complete specialization, the result becomes obvious. If there exists a pure-strategy Nash equilibrium with complete specialization, this will naturally entail efficient contracts and full extraction of consumer rent.

Next consider a small customer swap between the firms. Let a small number ε of low-demand customers go from firm A to firm B, who gives back a number δ of high-demand customers. Moreover, let the relation between ε and δ be such that firm A's profit is left unchanged. Since high-demand consumers are more valuable than low-demand ones, $\varepsilon > \delta$. Firm A's critical switching cost after such a swap is then described by Proposition 5[11]: (Proof in the appendix):

Proposition 5 *After the swap, to prevent firm A from undercutting with strategy "high", the switching cost $s \geq s^*_{high}(k, \varepsilon)$, where*

$$\frac{\partial s^*_{high}(k, \varepsilon)}{\partial \varepsilon} < 0$$

To prevent A from using strategy "all," the switching cost $s \geq s^*_{all}(k, \varepsilon)$, where

$$\frac{\partial s^*_{all}(k, \varepsilon)}{\partial \varepsilon} = 0 \text{ if } \varepsilon < 0$$

$$\frac{\partial s^*_{all}(k, \varepsilon)}{\partial \varepsilon} < 0 \text{ if } \varepsilon \geq 0$$

As for the symmetric composition case, it is still the case that equilibrium requires that neither player want to deviate. Consequently, we also need to worry about firm B's incentives to undercut. However, symmetry still enables us to write down firm B's critical switching costs without further hesitation. Firm B has a

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[11]It can be shown that similar results applies for larger changes in composition, but then with much more complicated expressions.

market share of $1 - k$ and is exposed to a swap of size $-\varepsilon$. Consequently, to prevent firm B from undercutting with strategy "high", $s \geq s^*_{high}(1 - k, -\varepsilon)$. Similarly, to keep firm B from using strategy "all," $s \geq s^*_{all}(1 - k, -\varepsilon)$.

The first thing to notice is that also pure composition asymmetry destabilizes the market. To see this, consider the symmetric size case. From Proposition 3 we know that for $k = \frac{1}{2}$, it is most difficult to keep the players from using strategy 'high'. By continuity, this will also hold in the neighborhood of the initial situation. From Proposition 5 we know that $s^*_{high}(k, \varepsilon)$ is decreasing in ε. This confirms the basic intuition that the one receiving high-demand customers in exchange for low-demand ones will become less tempted to try to attract all high-demand customers, while the rival feel just the opposite.

What about both types of asymmetry at the same time? From Proposition 5 we know that $s^*_{high}(k, \varepsilon)$ is not only decreasing in ε when evaluated for $k = \frac{1}{2}$, but also evaluated for any $k \in (0, 1)$. Moreover, we know that $s^*_{all}(k, \varepsilon)$ is decreasing in ε for positive ε, but constant for negative ε. Finally, for $k < \frac{1}{2}$, we need only consider firm A's incentives to undercut. Then we have:

Corollary 1 *When $k < \frac{1}{2}$, a swap involving increasing the smaller firm's number of high-demand customers will reduce the critical switching cost and thereby stabilize the market. An opposite swap will destabilize the market unless market shares are such that strategy "all" is most difficult to block.*

To sum up, the switching cost is downward-sloping for positive (ε, δ) pairs and constant for negative pairs. This implies that also when "all" is the relevant undercutting strategy, stability is enhanced if the smaller firm receives high-demand consumers in return for low-demand consumers. However, now stability is not threatened if customers are swapped the other way round.

We conclude with a brief discussion of how important the effects we have identified are. Suppose the swap is of size $\varepsilon = .1$, corresponding to 1% of the total number of low-demand consumers. The associated decrease in critical switching

costs depends on the initial size distribution according to the table below:[12]

k	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{2}{5}$
$-\frac{\Delta s^*}{s^*}$	0.014	0.0000473	0.0000577	0.0303

This implies that while there is hardly anything to gain for some values of k, there are substantial gains for other values: When $k = \frac{2}{5}$, a 1% shift of customer composition reduces the critical switching cost by 3%.

6   Concluding remarks

There are different ways to escape the Bertrand paradox threatening the profit of price-setting firms competing in a market for homogeneous products. We have studied one such possibility — the creation of consumer switching costs — in a market with heterogeneous consumers. We have earlier (Gabrielsen and Vagstad, 2000) argued that consumer heterogeneity tend to reduce collusive stability, with the immediate implication that the more heterogeneity, the higher efforts to raise barriers for consumers who may want to switch supplier.

