

A Theory of Stable Price Dispersion

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Abstract. We propose a two-stage replacement for established “clearinghouse” or “captive and shopper” pricing models: second-stage retail prices are constrained by first-stage list prices. In contrast to the mixed-strategy equilibria of single-stage games, a unique profile of distinct prices is supported by the play of pure strategies along the equilibrium path, and so we predict stable price dispersion. We find novel results in applications to models of sales, product prominence, advertising, and consumer search.

Keywords: price dispersion, clearinghouse models, prominence, advertising, buyer search.

1. INTRODUCTION

Seemingly identical products are often sold at different prices by several firms. The “clearinghouse” pricing framework, associated with Varian’s (1980) “model of sales” and other contributions (Shilony, 1977; Rosenthal, 1980; Narasimhan, 1988), generates price dispersion via the mixed-strategy equilibria of a single-stage pricing game. Such equilibria are naturally susceptible to ex post deviations and predict dynamically uncorrelated variation in firms’ prices. This is inconsistent with any ability of retailers to offer rapid discounts in response to others, and with the empirical lack of sufficiently frequent temporal variation in otherwise disperse prices.

We suggest a two-stage alternative that produces stable price dispersion. In a first stage, firms set list prices. In a second stage, they may discount (but not raise) those prices. Under several specifications, we find a unique set of prices that are supported by the equilibrium play of pure strategies. Firms’ prices differ (even for symmetric firms) and the opportunity to offer a second-stage discount is not used (but the possibility determines equilibrium prices). For asymmetric firms we pin down which supplier charges each price. We develop and apply our approach using a suite of three further models: we relate pricing positions to firms’ prominence; we characterize firms’ choice of advertising exposure; and we study the search decisions of buyers. The results suggest that our approach succeeds as a tractable replacement for the captive-and-shopper pricing stage of models in which buyers have incomplete or costly access to prices.

Before explaining our approach and the results that flow from it, we pause to describe the price dispersion that we seek to explain and the empirical justification for our assumptions.

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Empirical studies have identified extensive price dispersion. For example, Kaplan and Menzio (2015) used the large Kilts-Nielsen panel of 50,000 households to show that the standard deviation (relative to the mean) of prices at brick-and-mortar stores ranges from 19% (when products are defined narrowly) to 36% (when defined broadly). However, only a minority of variation can be attributed to intertemporal price changes.² This differs from a literal interpretation of the symmetric mixed equilibrium of a clearinghouse model.³ More recently, Aas, Wulfsberg, and Moen (2018) found high persistence of price dispersion: the same price typically lasts 1–3 months but many last for over a year, and stores charging prices in a particular quartile of the distribution tend to stay there with high probability (0.8–0.9) month-to-month. Relatedly, Gorodnichenko, Sheremirov, and Talavera (2018) examined daily online pricing data. They reported (pp. 1764–1766) that “although online prices change more frequently than offline prices, they nevertheless exhibit relatively long spells of fixed prices” and so “online price setting is characterized by considerable frictions.” Specifically, prices are fixed for long spells of 7–20 weeks and “clearly do not adjust every instant.” They concluded that prices tend to vary in the cross section rather than over time.⁴ A stylized summary of empirical findings is that firms persistently occupy different high and low pricing positions (with occasional dynamic changes) rather than rapidly flipping amongst them.⁵ This requires a theory that can explain stable price dispersion. We need an equilibrium in pure strategies with heterogeneous price choices.

We make our “no charging over list price” assumption because it is often easy to discount a price, but difficult to raise it. There are at least two applied motivations for this claim. Firstly, legal constraints may force a firm to meet any published offer. In his study of dispersed prices for prescription drugs Sorensen (2000, p. 837) reported that “price-posting legislation dictates that any posted price must be honored at the request of the consumer.” Charging an “over” at the point of sale can fall under many authorities’ definitions of deceptive pricing. For example, the UK’s Advertising Standards Authority advises that there should be availability of a product at a listed price. Similar advice is provided by Ireland’s Competition and Consumer Protection Division. Retailers using barcoding systems with GS1 New Zealand adopt a code of practice that prevents charging above a displayed price. Even if some price rises are allowed, there can be other limitations. Obradovits (2014) documented the Austrian gasoline market: a regulation from 2011 prohibited firms from raising their prices more than daily, and restricted them to implement any price rise at noon. Price cuts were freely permitted.⁶

