The Welfare Losses From Price Matching Policies[1]

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Abstract

Several recent papers argue that price matching policies raise equilibrium prices. We add to this literature by considering potential welfare losses, which have two sources: Harberger triangles from high prices and Posner rectangles from over-entry. We compare markets with price matching and free entry to monopoly or price matching markets without entry, and find that price matching with entry leads to greater welfare losses than monopoly in markets with a low ratio of fixed to marginal cost. We illustrate this general result using parameters from the wholesale gasoline and air travel markets, and relate our model to price matching on NASDAQ.

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1. Introduction

Sellers increasingly "guarantee" their prices by promising to match any lower price a buyer finds elsewhere.[2] Ironically, though, adopting a guaranteed-low-price policy is a good substitute for actually having low prices, and a number of recent papers have argued that such "price-matching" policies raise equilibrium prices (see, e.g., Salop [1986], Belton [1987], and Doyle [1988]).[3] This paper considers the welfare effects of price matching in a model with entry, thereby extending the existing price matching literature, which has focused on price effects.[4]

Industrial organization economists and antitrust authorities concerned about supra-

[2] These practices are commonly associated with resellers, however, they are also seen in other sectors, including banking (Bank of the West has advertised an interest rate matching policy on San Francisco Bay area radio stations), construction (Blain [1995]), funeral homes (Milkman [1994]), wholesale gasoline (Crocker and Lyon [1994]), electronic component manufacturers (Jorgenson [1993]) and among NASDAQ market makers, as we will discuss in Section 5. Their roots are traceable at least as far back as International Salt Co. v. United States 332 U.S. 131 (1947).

[3] There is also some experimental and empirical evidence that these policies raise prices (see Grether and Plott [1984] and Hess and Gerstner [1991]). On the other hand, two recent papers have argued that if firms can promise to *beat* as well as match posted prices, then the competitive outcome re-emerges (Corts [1995] and Hviid and Shaffer [1994]). These models restore the Bertrand intuition because firms can offer final prices that are unmatchable, and can only match or beat posted prices. As Doyle [1988] and Edlin [1998] explain, however, monopoly pricing is restored in a model where both final and posted prices can be matched or beaten. Though matching offers may sometimes be limited to posted or advertised prices, other matchers accept the final prices created by a price beating offer (Firestone Tires in Berkeley, for example, has this practice). Matching final prices perhaps better accords with the spirit of guaranteed low prices, which is to create genuinely unbeatable prices by willingly matching any legitimate offer.

Price beating clauses may also be viewed as an attempt to compensate consumers for the hassle of taking advantage of a matching offer. For instance, Hobson-Tasman Eye Group (www.hteyegroup.com) promises to match competitors' eyeglass prices, and add an extra 10% of the price difference "for your time and trouble." Including "hassle costs" in a model of price matching, however, introduces new complexities. Hviid and Shaffer [1997] present a compelling argument that price matching offers can be weakened or undone completely by these hassle costs. As a corollary, hassle costs may allow price beating offers to undo a high-price matching equilibrium. We discuss their basic argument in Section 2 below, and in Section 5 outline conditions under which the hassle cost model is appropriate and cases in which is less relevant.

[4] Hirshleifer and Png [1987] also consider a model with entry and show, interestingly, that under price matching, entry causes prices to rise. Their paper, however, does not directly compare price matching to non-price matching prices, or calculate welfare losses created by these policies.

competitive pricing have traditionally focused their attention on oligopoly markets where entry is difficult or impossible. Limited entry is often seen as a necessary condition for high prices, because, as Kleidon and Willig [1995, p. 6] argue

> When entry is easy, cooperative efforts by incumbents to maintain excessive prices simply attract entrants who undercut collusive prices and restore competitive outcomes.

We will argue, however, that when firms are price matchers, as were the NASDAQ market makers that Kleidon and Willig discussed, then supracompetitive prices can persist in the face of widespread entry.[5] One straightforward reason that we should be concerned about price matching, then, is that it allows supracompetitive pricing to occur in a much larger set of industries than are susceptible to monopoly or collusive agreement.

The more subtle danger of price matching, which we explore in this paper, is that welfare losses arise not just due to the allocative inefficiency of high prices but also due to the productive inefficiency of higher industry-wide average costs. When a high price is locked in by price matching, entry occurs until firms' average costs rise to equal the high price, and all producer surplus is eliminated. The total welfare loss thus includes both the traditional Harberger deadweight loss triangle from the price distortion and the Posner rectangle from increased average costs due to over-entry.[6]

We compare this welfare loss of price matching with entry to welfare losses under monopoly and under price matching without entry. The price matching without entry scenario allows us to separate the price and entry effects of price matching. Alternatively, it can represent a classic cartel in which firms raise price to a collusive

[5] When price-matching offers are pervasive, new entrants have no incentive to undercut the industry price, since their prices will be instantly matched by the rest of the market.

[6] Our model represents a specific instance of the tendency, explained by Mankiw and Whinston [1986], Spence [1976] and others, for entry to be excessive in homogeneous product markets with fixed costs.

level while blockading entry. We first make these comparisons analytically, then numerically.

When fixed costs are high, monopoly produces the largest welfare loss, because it has the largest price distortion. To see this, note that a monopoly typically will have no excess capacity, since it will build just sufficient plants to satisfy demand at the price it charges. If satisfying industry demand requires many plants, as we assume, the monopolist will incorporate the construction cost as part of the true shadow cost of additional output and so charge a monopoly markup on the minimum of average cost. In contrast, high prices in our price matching models lead to excess capacity and high average costs. This excess capacity means that, for a price-matching firm, producing an additional unit does not entail building an additional plant. Thus the optimal markup for a price-matching firm is based solely on marginal production cost and is not affected by the plant construction cost.

When fixed costs are large, therefore, a monopoly charges a significantly higher price than a price-matching firm. In this case, the larger Harberger triangle from the additional price distortion under monopoly outweighs the Posner rectangle from over-entry under price-matching. In contrast, in industries where fixed costs are small relative to variable costs, price matching with entry produces larger welfare losses than either monopoly or price matching without entry.[7] In these industries, marginal cost is close to the minimum average cost, so that markups are similar across the three scenarios. Excessive entry creates large Posner rectangles under price matching, however, which eliminates producer surplus.

We calibrate our model using data from the U.S. wholesale gasoline and air travel

[7] This result may seem surprising. For instance, in Mankiw and Whinston's [1986] model of entry, welfare losses go to zero as fixed costs become smaller. The difference lies in the effect of entry on price. Their result depends on the assumption that price approaches marginal cost as the number of firms grows infinitely large, whereas in our price matching model the number of firms has no effect on price. In the limiting case in which fixed costs are zero, however, monopoly again leads to higher welfare losses than price matching in our model – in this case, there is no welfare cost to entry.

markets, two markets that might in principle be susceptible to matching since the goods are fairly homogenous. Assuming that these markets are currently competitive, we ask what would happen if competition were replaced by monopoly, price matching without entry, or price matching with entry. We find that the former two scenarios would lead to welfare losses of approximately \$12 billion, compared to total U.S. sales of approximately \$70 billion, in each market. Price matching with entry yields somewhat higher losses (at \$16 billion) than the other two in the air travel market. In contrast, losses soar to \$30 billion under price matching with entry in the wholesale gasoline market. The difference results from the fact that fixed costs are much smaller in the wholesale gasoline market than in the air travel market.