While our first paper restricted attention to symmetric duopoly, this paper has opened for firm asymmetries. We have (in sequence) shown that pure size asymmetry reduces stability, that pure composition asymmetry does the same, while the combined effect of the two sources of asymmetry may be smaller or larger than one single effect, depending mostly on the direction of asymmetries: stability is enhanced if the smaller firm has a larger share of the high.-demand consumers. However, the combined effect also depends on the form of the temptation: in particular, if it is most tempting to try to attract the entire market, then stability is not threatened if the smaller firm gives up some high-demand consumers in exchange for low-demand ones.

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[12]The changes are calculated using the following formula:

$$-\frac{\Delta s^*}{s^*} = \frac{\max\{s^*_{high}(k,0), s^*_{all}(k,0)\} - \max\{s^*_{high}(k,0.1), s^*_{all}(k,0.1)\}}{\max\{s^*_{high}(k,0), s^*_{all}(k,0)\}}$$

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In future work we would also like to extend our analysis in a more fundamental way, by allowing for dynamics, that is, by allowing for tacit collusion in addition to switching costs. Padilla (1995) has studied the interplay between switching costs and the scope for reaching a collusive agreement in a repeated price game, and it should be possible to extend his analysis to allow for heterogeneous consumers and asymmetries.

7 Appendices

7.1 Proof of Proposition 1

First, if all types of consumers are to be served, the low-demand consumers' participation constraint the high-demand consumers' incentive constraints bind (it is easily checked that the remaining participation and incentive constraints do not bind for the optimal mechanism, as long as all consumers are served in equilibrium). Hence, we must have:

$$
\begin{aligned}
F_L &= \frac{1}{2}(L - p_L)^2 \\
F_H &= \frac{1}{2}(1 - p_H)^2 - \frac{1}{2}(1 - p_L)^2 + \frac{1}{2}(L - p_L)^2
\end{aligned}
$$

Hence, profit can be written as a function of p_L and p_H without any further constraints:

$$
\begin{aligned}
\pi &= l(p_L(L - p_L) + F_L) + h(p_H(1 - p_H) + F_H) \\
&= l\left(p_L(L - p_L) + \left(\frac{1}{2}(L - p_L)^2\right)\right) \\
&\quad + h\left(p_H(1 - p_H) + \left(\frac{1}{2}(1 - p_H)^2 - \frac{1}{2}(1 - p_L)^2 + \frac{1}{2}(L - p_L)^2\right)\right)
\end{aligned}
$$

Straightforward maximization yields $p_H = 0$ and $p_L = \frac{h}{l}(1 - L)$. Given these prices, the corresponding expressions for the fixed fees and the profit are given in part i) of the proposition.

Next, if the firm decides not to serve its low-demand consumers, only one contract need to be offered, with $p = 0$ and $F = \frac{1}{2}$, yielding profit of $\pi = \frac{h}{2}$. Low-demand

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consumers will be served if and only if profit from serving both types is not exceeded by profit when low-demand consumers are excluded. That is, interior solutions requires

$$\frac{1}{2l}\left(L^2l^2 + h^2 - 2h^2L + h^2L^2 + L^2lh\right) \geq \frac{h}{2}$$

Substituting $\alpha = \frac{h}{l}$, the above inequality can be written $L \geq \frac{\alpha^2 + \sqrt{\alpha}}{1 + \alpha^2 + \alpha}$, which completes the proof.

7.2 Proof of Proposition 2

With symmetric composition, equilibrium prices are given by $p_H = 0, F_H = \frac{5}{18}$ and $p_L = \frac{1}{6}, F_L = \frac{1}{8}$, yielding $\pi_A = \frac{125}{36}k$ and $\pi_B = \frac{125}{36}(1 - k)$.

Consider firm A's incentives to undercut. First we consider strategy "high". Suppose $s = \frac{1}{18}$. Then optimal undercutting entails $F_H = F_L = \frac{2}{9}$ and $p_L = p_H = 0$. This would yield profit of $\frac{2}{9}\left(10k + \frac{5}{2} + \frac{5}{2}\right)$, which exceeds the equilibrium profit (e.g. $\frac{125}{36}k$) for all $k \leq \frac{1}{2}$, implying that a switching cost of $\frac{1}{18}$ is insufficient to deter deviations from monopoly pricing. Consequently, larger switching costs must be studied, and the relevant constraints to be incorporated includes not the high-demand type's but the low-demand type's incentive constraint. Formally, for $s > \frac{1}{18}$ the undercutting firm maximizes

$$\pi_A = l_A\left(F_L + p_L(L - p_L)\right) + (h_A + h_B)(F_H + p_H(1 - p_H))$$

subject to

$$\frac{1}{2}(L - p_L)^2 - F_L \geq \frac{1}{2}(L - p_H)^2 - F_H$$
$$\frac{1}{2}(1 - p_H)^2 - F_H \geq \frac{1}{2} - \frac{5}{18} + s$$