²Kaplan and Menzio (2015) distinguished between three components of variation: a store-specific component, across stores for all products; a store-specific product component, from variation across stores for individual products; and a transaction component, defined as within-store variation for the same product over time. This final component accounts for a substantial fraction (approaching one half) of variation, but not all of it.

³If the symmetric mixed equilibrium of Varian (1980) were played each period then the variance of prices through time for a particular firm (the transaction component) would explain all of the observed variation.

⁴They also documented that temporary sales (defined as lasting two weeks or less) occur with a mean weekly frequency of only 1-3%, similar to brick and mortar stores.

⁵Many industry-specific studies that document price dispersion for products including prescription drugs (Sorensen, 2000), illicit drugs (Galenianos, Pacula, and Persico, 2012), memory chips (Moraga-González and Wildenbeest, 2008), and textbooks (Hong and Shum, 2010), are also consistent with this summary. A contrasting conclusion was provided by Lach (2002), who placed greater emphasis on the observation that (p. 433) “stores move up and down the cross-sectional price distribution.”

⁶Obradovits (2014) reported that similar regulations were proposed in New York State and in Germany.

Secondly, customers may see any attempt to charge above a list price as unfair, may find it socially unacceptable, or it may otherwise reduce their demand. For example, if a list price sets a reference point then loss-aversion arguments (Kahneman and Tversky, 1979) may suggest a higher elasticity of demand above the list price than below (Ahrens, Pirschel, and Snower, 2017). Marketing researchers have documented how “advertised reference prices” can impact consumers’ perception of value and purchase intentions (e.g., Urbany, Bearden, and Weilbaker, 1988; Lichtenstein, Burton, and Karson, 1991; Grewal, Monroe, and Krishnan, 1998; Alford and Engelland, 2000; Kan, Lichtenstein, Grant, and Janiszewski, 2013). The role of fairness concerns as a constraint on profit-seeking was central to the work of Kahneman, Knetsch, and Thaler (1986). Relating their ideas to Okun (1981), they noted “the hostile reaction of customers to price increases that are not justified by increased costs and are therefore viewed as unfair.” The importance of fairness considerations in pricing is central to other marketing studies (Campbell, 1999, 2007; Bolton, Warlop, and Alba, 2003; Xia, Monroe, and Cox, 2004).

Our “no charging above list price” assumption is readily incorporated into the Varian (1980) “model of sales” setting. In that benchmark model, customers are either shoppers (“informed”) who buy at the lowest price, or are captive to one firm (“uninformed” about other suppliers). Starting from any profile of high prices for the same product, some firm will undercut the lowest price and so capture the shoppers. Further best-replies walk the firms down a staircase of prices. At sufficiently low prices firms abandon the hunt for shoppers and instead exploit captive customers, which elevates prices back up to the monopoly level. This “Edgeworth cycle” logic (Maskin and Tirole, 1988a,b) rules out an equilibrium in pure strategies.⁷

If raising price is impossible, then the “elevator” from a shopper-capturing low price to a captive-exploiting high price is removed. Furthermore, the ability of a firm to post a price in advance offers commitment power. In a subgame perfect equilibrium, one (aggressive) firm posts a low list price and serves all shoppers; other firms post high list prices to exploit fully their captive customers.⁸ A sufficiently low limit price dissuades those others from discounting.

Adopting a natural two-stage pricing process (simultaneous choice of list prices, followed by the opportunity to offer discounted retail prices) we find a unique price profile that is implemented via pure strategy choices along the (subgame perfect) equilibrium path.⁹

⁷More formally: if there is a unique lowest price then the lowest-price firm could profitably raise it; if multiple firms are cheapest then one could undercut the others. Varian (1980) constructed a symmetric equilibrium in which firms continuously randomize over an interval which extends downward from the reservation price of captive customers; Baye, Kovenock, and de Vries (1992) characterized the full set of equilibria.