Welfare losses are highest in markets that combine price matching, entry, and low fixed cost relative to marginal cost. Thus, industries that appear competitive under traditional market structure criteria can actually be subject to higher welfare losses than pure monopoly. Antitrust enforcers and lawmakers should therefore be prepared to broaden their focus beyond traditional Sherman Act Section 1 and 2 concerns, subject to the following caveats.

While our analysis illustrates the tremendous anti-competitive *potential* of price matching, we do not contend that this potential will be realized in every case, or even that it will be *fully* realized in any case. Entry barriers may reduce the size of the loss, and it is extreme to suppose that the Posner rectangles will be wholly wasted. If firms cannot lower price to attract business, they may compete along other dimensions, such as quality. This could reduce waste, and in extreme cases could eliminate it entirely.[8] Alternatively, firms may find another avenue, such as

[8] Another avenue by which losses from price matching may be mitigated in a retail context has been offered by David Butz [1993]. He argues that price matching is a *legal* substitute for resale price maintenance. Hence, if resale price maintenance is efficient, retail price matching might also be efficient, at least if price matching happened to achieve the same price as the manufacturer would set under resale price maintenance. This argument undoubtedly has some merit, and we will not opine here on whether resale price maintenance is efficient, or whether price matching in retail markets serves as a close substitute. Instead, we limit the application of our welfare calculations to

coupons, by which to lower price.[9] As Corts [1995] and Hviid and Shaffer [1994] suggest, the key is to find a way to raise value or lower price that is not matchable.

Similarly, the anti-competitive power of price matching may be reduced if a "matched" price is not equivalent to a posted price in buyers' eyes. Hviid and Shaffer [1997] have argued that the "hassle costs" buyers must pay to take advantage of a price matching offer can significantly constrain supracompetitive pricing.[10] Where their model applies, the effects of price matching will indeed be reduced, though entry, which they do not consider, may exacerbate welfare costs beyond the price distortion. Their model does not apply, however, in markets such as NASDAQ where firms assume the cost of price matching. Also, to the extent that firms can compensate buyers for hassle costs, the tendency of hassle costs to drive prices down may be moderated. Of course, whether these strategies are feasible depends on the particular market, an issue we address in Section 5.[11]

The recent SEC and DOJ investigations into the NASDAQ stock market have uncovered good illustrations of many of the issues discussed in this paper. Price matching by NASDAQ market makers may have raised bid-ask spreads, despite the fact that there were numerous competitors and that entry was easy. The NASDAQ case, which we discuss in Section 5, illustrates how price matching and price matching-like phenomena can be facilitated by computerized trading systems. Since these systems are becoming more pervasive, the potential for significant welfare losses from

manufacturers or other primary sellers.

[9] Observe, though, that coupons are often matched (see, e.g., Hess and Gerstner [1991]).

[10] These "hassle costs" represent the time and energy a buyer must expend to bring a matchable price to a firm's attention and verify that it fulfills the requirements of a price matching guarantee. In a retail context, for example, this could be the effort expended clipping a price from a competitor's advertisement, finding the store's manager, and waiting for the guarantee to be verified and the price adjusted. As discussed in footnote 8, however, this paper focuses on wholesale markets. In these markets, hassle costs are likely smaller relative to the price paid than in retail markets.

[11] Sellers often encourage buyers to utilize price-matching policies instead of switching sellers by advertising low hassle costs and offering bonuses to compensate for hassle costs. Circuit City has run television advertisements, for example, showing that a small child is able to take advantage of a matching offer with a smiling salesperson in a matter of seconds.

price matching merits attention.

This paper is organized as follows. Section 2 calculates the equilibrium under price matching. Section 3 makes analytic comparisons of the welfare losses of price matching with and without entry to those of monopoly. Section 4 makes numeric calculations of losses across these scenarios, first generally and then for two particular industries, air travel and wholesale gasoline. Finally, Section 5 discusses the implications of our analysis for antitrust policy, with particular focus on computerized trading systems such as NASDAQ.

2. Price-Matching Equilibrium

This section defines a price-matching equilibrium and calculates equilibrium prices for a market with a homogeneous good. Our model has an unlimited number of firms, each of which can build a plant for a fixed cost $F > 0$ that allows it to produce any quantity q up to some capacity Q at a marginal cost of c. Hence each firm's average cost is $AC(q) = \frac{F}{q} + c$ for $q \in (0, Q]$. Each firm i decides (1) whether to enter the market, (2) what price p_i to post, and (3) whether to match prices. For simplicity, we assume that firms cannot expand capacity by building additional plants.[12]

In our model, all buyers are fully informed of available prices. This assumption is admittedly unrealistic, but the Appendix considers an explicit model of search and finds identical results. Since the purpose of our paper is not to prove that price matching leads to high prices, but rather to study the consequences *when* price matching leads to high prices, we choose to present the simplest model, instead of the most realistic one, in the main text. When search is included in the model, price discrimination may be an initial motivation for price-matching policies, though it

[12] As demonstrated in Edlin and Emch [1997, Appendix B], this possibility complicates our derivations but does not affect the equilibrium.

does not necessarily survive in equilibrium.[13] The interested reader should refer to the Appendix, which presents price matching under a Salop-Stiglitz search model and a generalization of that model.

Since buyers are fully informed in our model, none is willing to pay a price above $p_{\min} \equiv \min_i p_i$. A firm that promises to match prices will sell at $p_{\min}$ even if it posts a higher price, so that buyers can purchase at this price either from a firm actually posting $p_{\min}$ or from a matcher (regardless of the matcher's posted price). We assume there is no transaction cost of obtaining a "match," so that demand $D(p_{\min})$ is divided evenly among firms that either post the lowest price in the market or promise to match prices, as assumed in Corts [1995], Doyle [1988], Belton [1987], and Salop [1986]. Our assumption is probably realistic for the NASDAQ market, which we discuss in Section 5, and for other settings where the firm assumes the cost of price matching – for example, by checking the prices of other sellers after a purchase and sending refunds to buyers if others offer lower prices.[14] Although our demand assumption facilitates the extreme anticompetitive results this paper presents, it turns out not to be as critical as one might think. In fact, one finding of Hviid and Shaffer [1997] is that in an asymmetric model of duopoly with price matching, supracompetitive prices can persist even with hassle costs, though prices will then not rise as high as

[13] In the search model presented in the Appendix, price discrimination does not survive in equilibrium. In some other models of price matching, price discrimination does survive. For instance, in the Hirshleifer and Png [1987] model, in equilibrium, firms post different prices, and price matching facilitates ongoing price discrimination between two classes of customers with different demand curves. In the Hviid and Shaffer [1997] model, ongoing price discrimination results from asymmetries between firms.