Suppose both constraints bind (this is easily verified to hold for the optimal mechanism). Then

$$F_L = Lp_H + \frac{5}{18} - s - p_H - Lp_L + \frac{1}{2}p_L^2$$
$$F_H = \frac{5}{18} - s - p_H + \frac{1}{2}p_H^2$$

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yielding the following expression for profits:

$$\pi_A = 10k\left(Lp_H + \frac{5}{18} - s - p_H - Lp_L + \frac{1}{2}p_L^2 + p_L(L - p_L)\right)$$
$$+5\left(\frac{5}{18} - s - p_H + \frac{1}{2}p_H^2 + p_H(1 - p_H)\right)$$

Straightforward maximization yields $p_L = 0$ and $p_H = -\frac{2}{3}k$. Plugging these prices back into the profit function yields

$$\pi_A = \frac{10}{9}k^2 + \frac{25}{9}k + \frac{25}{18} - (10k + 5)s$$

Therefore, undercutting is blocked iff

$$\frac{10}{9}k^2 + \frac{25}{9}k + \frac{25}{18} - (10k + 5)s \leq \frac{125}{36}k$$
$$s \geq \frac{1}{36}\frac{8k^2 - 5k + 10}{2k + 1}$$

Next consider strategy "all." As long as composition is the same across firms, optimal undercutting to attract all the rival's customers leave marginal prices unchanged, while both fixed fees are reduced by s. Consequently, profit can be written

$$\pi_I - ns$$

where n is the total number of customers (i.e. 15 in our examples) and π_I is the monopoly profit (i.e. $\frac{125}{36}$). Moreover, undercutting this way is deterred iff

$$\pi_I - ns \leq \pi_A \iff s \geq \frac{25}{108}(1 - k)$$

This completes the proof.

7.3   Proof of Proposition 4

>From the initial situation, consider a customer swap: let a small number ε of low-demand customers go from firm A to firm B, who gives back a number δ of high-demand customers. For sufficiently small ε, the equilibrium would remain an

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interior one. After swapping, the market structure is described as follows:

$$
\begin{array}{ccc}
 & A & B \\
l_i & 10k - \varepsilon & 10(1-k) + \varepsilon \\
h_i & 5k + \delta & 5(1-k) - \delta
\end{array}
$$

Consequently, $\alpha_A = \frac{5k+\delta}{10k-\varepsilon}$ and $\alpha_B = \frac{5(1-k)-\delta}{10(1-k)+\varepsilon}$. Therefore, in equilibrium,

$$
\begin{aligned}
p_H &= 0 \\
p_L &= \frac{1}{3}\alpha_i \Longrightarrow p_{LA} = \frac{1}{3}\frac{5k+\delta}{10k-\varepsilon}, p_{LB} = \frac{1}{3}\frac{5(1-k)-\delta}{10(1-k)+\varepsilon}
\end{aligned}
$$

The accompanying payments and profit can be written

$$
\begin{aligned}
F_L &= \frac{1}{18}(2-\alpha_i)^2 \\
&\Longrightarrow F_{LA} = \frac{1}{18}\left(2 - \frac{5k+\delta}{10k-\varepsilon}\right)^2 \\
&\Longrightarrow F_{LB} = \frac{1}{18}\left(2 - \frac{5(1-k)-\delta}{10(1-k)+\varepsilon}\right)^2 \\
F_H &= \frac{1}{9}(2+\alpha_i) \\
&\Longrightarrow F_{HA} = \frac{1}{9}\left(2 + \frac{5k+\delta}{10k-\varepsilon}\right) \\
&\Longrightarrow F_{HB} = \frac{1}{9}\left(2 + \frac{5(1-k)-\delta}{10(1-k)+\varepsilon}\right) \\
\pi &= \frac{l_i}{18}(2+\alpha_i)^2 \\
&\Longrightarrow \pi_A = \frac{10k-\varepsilon}{18}(2 + \frac{5k+\delta}{10k-\varepsilon})^2 \\
&\Longrightarrow \pi_B = \frac{10(1-k)+\varepsilon}{18}(2 + \frac{5(1-k)-\delta}{10(1-k)+\varepsilon})^2
\end{aligned}
$$

The change in industry profit after the swap can then be written

$$
\begin{aligned}
\pi_A + \pi_B - \frac{125}{36} &= \frac{10k-\varepsilon}{18}(2 + \frac{5k+\delta}{10k-\varepsilon})^2 \\
&\quad + \frac{10(1-k)+\varepsilon}{18}(2 + \frac{5(1-k)-\delta}{10(1-k)+\varepsilon})^2 - \frac{125}{36} \\
&= \frac{5}{36}\frac{(\varepsilon+2\delta)^2}{(10k-\varepsilon)(10(1-k)+\varepsilon)} > 0
\end{aligned}
$$

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for all $\varepsilon \neq -2\delta$, that is, for all changes that changes the composition of customers. (Note that $\varepsilon = -2\delta$ leaves composition unchanged, and only changes market shares.) This completes the proof.

7.4 Proof of Proposition 5

From the proof of Proposition 4 we have that firm A's profit equals $\pi_A = \frac{10k-\varepsilon}{18}(2 + \frac{5k+\delta}{10k-\varepsilon})^2$ after the swap and $\frac{125}{36}k$ before. Preservation of equilibrium profit therefore requires

$$\frac{10k-\varepsilon}{18}(2 + \frac{5k+\delta}{10k-\varepsilon})^2 = \frac{125}{36}k \iff \delta = \frac{5}{2}\sqrt{100k^2 - 10k\varepsilon} - 25k + 2\varepsilon \approx \frac{3}{4}\varepsilon$$

for small ε.

7.4.1 Undercutting with strategy "high"

First consider firm A undercutting with strategy "high". Then firm A maximizes

$$\pi_A = l_A \left(F_L + p_L(L - p_L) \right) + (h_A + h_B)(F_H + p_H(1 - p_H))$$

subject to

$$\frac{1}{2}(L - p_L)^2 - F_L \geq \frac{1}{2}(L - p_H)^2 - F_H$$
$$\frac{1}{2}(1 - p_H)^2 - F_H \geq \frac{1}{2} - F_{HB} + s$$

Suppose both constraints bind. Then

$$F_L = L p_H + F_{HB} - s - p_H - L p_L + \frac{1}{2}p_L^2$$
$$F_H = F_{HB} - s - p_H + \frac{1}{2}p_H^2$$

yielding the following expression for profits:

$$\pi_A = (10k - \varepsilon)\left(L p_H + F_{HB} - s - p_H - L p_L + \frac{1}{2}p_L^2 + p_L(L - p_L) \right)$$
$$+ 5\left(F_{HB} - s - p_H + \frac{1}{2}p_H^2 + p_H(1 - p_H) \right)$$

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Straightforward maximization yields $p_H = -\frac{2}{3}k + \frac{1}{15}\varepsilon$ and $p_L = 0$. Plugging these prices back into the profit function yields profits of

$$\pi_A = \frac{10}{9}k^2 - \frac{2}{9}k\varepsilon + 10kF_{HB} - 10sk + \frac{1}{90}\varepsilon^2 - \varepsilon F_{HB} + \varepsilon s + 5F_{HB} - 5s$$

To prevent firm A from undercutting,

$$\frac{125}{36}k \geq \frac{10}{9}k^2 - \frac{2}{9}k\varepsilon + 10kF_{HB} - 10sk + \frac{1}{90}\varepsilon^2 - \varepsilon F_{HB} + \varepsilon s + 5F_{HB} - 5s$$

$$\iff s \geq \frac{1}{180}\frac{200k^2 - 40k\varepsilon + 1800kF_{HB} + 2\varepsilon^2 - 180\varepsilon F_{HB} + 900F_{HB} - 625k}{10k + 5 - \varepsilon}$$