[14] Tweeter, etc., a consumer electronics firm in New England, has this practice (see Berner [1993]). Price matching on NASDAQ, as detailed in Section 5, is invisible to the buyer. In addition, American TV and Appliance advertises a price checking system that updates store prices twice daily to duplicate the lowest in the market, based on reports from in-store shoppers and competitors' advertisements (see www.americantv.com/pricecheck.html). Rasputin Records in Berkeley, which accepts competitors' discount coupons, until recently compensated its customers for this transaction cost by offering a free slice of pizza at nearby Blondie's Pizza for anyone taking advantage of the offer. Though this is a rather crude method of compensation since it depends on the consumer's taste for pizza, it at least reduces net hassle costs. Other examples in which the seller rather than the buyer incurs the cost of matching include the grocery stores discussed in Hess and Gerstner [1991], the U.K. retail gasoline market discussed in Hviid and Shaffer [1997] and Corzine [1996].

they do here.[15]

Let demand be some monotonically decreasing function $D(p)$, with unique price p maximizing $D(p)(p-c)$, and let

$$p^{pm} \equiv \max\left\{\frac{F}{Q} + c, \arg\max D(p)(p-c)\right\}.$$

Thus, p^{pm} is the greater of the minimum of $AC(\cdot)$ and the monopoly markup on c. Observe that the inverse of average cost, $AC^{-1}(\cdot)$, has domain $[\frac{F}{Q} + c, \infty)$ and range $(0, Q]$, so we can define $q^{pm} \equiv AC^{-1}(p^{pm})$. We assume that $N^{pm} \equiv \frac{D(p^{pm})}{q^{pm}}$ is an integer. This assumption avoids standard integer problems and is justified as an approximation when N^{pm} is large, which is the primary interest of this paper.

Proposition 2.1. *It is a Nash equilibrium for N^{pm} firms to enter the market, post price p^{pm}, and match prices. Each firm sells quantity q^{pm} and breaks even.*

Proof: In the proposed equilibrium, the N^{pm} entering firms split the demand, so each firm sells $\frac{D(p^{pm})}{N^{pm}} = q^{pm}$. Since $p^{pm} = AC(q^{pm})$, the entering firms break even. Hence, they cannot increase profits by exiting. They also cannot increase their profits by raising prices, since if they continue to match, their effective price remains p^{pm}, and if they don't, they lose all of their business.

To complete the proof, we must show that lowering price cannot increase a firm's profits and that no additional firms enter. Since all N^{pm} firms match prices, even if one deviates by posting a price $p < p^{pm}$, the N^{pm} firms will still split the market, selling at

[15] In the Hviid and Shaffer [1997] model with hassle costs, a combination of price matching and significant asymmetry between duopoly firms supports a price above the Bertrand equilibrium, but below the range of prices supported by price matching in the absence of hassle costs. On the other hand, when firms are symmetric or only slightly asymmetric, hassle costs nullify the ability of price matching offers to raise industry prices above the Bertrand equilibrium. Intuitively, hassle costs give a firm "room" to undercut its rival, and move closer to its best response function even in the presence of a matching offer. If hassle costs are larger than the difference in Bertrand equilibrium prices, instituting price matching policies will not raise prices at all. In this case, at any price above the Bertrand equilibrium, each firm will want to undercut the other, and the presence of significant hassle costs means that a price matching offer cannot prevent this undercutting.

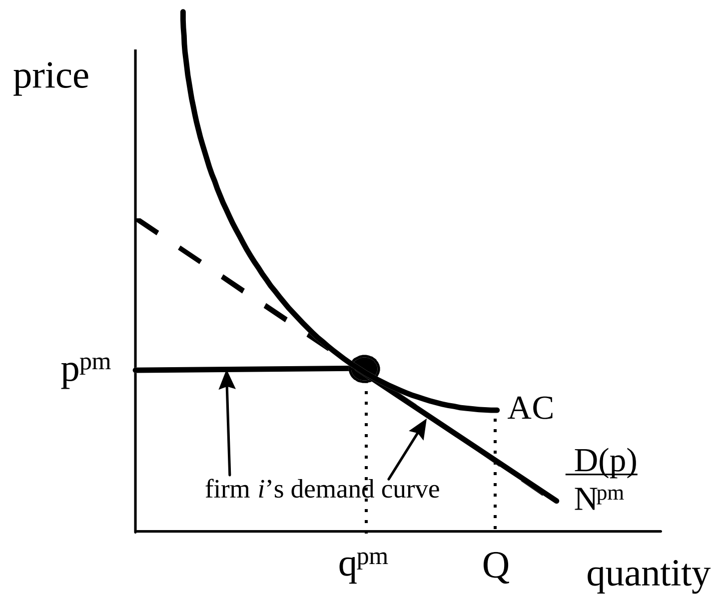

Figure 2.1: **A price matching equilibrium at p^{pm}.**

p, regardless of the deviator's matching policy. Pricing below $AC_{\min} = \frac{F}{Q}+c$ cannot be profitable, so the deviator's pricing problem reduces to solving $\underset{p\in[\frac{F}{Q}+c,p^{pm}]}{max} \frac{D(p)}{N^{pm}}(p-c)$. Since p^{pm} solves this problem by construction, cutting price is not profitable.

The same argument (but substituting $N^{pm} + 1$ for N^{pm} in the pricing problem) shows that new entrants also cannot do better than to post p^{pm}. They won't enter because $p^{pm} < AC\left(\frac{D(p^{pm})}{N^{pm}+1}\right)$. ■

This price matching equilibrium is illustrated in Figure 2.1. Firms will continue to enter as long as there are profits to be earned, so in equilibrium market demand is sufficiently fragmented that each firm's demand touches its average cost curve. By the construction of p^{pm}, $\frac{D(p)}{N^{pm}}$ lies below the average cost curve except at $\left(\frac{D(p)}{N^{pm}}, p^{pm}\right)$.

This proposition is essentially similar to ones in Salop [1986], Belton [1987], Hirshleifer and Png [1987], Doyle [1988], Corts [1995], and Edlin [1998]. As in these analyses, the high-price equilibrium described in Proposition 2.1 is not unique. There is also a low-price Nash equilibrium at the competitive price $p^{co} \equiv \frac{F}{Q} + c$, with each of $N^{co} \equiv \frac{D(p^{co})}{q^{co}}$ firms selling $q^{co} \equiv AC^{-1}(p^{co})$ and earning zero profits. To see this, note that as in the proof of Proposition 2.1, a firm cannot increase profits by raising its price, since if it matches, its effective price remains p^{co} and if it does not, it loses all of its business. Since $p^{co} = \min_{q \in (0,Q]} AC(q)$, deviating from the proposed equilibrium by choosing any price $p < p^{co}$ also would not be profitable, either with or without a matching policy. Similarly, new firms will not enter the market since they cannot make any sales at $p > p^{co}$, and sales at $p \leq p^{co}$ are unprofitable since $p^{co} < AC(\frac{D(p^{co})}{N^{co}+1})$.

Any intermediate price between $\frac{F}{Q} + c$ and p^{pm} may also support a Nash equilibrium, depending on the shape of the demand curve. In particular, if $D(p)(p - c)$ is quasi-concave within $p \in [\frac{F}{Q} + c,\ p^{pm}]$, then the logic of Proposition 2.1 can be used to show that any $\widetilde{p} \in \left(\frac{F}{Q} + c,\ p^{pm}\right)$ is part of an equilibrium with each of $\widetilde{N} \equiv \frac{D(\widetilde{p})}{\widetilde{q}}$ firms selling $\widetilde{q} \equiv AC^{-1}(\widetilde{p})$, matching, and earning zero profits.

There are several reasons, however, to favor the high-price equilibrium at p^{pm}. In Belton's [1987] duopoly model, the high price equilibrium emerges because of subgame perfection: one firm moves first, and so chooses the collusive price and a matching policy, anticipating that this choice will induce the other firm to choose the collusive price. It may be possible to extend such arguments beyond duopoly, though they hinge on timing. Another argument for p^{pm} emerging involves iteratively striking weakly dominated strategies (see, e.g., Doyle [1988]).

Perhaps the strongest reason to favor the equilibrium of Proposition 2.1 is that it is the only equilibrium robust to having some poorly informed buyers, or alternatively, customers with attachments to a particular store. In particular, consider the Salop and Stiglitz [1977] model of bargains and ripoffs, in which some buyers choose not to become informed and instead buy at random. Even if there are only a few buyers who will pay high posted prices when lower prices are available, a price-matching firm can price discriminate by charging high posted prices to poorly informed buyers without driving away savvy buyers, who get low prices because of the matching offer. Once other firms in the industry duplicate this behavior, there are no bargains left for even the savviest shopper to find. That p^{pm} is the unique equilibrium in such a model is proven formally and generalized for more complex search in the Appendix.

3. Analytic Welfare Comparisons

This section compares the welfare properties of the price matching with entry equilibrium developed in Section 2 with equilibria under competition, monopoly, and price matching without entry. In doing these comparisons, we assume a constant elasticity demand function $D(p) = p^{-\varepsilon}$, with $\varepsilon > 1$. The constant elasticity demand function simplifies some of the welfare calculations, but is not essential to the results in Propositions 3.1 and 3.2. These relationships also hold, for example, under linear demand.

When the market price is p, consumer surplus is

$$CS(p) = \int_p^\infty t^{-\varepsilon} dt = \frac{1}{\varepsilon - 1} p^{1-\varepsilon}.$$

In both the competitive and the price matching with entry equilibria, firms make no profits, so total welfare equals consumer surplus. Hence, competitive welfare is given by

$$W^{co} = \frac{1}{\varepsilon - 1} \left(p^{co}\right)^{1-\varepsilon}, \text{where } p^{co} = \frac{F}{Q} + c,$$

while welfare under price matching with entry is

$$W^{pm} = \frac{1}{\varepsilon - 1} \left(p^{pm}\right)^{1-\varepsilon}, \text{ where } p^{pm} = \max\left\{\frac{F}{Q} + c, \arg\max D(p)(p-c)\right\}.$$

Price matching with entry causes a loss of welfare with respect to competitive welfare whenever the markup on c, $c\left(\frac{\varepsilon}{\varepsilon-1}\right)$, exceeds $\frac{F}{Q} + c$. There are two reasons for this welfare loss. First, there is a price distortion relative to the competitive equilibrium. Second, average cost is higher under price matching because all firms have excess capacity, and thus $AC(q)$ is not minimized as it is under competition.

If the market were monopolized instead, the monopoly would solve

$$\max_{p,N} (p-c)D(p) - NF, \qquad \text{s.t. } N \geq \frac{D(p)}{Q},\ N \in \mathbf{Z}^{+}.$$

to find the optimal price p^m and number of plants N^m. When N^m is large, as we assume, the monopoly will essentially markup the cost $\frac{F}{Q}+c$ and charge approximately $\left(\frac{F}{Q}+c\right)\left(\frac{\varepsilon}{\varepsilon-1}\right)$. Hence, consumer plus producer surplus is

$$W^m = \frac{1}{\varepsilon-1}\left(p^m\right)^{1-\varepsilon} + D\left(p^m\right)\left(\frac{F}{Q}+c\right)\left(\frac{1}{\varepsilon-1}\right), \text{ where } p^m = \left(\frac{F}{Q}+c\right)\frac{\varepsilon}{\varepsilon-1}.$$

Since the monopoly treats $\frac{F}{Q}+c$ as the marginal cost, it always charges a higher price than is charged under price matching. On the other hand, the monopoly does not needlessly replicate fixed costs. Hence, whether monopoly or price matching is more efficient depends on $\frac{F}{Q}$, c, and ε. The question is whether the shaded triangle (A) is bigger than the rectangle (B) in Figure 3.1.

Proposition 3.1. *The welfare losses from price matching are greater (smaller) than those from monopoly if*

$$\left(p^{pm}-p^{co}\right)D(p^m) > (<) \frac{1}{\varepsilon-1}\left[\left(p^{pm}\right)^{1-\varepsilon} - \left(p^m\right)^{1-\varepsilon}\right] - \left(p^m - p^{pm}\right)D(p^m),$$

or, equivalently, if

$$\left(p^{m}-p^{co}\right)D(p^m) > (<) \frac{1}{\varepsilon-1}\left[\left(p^{pm}\right)^{1-\varepsilon} - \left(p^m\right)^{1-\varepsilon}\right] = CS(p^{pm}) - CS(p^m).$$

Proof: Compare W^{pm} to W^m, as defined above. ■

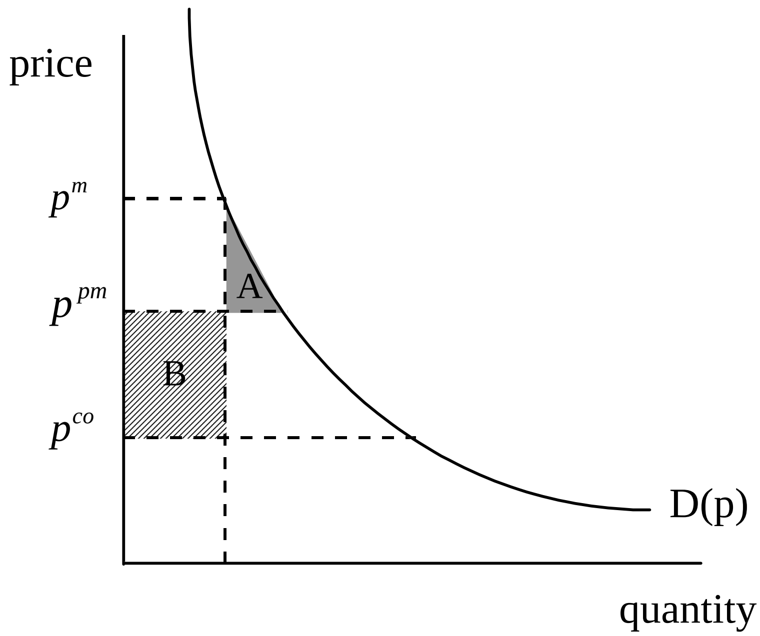

Figure 3.1: **Welfare losses from price matching are greater than those from monopoly if rectangle B is larger than triangle A; otherwise, they are smaller.**