Replacing F_{HB} by $\frac{1}{9}\left(2 + \frac{5(1-k)-\delta}{10(1-k)+\varepsilon}\right)$ and δ by the approximation $\frac{3}{4}\varepsilon$, and deleting any second and higher order terms in ε yields[13]

$$s \geq \frac{1}{180}\frac{3250k^2 - 2000k^3 + 600k^2\varepsilon - 275k\varepsilon - 3750k - 375\varepsilon + 2500}{(10 - 10k + \varepsilon)(10k + 5 - \varepsilon)} \equiv s^*_{high}(k, \varepsilon)$$

where it is easily verified that

$$\frac{\partial s^*_{high}(k, \varepsilon)}{\partial \varepsilon} < 0$$

7.4.2 Undercutting with strategy "all"

Next consider firm A undercutting with strategy "all". Then firm A maximizes

$$\pi_A = (l_A + l_B)\left(F_L + p_L(\frac{2}{3} - p_L)\right) + (h_A + h_B)(F_H + p_H(1 - p_H))$$

subject to

$$\frac{1}{2}(1 - p_H)^2 - F_H \geq \frac{1}{2}(1 - p_L)^2 - F_L$$

$$\frac{1}{2}(1 - p_H)^2 - F_H \geq \frac{1}{2} - F_{HB} + s$$

$$\frac{1}{2}(\frac{2}{3} - p_L)^2 - F_L \geq s$$

First suppose the first two constraints bind (but not the third). Then

$$F_L = F_{HB} - s - p_L + \frac{1}{2}p_L^2$$

$$F_H = F_{HB} - s - p_H + \frac{1}{2}p_H^2$$

---

[13] Using the true value $\delta = \frac{5}{2}\sqrt{100k^2 - 10k\varepsilon} - 25k + 2\varepsilon$ vastly complicates the expressions without affecting the results.

yielding the following expression for profits:

$$\pi_A = 10\left(F_{HB} - s - p_L + \frac{1}{2}p_L^2 + p_L(\frac{2}{3} - p_L)\right)$$
$$+5\left(F_{HB} - s - p_H + \frac{1}{2}p_H^2 + p_H(1 - p_H)\right)$$

Straightforward maximization yields $p_H = 0$ and $p_L = -\frac{1}{3}$. The strongly negative p_L should make us worry about the third constraint, which can be written

$$\frac{1}{2}(\frac{2}{3} - p_L)^2 \geq s + F_L$$

However,

$$F_L = F_{HB} - s - p_L + \frac{1}{2}p_L^2 \iff F_L + s = F_{HB} - p_L + \frac{1}{2}p_L^2$$

and the third constraint will be satisfied iff

$$F_{HB} - p_L + \frac{1}{2}p_L^2 \leq \frac{1}{2}(\frac{2}{3} - p_L)^2$$

Plugging in the proposed solution yields

$$F_{HB} - p_L + \frac{1}{2}p_L^2 \leq \frac{1}{2}(\frac{2}{3} - p_L)^2$$
$$\Updownarrow$$
$$F_{HB} + \frac{7}{18} \leq \frac{1}{2}$$

but since $F_{HB} = \frac{1}{9}\left(2 + \frac{5(1-k)-\delta}{10(1-k)+\varepsilon}\right) \approx \frac{5}{18}$, the left hand side exceeds the right hand side. Consequently, the third constraint must bind in equilibrium.

Next suppose the *last* two constraints bind, but not the first. Then firm A maximizes

$$\pi_A = (l_A + l_B)\left(F_L + p_L(\frac{2}{3} - p_L)\right) + (h_A + h_B)(F_H + p_H(1 - p_H))$$

subject to

$$F_H = F_{HB} - s - p_H + \frac{1}{2}p_H^2$$
$$F_L = \frac{1}{2}(\frac{2}{3} - p_L)^2 - s$$

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This implies that profit can be written

$$\pi_A = 10\left(\frac{1}{2}(\frac{2}{3} - p_L)^2 - s + p_L(\frac{2}{3} - p_L)\right) + 5(F_{HB} - s - p_H + \frac{1}{2}p_H^2 + p_H(1 - p_H))$$

without further constraints. Straightforward maximization yields $p_H = p_L = 0$, and $F_H = F_{HB} - s$ and $F_L = \frac{2}{9} - s$. Clearly, this can only be incentive compatible if

$$F_{HB} = \frac{1}{9}\left(2 + \frac{5(1-k) - \delta}{10(1-k) + \varepsilon}\right) = \frac{2}{9}$$

However, for small ε and δ, $F_{HB} \approx \frac{5}{18} \neq \frac{2}{9}$. Consequently, also the first (incentive) constraint must always bind.