Finally, we want to determine how much of the welfare losses under price matching are due to entry. The price in this price matching without entry scenario is again p^{pm} , so welfare will be

$$W^{ne} = \frac{1}{\varepsilon - 1} (p^{pm})^{1-\varepsilon} + (p^{pm} - c)\, D(p^{pm}) - N^{co}F, \text{ where } N^{co} = \frac{D(p^{co})}{Q}.$$

Proposition 3.2. *When $p^{pm} > \frac{F}{Q} + c$, the welfare losses from price matching with entry exceed those from a price matching without entry. Otherwise, there are no welfare losses from either.*

Proof: Compare W^{pm} with W^{ne}, as defined above.■

The equivalence of price matching, cartel, and competition when demand elasticity is large enough ($\varepsilon \geq \frac{Qc}{F}+1$), is caused by the kink in the average cost curve at Q, which makes it possible for an individual firm's demand, $\frac{D(p)}{N^{co}}$, to be flatter than average

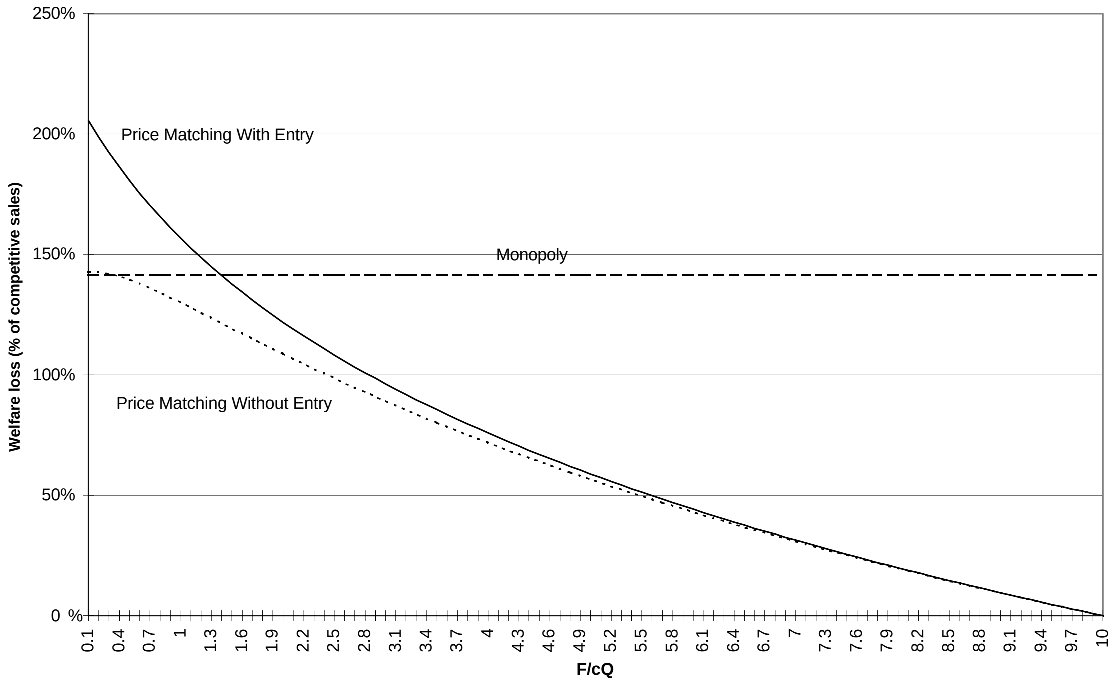

Figure 4.1: **Welfare losses under price matching, cartel and monopoly when** $\varepsilon = 1.1$.

cost at the minimum of the average cost curve. If this kink were smoothed out, then price-matching firms and cartels would price above $AC_{\min}$ even when demand is very elastic, so that $W^{pm} < W^{ne} < W^{co}$. But these welfares would be almost equal since price would rise only slightly above competitive levels.

4. Numeric Welfare Calculations and Calibration

In this section we first show, numerically, how the welfare losses derived in Section 3 vary with industry costs. We then calculate losses in two particular industries that could in theory be susceptible to price matching – air travel and wholesale gasoline – using published estimates of relevant parameters.

In industries with high marginal costs relative to fixed costs (low $\frac{F}{cQ}$), price matching with entry yields high welfare losses, and higher losses than monopoly. Figure 4.1 demonstrates this pattern. It shows welfare losses when $\varepsilon = 1.1$ across a variety of industries with varying $\frac{F}{cQ}$. Losses from price matching increase as $\frac{F}{cQ}$ decreases, to roughly 200% of competitive sales when $\frac{F}{cQ} = \frac{1}{10}$. By the same token, when fixed costs are high relative to marginal costs, price matching is not very costly, and is much less costly than monopoly. In the case of Figure 4.1, price matching (with and without entry) replicates the competitive outcome for all $\frac{F}{cQ} \geq 10$, while monopoly yields a constant welfare loss of 145% of competitive sales. This pattern is also evident at higher elasticities, though as demand elasticity increases, losses decrease under all three scenarios.

The fact that losses from price matching with entry fall as fixed costs rise may seem counterintuitive – after all, the particular harm of price matching with entry comes from the inefficient replication of fixed costs. But the magnitude of this harm is determined entirely by the price markup above $\frac{F}{Q}+c$, and this markup rises under price matching when c rises relative to $\frac{F}{Q}$. The monopoly markup, in contrast, depends on the sum of c and $\frac{F}{Q}$ and not on the size of each component (which is why monopoly welfare losses are represented by a horizontal line in Figure 4.1). The monopoly markup is thus always larger than the markup under price matching, but the price matching markup brings the additional harm of higher average costs, which makes it more costly when $\frac{F}{cQ}$ is low.

The price matching without entry scenario may alternatively be thought of as a classic cartel that is able to fix prices while restricting entry. Of course, many industry structures are commonly grouped together under the heading of "cartel," and this is only one possible representation. If a cartel could have more than the competitive number of firms and still maintain high prices, its welfare would more closely resemble welfare under price matching with entry. On the other hand, a cartel in an oligopoly industry with only a few firms, each with many plants, might yield welfare closer to that of our monopoly, and if cartel firms could avoid building extra capacity, the two would be identical. Our representation of monopoly is subject to similar qualifications. If a monopolist held extra capacity in reserve to deter entry, its prices would fall toward the price matching level, while this excess capacity would in turn increase average cost. Also, we do not consider the case of natural monopoly. An industry with increasing returns to scale across all production levels is somewhat of a special case, which lends itself to monopoly outcomes rather than price matching or some version of cartel.

To get a sense of the size of the welfare effects of price matching under realistic sets of parameter values, we calculate welfare losses from our three scenarios using data from the U.S. wholesale gasoline and air travel markets. Products are fairly homogenous in these two industries, making them good candidates for our price matching model. We assume in each case that the current market structure is competitive, and calculate the losses that would be incurred by switching to a regime of monopoly or price matching with or without entry. This calculation requires estimating the ratio of fixed to marginal cost in each industry, and then incorporating published estimates of demand elasticity in order to perform welfare calculations of the type described in Section 3.

Air travel is an example of an industry with a high $\frac{F}{cQ}$ and a relatively low elasticity of demand – we find values of 6.5 and .7, respectively.[16] Under linear demand, and assuming that the 1993 average price of \$.13 per passenger mile is competitive, a price matching regime causes welfare losses of 25% of sales.[17] Given 1993 total U.S. passenger revenues of \$64 billion, this translates to welfare losses of \$16.2 billion under price matching with entry, compared to losses of \$11.4 billion under monopoly and

[16] For descriptions of the data sources used in this calibration exercise, see the Data Appendix.

[17] We assume linear demand, as opposed to constant elasticity demand, because given the observed elasticities in each market, the markup under a constant elasticity demand curve is not defined.

	Air travel	Wholesale gasoline
F/cQ	6.5	0.2
ε	0.7	0.86
Competitive sales	$64 billion	$79 billion
Losses under price matching with entry	$16.2 billion	$30.2 billion
Losses under monopoly	$11.4 billion	$11.5 billion
Losses under price matching without entry	$12.7 billion	$13.3 billion

Figure 4.2: **Potential welfare losses in the air travel and wholesale gasoline markets in the United States relative to perfect competition.**

$12.7 billion under price matching without entry. Note that, even though $\frac{F}{cQ}$ is high, welfare losses are still greater under price matching than under monopoly due to the low elasticity of demand.

Wholesale gasoline represents, in contrast, an industry with *low* $\frac{F}{cQ}$ and a low elasticity of demand, with values of .2 and .86, respectively. Given 1993 U.S. market size of $79 billion dollars, we find losses of $30.2 billion under price matching, compared to $11.5 billion under monopoly and $13.3 billion under cartel. In this industry, potential welfare losses from price matching with entry are nearly triple those under monopoly and price matching without entry.

5. Implications

In comparing our monopoly and price matching models, one fact stands out. Welfare losses are highest in markets where fixed costs are low relative to marginal costs, firms match prices, and entry is possible. In these situations, price matching yields a particularly large markup over the competitive price, which attracts a great deal of inefficient entry. This observation suggests that government attention should focus on these markets.

It is more traditional, of course, to worry about supracompetitive pricing in industries with large fixed costs. Posner [1976, pp. 39-78], for example, argues that authorities should focus their attention on these industries because they will be more susceptible to collusion and consequently experience more frequent and substantial price distortions. Price matching, however, does not require concerted effort, and thus may be possible in many more industries than is oligopoly coordination. As we have demonstrated above, it may also be more costly.[18]

Our model examines the upper bound of possible price effects from matching policies. Whether price matching supports this monopoly price, or the significantly lower but still supracompetitive price of Hviid and Shaffer's [1997] hassle costs model, will depend in large part on the ease of price dissemination in a market. In retail markets, where price matching offers are now most common, obtaining a match will indeed be costly for a customer, as either the customer or the store must manually check a competitor's price. Attempts to compensate customers for hassle costs may be crude, and firms may have difficulty completely assuming these hassle costs themselves.

On the other hand, when prices are posted to a common computer system, it becomes cheap for firms to monitor each others' prices. This may facilitate quick response equilibria, as in Anderson [1985], or explicit price matching policies, where firms pay the transaction cost of matching by searching for the lowest price themselves. The $250 billion office materials procurement market, for instance, is moving

[18] An essential difference between our view and Posner's is the extent to which entry depresses prices. If entry has little or no effect on price, as in our price matching model, then welfare losses may be large in markets with plentiful entry, since entry only serves to increase industry-wide average costs.

towards automated, online, business-to-business transactions.[19] Procurement software creates a virtual common catalog of prices posted by a firm's suppliers. In such an environment, implementing a price matching strategem may be particularly easy, and the hassle costs of obtaining a match essentially zero. Retailers, too, have begun to experiment with hassle-free ways of matching prices. American TV and Appliance describes its new "patent pending Price Check Network" as follows:

> Price changes are made twice a day. We get our competitors' price information from two sources: in store shopping and competitive ads. If the sources don't agree, our system uses the lower price. If a competitor has multiple stores in our market and one store has a lower price than another, we again use the lower price to compare our price. As a result every sale price available in the market from our competitors is on our floor every day![20]

Since our model captures a worst-case scenario, our analysis should not be viewed as a definitive guide for U.S. antitrust policy. It suggests, however, that unconcentrated markets should not be immune from public scrutiny. It also suggests that we should be concerned that unconcentrated industries with relatively unfettered entry have witnessed a proliferation of price matching policies and related strategies in recent years. Another concern is the predicted growth of computerized sales and trading systems, which facilitate price dissemination and thus the efficacy of price matching. The danger of price matching in such a context is more than theoretical – on the NASDAQ stock exchange, for example, a computerized matching system may be an important factor in explaining recent findings that bid-ask spreads were above competitive levels.[21]

[19] See Loizos [1998] for a description of the development of Internet procurement systems.

[20] From American TV's web page at www.americantv.com/pricecheck.html

[21] Both the SEC [1996b] and the Department of Justice [1996] have recently concluded that bid-ask spreads on NASDAQ were higher than competitive levels. Huang and Stoll [1996] find NASDAQ spreads to be significantly higher than spreads on the New York Stock Exchange, and conclude that the difference cannot be explained by traditional economic determinants of the bid-ask spread.

Retail trades on NASDAQ are generally placed with brokers, who then direct them to market makers for execution, although most of the 512 NASDAQ market makers offer brokerage services as well.[22] A market maker is required to execute a customer order at the most favorable terms available, which has been interpreted to mean that market orders are executed at best price posted on the NASDAQ computer system. (SEC [1996b, p. 14]). When a broker receives an order for a stock for which it is a market maker, it will generally match the best posted price, rather than passing sales to the low-price market maker. As the SEC notes in its recent review of NASDAQ,

> It is also a general practice for a NASDAQ market maker receiving a retail customer order to execute the order itself rather than send it to another market maker, even if that market maker is posting the best price (i.e., the best inside bid or offer) and the executing market maker is not. The executing market maker will provide the customer with the price displayed in the inside quotes, whether or not it is quoting those prices itself. (SEC [1996b, p. 15]).

When a broker does not execute an order itself, it is typically "preferenced" to a market maker who has agreed in advance to match the inside spread, even when that market maker is not quoting the best price. This preferencing may reflect a long-term business relationship, or it may be in return for payment under a "payment for order flow" agreement. Since most or all market makers will trade at the inside spread, posting the best price is not what brings in trades: A market maker gets trades from its own brokerage services or from brokers with which it has an arrangement.