Consequently, both the first and the third constraints always bind. Next suppose that the second constraint is slack. Then firm A maximizes

$$\pi_A = (l_A + l_B)\left(F_L + p_L(\frac{2}{3} - p_L)\right) + (h_A + h_B)(F_H + p_H(1 - p_H))$$

subject to

$$\frac{1}{2}(1 - p_H)^2 - F_H \geq \frac{1}{2}(1 - p_L)^2 - F_L$$
$$\frac{1}{2}(\frac{2}{3} - p_L)^2 - F_L \geq s$$

This is identical to the problem of a monopolist serving the entire market, except for the participation constraint for the low-demand customers being increased by s. Consequently, the solution entails $p_H = 0$ and $p_L = \frac{1}{6}$, yielding

$$F_L = \frac{1}{2}(\frac{2}{3} - p_L)^2 - s = \frac{1}{8} - s$$
$$F_H = \frac{1}{2}(1 - p_H)^2 - \frac{1}{2}(1 - p_L)^2 + \frac{1}{2}(\frac{2}{3} - p_L)^2 - s = \frac{5}{18} - s$$

and

$$\pi_A = \frac{125}{36} - 15s$$

Suppose k is such that the smaller firm is most tempted to use strategy "all". The omitted constraint is satisfied iff

$$\frac{1}{2}(1 - p_H)^2 - F_H \geq \frac{1}{2} - F_{HB} + s$$

$$\Updownarrow$$

$$\frac{1}{2} - \frac{5}{18} + s \geq \frac{1}{2} - F_{HB} + s$$

$$\Updownarrow$$

$$F_{HB} = \frac{1}{9}\left(2 + \frac{5(1-k)-\delta}{10(1-k)+\varepsilon}\right) \geq \frac{5}{18}$$

$$\Updownarrow$$

$$\delta \leq -\frac{1}{2}\varepsilon$$

which is always satisfied for negative ε but never for positive. For negative ε, therefore, undercutting is blocked iff the following constraint holds:

$$\frac{125}{36} - 15s \leq \frac{125}{36}k \iff s \geq \frac{25}{108}(1-k)$$

Note that this is the same condition as before we started to shift consumers around.

For positive (ε, δ) we know that all three constraints bind. This should make undercutting less profitable and thereby make the critical switching cost decrease. This must be studied in more detail. For positive δ, the undercutting firm A maximizes

$$\pi_A = (l_A + l_B)\left(F_L + p_L(L - p_L)\right) + (h_A + h_B)(F_H + p_H(1 - p_H))$$

subject to

$$\frac{1}{2}(1 - p_H)^2 - F_H = \frac{1}{2}(1 - p_L)^2 - F_L$$
$$\frac{1}{2}(1 - p_H)^2 - F_H = \frac{1}{2} - F_{HB} + s$$
$$\frac{1}{2}(L - p_L)^2 - F_L = s$$

Solving the three constraints for the three unknown (F_L, F_H, p_L) yields

$$F_L = \frac{8}{9} - 4F_{HB} + \frac{9}{2}F_{HB}^2 - s$$
$$F_H = -p_H + \frac{1}{2}p_H^2 + F_{HB} - s$$
$$p_L = 3F_{HB} - \frac{2}{3}$$

where

$$F_{HB} = \frac{1}{9}\left(2 + \frac{5(1-k)-\delta}{10(1-k)+\varepsilon}\right)$$

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The profits can be written

$$\pi_A = 10\left(F_L + p_L(L - p_L)\right) + 5(F_H + p_H(1 - p_H))$$
$$= 25F_{HB} - 45F_{HB}^2 - 15s - \frac{5}{2}p_H^2$$

Straightforward maximization yields $p_H = 0$, hence

$$\pi_A = 25F_{HB} - 45F_{HB}^2 - 15s$$

Consequently, to block undercutting,

$$\frac{125}{36}k \geq 25F_{HB} - 45F_{HB}^2 - 15s$$
$$\Updownarrow$$
$$s \geq \frac{25}{108}(1 - k) - \frac{25}{432}\frac{\varepsilon^2}{100\left(1 - k\right)^2 + 20\varepsilon(1 - k) + \varepsilon^2}$$

Hence, we have that

$$s \geq s_{all}^*(k, \varepsilon) \equiv \begin{cases} \frac{25}{108}(1 - k) & \text{if } \varepsilon < 0 \\ \frac{25}{108}(1 - k) - \frac{25}{432}\frac{\varepsilon^2}{100(1-k)^2 + 20\varepsilon(1-k) + \varepsilon^2} & \text{if } \varepsilon \geq 0 \end{cases}$$

For $\varepsilon \geq 0$ it is straight forward to verify that

$$\frac{\partial s_{all}^*(k, \varepsilon)}{\partial \varepsilon} < 0$$

which completes the proof.

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