Christie and Schultz [1994] and Christie, Harris and Schultz [1994] were the first to call attention to the wide bid-ask spreads of many stocks traded on NASDAQ. They argued that the dearth of odd-eighth quotes among heavily-traded stocks could

[22] Market makers buy, sell, and hold inventory of NASDAQ stocks. There were an average of 11 market makers per NASDAQ stock in 1995 (SEC [1996b, p. 14]). The bid and ask prices posted by market makers define the "quoted spread" for a stock. Smaller trades are usually conducted at the quoted spread, while large traders with more bargaining power can often negotiate a trade "inside the spread." See Schwartz [1991, pp. 136-164].

not be explained by economic fundamentals, and may have resulted from an implicit agreement among market makers. This assertion has been controversial. Kleidon and Willig [1995], for example, compared NASDAQ to the New York Stock Exchange and argued that differences in spreads could be explained without resorting to collusion.[23] In addition, they argued that with up to 50 or more market makers trading in each stock, and low entry and exit barriers, collusion was *a priori* impossible (Kleidon and Willig [1995, p. 6]).

Although price matching policies may not reflect collusion, we have argued that the danger of price matching is precisely that it can lead to high, cartel-like prices in industries where traditional market structure analysis predicts competitive outcomes. The price matching on NASDAQ makes the findings of Christie and Schultz plausible, despite the large number of market makers. The existence of payment for order flow contracts bolsters this conclusion, since such contracts would cause market makers to lose money if spreads were competitive.

Our model predicts that the welfare losses from price matching on NASDAQ must be small as a fraction of sales if, as we presume, demand elasticity is high and fixed costs are high relative to marginal costs.[24] The attention of the DOJ and SEC may have been justified, however, by the huge market size. In 1995, 101.2 billion shares were traded on NASDAQ, which means that if spreads averaged 1/8 point over competitive levels, welfare losses could have exceeded $12 billion in that year.

This figure represents an upper bound on welfare losses, however, since revenues earned from high spreads were probably not entirely dissipated by over-entry, as

[23] The bulk of the economics literature, as well as reports by the Department of Justice and the SEC, runs contrary to Kleidon and Willig's assertion that NASDAQ spreads were competitive. See Edlin and Emch [1997, pp. 26-27] for more extensive discussion of this literature and recent SEC rule changes.

[24] Demand to buy or sell a given security should be fairly elastic because there are other securities, on NASDAQ or elsewhere, that when bundled are good substitutes. We are less certain of our technological presumption, but we suspect there are significant fixed costs in buying computers for trading or hiring a licensed broker to be a market maker for a given security.

in our model. Some could have been dissipated on service-based competition for retail customers, which may have been only partially wasteful. More directly, we might expect revenues from supracompetitive spreads to be simply funneled back to customers via lower retail commissions.[25]

More generally, in markets where avenues of non-price competition are available, high prices may not attract as much entry as they would otherwise, and thus price matching's full anti-competitive potential may not be realized. In some other markets, as Hviid and Shaffer [1997] argue, the hassle costs of taking advantage of a price matching offer may mean that prices do not rise all the way to p^{pm}, or fail to rise at all above the competitive price. Ultimately, determining the price effects of matching policies in different types of markets is an empirical exercise – one whose pursuit we recommend with enthusiasm.

Even without the sort of explicit matching policies envisioned in our model, computerized trading may present problems quite similar to the matching we discuss. A firm's incentive to undercut a price that exceeds cost naturally depends on how that firm expects rivals to react. In our price matching model, customers demand that rivals who adopt a matching policy instantaneously track a price cutter's price. It has long been observed that when rivals' reaction times decrease sufficiently, undercutting becomes unprofitable. One feature of computerized trading systems is that reaction times may be very short, even if they are not immediate as under the NASDAQ system. Although quick-response price matching may not solve the problem of

[25] Note that large transactions on NASDAQ are sometimes conducted "net," that is, without commission, but smaller customers usually pay a commission to the retail broker executing the trade.

If the brokerage market were perfectly competitive, we would expect to see commission schedules with a fixed fee paid by the customer, accompanied by an order flow payment from the broker to the customer to compensate for the supracompetitive spread. We are not convinced, however, that the market for brokerage services is perfectly competitive. In fact, instead of brokers paying customers for order flow, their commissions have traditionally *increased* with volume. This tendency has been mitigated recently as some brokers have begun to offer flat fee trades. Still, we have yet to see any brokers pass along a payment for order flow, suggesting that the market may not be perfectly competitive.

coordinating on a price hike, the potential for downward price stickiness could become increasingly important as more business gets conducted on the Internet or on proprietary computer systems such as NASDAQ or the airlines' reservation systems. In some cases, near-frictionless price "competition" may lead to higher welfare losses than if there were no competition at all. This possibility warrants more study and attention.

6. Appendix

Here we modify the Salop and Stiglitz [1977] model of bargains and ripoffs to allow firms to offer price matching pledges. Buyers are aware of the equilibrium price distribution, but must pay some individual cost s to know which sellers post which prices. The cost s has a cumulative distribution function given by $G(s)$. A buyer who buys at price p has consumer surplus of $CS(p) = \int_p^\infty d(\overline{p})d\overline{p}$. Individual demands are identical so that with L buyers, $D(p) \equiv Ld(p)$.

An uninformed buyer buys from store i at price p_i with probability $\frac{1}{N}$, where N is the equilibrium number of stores, and so has expected consumer surplus equal to $\sum_{i=1}^{N} \frac{CS(p_i)}{N}$. A buyer will pay s to become informed if $s < \widehat{s}$, where $\widehat{s} = CS(p_{\min}) - \sum_{i=1}^{N} \frac{CS(p_i)}{N}$. Then, $G(\widehat{s})$ is the fraction of buyers who become informed. Salop and Stiglitz show (in a model with no price matching) that the unique equilibrium typically involves two prices. Low-priced firms sell at "bargains" for $p = \frac{F}{Q} + c$, and high-priced firms sell at "ripoffs" for p^{pm}.[26]

Price matching breaks the Salop-Stiglitz two-price equilibrium. As shown below, low-priced firms will adopt price matching polices and raise prices to price discriminate. In equilibrium, there are no low prices left, and all buyers pay p^{pm}.

[26] Technically, this result requires that $G(0)$ be sufficiently low and that ε is low enough so that $p^{pm} > \frac{F}{Q} + c$.

Buyers' search strategies depend on the equilibrium price dispersion and do not take into account deviations by firms.[27] In an equilibrium, a fraction $G(\widehat{s})$ buyers are informed, where $\widehat{s}$ is determined by the equilibrium price dispersion. Let $p_{\min} \equiv \min_j \{p_j\}$ and M = number of firms either posting $p_{\min}$ or agreeing to match. Then, firm i's profits are:

$$\pi_i = \begin{cases} \frac{D(p_i)(1-G(\widehat{s}))}{N}(p_i - c) - F & \text{if } p_i > p_{\min} \text{ and the firm doesn't match,} \\ \frac{D(p_i)(1-G(\widehat{s}))}{N}(p_i - c) + \frac{D(p_{\min})G(\widehat{s})}{M}(p_{\min} - c) - F & \text{if } p_i = p_{\min} \text{ or the firm matches.} \end{cases}$$

There is no equilibrium in which some firm i charges $p_i < p^{pm}$, since firms' incentives to price discriminate would undo such an outcome. This result is summarized as follows:

Proposition 6.1. *If matching is possible in the Salop-Stiglitz model, then all firms post p^{pm} in any equilibrium with some uninformed buyers.*

Proof: Observe first that in equilibrium, no firm will post $p_i > p^{pm}$ since such a firm could increase profits by posting p^{pm}, whether or not it matches prices. Suppose, then, that some firm posts $p_i < p^{pm}$. Note that there can be no firm charging an intermediate price $p \in (p_{\min,}p^{pm})$, since this firm could increase profits by matching and posting p^{pm}. Profits increase by $\frac{(1-G(\widehat{s}))}{N}((p^{pm} - c)D(p^{pm}) - (p_i - c)D(p_i))$ if the firm was initially a matcher and by $\frac{(1-G(\widehat{s}))}{N}((p^{pm} - c)D(p^{pm}) - (p_i - c)D(p_i))$ $+\frac{D(p_{\min})G(\widehat{s})}{M}(p_{\min} - c)$ if it was not. Note also that $1 - G(\widehat{s})$ is positive since we assume there are some uninformed buyers, and that $p_{\min} > c$ in equilibrium, since if $p_{\min} \leq c$, firms charging $p_{\min}$ cannot cover their fixed costs.

Any firm charging $p_{\min}$ can increase profits by raising price to p^{pm} and matching, unless $p_{\min} = p^{pm}$. This is straightforward when there are other firms charging $p_{\min}$,

[27] Essentially, Salop-Stiglitz have a simultaneous game with a Nash equilibrium concept. Another view of this assumption is that it represents an approximation which captures the idea that with many firms, one firm's price has a negligible effect on the price distribution, and so should not affect search appreciably.

because then profits increase by $\frac{(1-G(\widehat{s}))}{N}((p^{pm}-c)D(p^{pm})-(p_{\min}-c)D(p_{\min}))$. If there is only one firm charging $p_{\min}$ and all buyers are uninformed ($G(\widehat{s})=0$), then the firm can raise its profits by $\frac{1}{N}((p^{pm}-c)D(p^{pm})-(p_{\min}-c)D(p_{\min}))$ by posting p^{pm}. If, finally, there is only one firm charging $p_{\min}$ and some buyers are informed, then all firms charging p^{pm} must be matching,[28] and so the single firm charging $p_{\min}$ can raise its profits by $\frac{1}{N}((p^{pm}-c)D(p^{pm})-(p_{\min}-c)D(p_{\min}))$ by posting a price of p^{pm}. ■

As in Proposition 2.1, in which all buyers were informed, it is an equilibrium for N^{pm} firms to enter, post p^{pm}, and match prices. With some uninformed buyers, however, it is typically the only equilibrium. If *all* buyers are uninformed, this result is straightforward. If there are both informed and uninformed customers, as Proposition 6.1 shows, firms pricing below p^{pm} will generally have an incentive to price discriminate by raising their posted price to p^{pm} while offering a matching policy. This maximizes profits on uninformed customers while retaining an equal share of informed customers.[29] In equilibrium, only p^{pm} survives.

In the Salop-Stiglitz model, buyers choose either to search all firms or take their chances and canvas only one seller. The proof given above can be extended to the case where buyer k chooses to search some number of firms n and has total search costs of $s^k(n)$. A firm charging $p_{\min}$ would still be better off matching and charging p^{pm}, as long as this did not make it less likely to be among the sets of firms from which any buyer chooses. With this proviso, raising price to p^{pm} will increase profits from buyers who do not draw a $p_{\min}$ from the n firms they choose to search, while the firm is protected by the price matching pledge from losing customers who do.

[28] Every firm charging p^{pm} prefers to match , since this will capture a share of the informed market and increase profits by $\frac{D(p_{\min})G(\widehat{s})}{M}(p_{\min}-c)$. Recall, also, that $p_{\min}>c$ in equilibrium – otherwise, firms charging $p_{\min}$ could not cover their fixed costs.

[29] Strictly speaking, for this intuition to be correct, all firms must be price matchers (otherwise, a low-price firm might decrease its share of the informed customers when it posts a higher price, which could lower profits). However, even when not all other firms match, a low-price firm will want to match and raise p somewhat to price discriminate, as long as $D(p)(p-c)$ is quasi-concave.

7. Data Appendix

Airlines: The "rule of thumb" in the airline industry is that short-run demand elasticity is .7 (Morrison and Winston [1995, p. 119]). The majority of costs are fixed. The marginal cost of an extra passenger primarily consists of ticketing commissions paid to travel agents and owners of the computerized reservation system used to book the flight, and in-flight food (we ignore extra fuel costs due to the weight of an additional passenger). These total about 13.4 percent of costs, yielding an $\frac{F}{cQ}$ of 6.5, since we assume price is equal to average cost. Passenger ticketing costs and passenger food were 10.8 and 3.4 percent of operating expenses plus interest less depreciation and amortization in 1993. Since depreciation and amortization are about 6% of total operating expenses in a typical airline, these figures translate to 10.2 and 3.2 percent of total operating expenses plus interest. All airline cost data are from U.S. Bureau of the Census [1995, p. 656]. The 1993 average airline price of \$.13 per passenger mile and total passenger revenue of \$64 billion are from Morrison and Whinston [1995, p. 7].

Wholesale gasoline: In a recent survey article, estimates of the long-run elasticity of demand for gasoline range from .23 to 1.05; we use the mean figure of .86 (Dahl and Sterner [1991, pp. 206, 210]). The most significant marginal cost in producing wholesale gasoline at a refinery is the cost of the crude oil used to produce it. The November 19, 1996 Wall Street Journal (p. C18) reports prices of \$24.48 for a 42-gallon barrel of West Texas intermediate crude oil and \$0.69 a gallon for New York wholesale unleaded regular gasoline. The figure $\frac{F}{cQ} \approx .2$ results from assuming that the oil fuel cost of a gallon of gasoline is $\frac{\$24.48}{42}$; although a gallon of crude oil only yields approxomiately $\frac{1}{2}$ gallon of gasoline, this calculation is appropriate because the other oil products, such as kerosene, have roughly comparable value. This calculation represents an upper bound on $\frac{F}{cQ}$; the true figure is slightly lower because ours assumes that all costs other than fuel costs are fixed, ignoring other marginal costs, such as transportation costs, which are approximately \$.02 per gallon. Total market size was calculated in the following way: In 1993, the average retail price of regular grade unleaded gasoline was \$0.754 (American Petroleum Institute [1995, Section VI, Table 5]). Of this, approximately \$.07 represents retail markup over costs (using the most recent estimate from Borenstein [1991, p. 360]). Total U.S. demand for gasoline was 7,456,000 (42-gallon) barrels per day (American Petroleum Institute [1995, Section VII, Table 3d]). Total wholesale market size thus equals approximately $.684 \times 7,456,000 \times 42 \times 365 = \$79$ billion. Note that $\frac{F}{cQ}$ is calculated from current data while market size data are from 1993.

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