⁸In essence, our first list-price stage offers each firm the possibility of taking a Stackelberg leadership position. Later in our paper, we briefly explain that our results can be replicated under a Stackelberg specification.

⁹Others have also studied discounts to list prices, across various contexts. Anderson, Baik, and Larson (2016) studied mixed-strategy pricing for targeted price discrimination. Personalized offers are not observed by competing firms, and so the single-stage game is reasonable. Chen and Rosenthal (1996a,b) revealed how seller-commitment to “ceiling” prices entice buyers to sink search costs. Harrington and Ye (2017) showed how non-binding list prices can facilitate collusion. Gill and Thanassoulis (2016) studied a Hotelling duopoly in which some customers see only firms’ list prices, while others also have access to second-stage discounts.

We predict stable price dispersion, in the sense that prices vary across firms and yet the play of pure strategies eliminates any incentive to deviate. Working with asymmetric firms, we identify the limit-pricing firm that captures the shoppers. A firm is more willing to act aggressively if it has a smaller captive customer base, and is more able to do so if it enjoys a lower marginal cost. These parameters determine the firm that can offer the lowest undominated list price, and it is this firm that captures the shoppers. Helpfully, our equilibrium shares several comparative-static properties of standard single-stage specifications, and so is not in conflict with them.

An advantage of our approach is that it predicts price dispersion in pure strategies, and yet yields expected profits that match those from a single-stage model. A disadvantage is that, in the special case of the captives-and-shoppers world, the dispersion involves only two price points. This is because there is, in effect, only a single shopper type that performs comparisons amongst all prices. Fuller specifications allow for an additional customer type for each possible “consideration set” of suppliers.¹⁰ To obtain a richer pattern of dispersion, we study three broader models. For each model, we find fully distinct prices that are played as pure strategies. When firms are asymmetric, we predict which firm charges which price. These three cases generate novel results on endogenous prominence, advertising exposure, and buyer search.

Our first extended setting is a model of prominence. A prominent firm (perhaps a national supplier) has some captive customers, but is also available to all other customers. Non-prominent rivals (for example, local suppliers) only reach customers who also see the prominent firm’s price. We find that each firm charges a distinct price. The prominent firm is the most expensive.¹¹ Others post prices that are sufficiently low to dissuade the prominent firm from undercutting them. Amongst the non-prominent firms, the one with a larger reach (and so the one that is most tempting for the prominent firm to challenge) is cheaper.¹²

Our model of pricing prominence also provides an opportunity for us to demonstrate how the two-stage pricing framework can be a component of a deeper model. We add an earlier stage to consider the incentives of a “prominence provider” who elevates one of many local firms to national prominence. We find that this provider makes a prominence offer (which is accepted) to the local firm with the largest reach (equivalently, the largest local customer base).

¹⁰For single-stage models, we do not know of a complete analysis of the pricing game with no restriction placed on the structure of consideration sets (this terminology from the marketing literature has been used by Eliaz and Spiegler (2011), Manzini and Mariotti (2014) and several others) or what Armstrong and Vickers (2019) have called “the pattern of competitive interaction.” The early literature offered a comprehensive analysis of duopoly (Narasimhan, 1988) and of situations in which customers are either captive to one firm or shop amongst all of them (Rosenthal, 1980; Varian, 1980). Other papers considered “independent awareness” specifications in which the proportion of buyers who see a firm’s offer is unrelated to their access to other firms’ prices (Ireland, 1993; McAfee, 1994). In their recent paper, Armstrong and Vickers (2019) offer a near-to-complete analysis of mixed-strategy equilibria for the triopoly case, and for a particular (and natural) “nested reach” specification.

¹¹This holds for the ordered-search model of Arbatskaya (2007) and in the search-and-prominence duopoly model of Moraga-González, Sándor, and Wildenbeest (2018). In contrast, Armstrong, Vickers, and Zhou (2009) used a sequential-search model to predict that a prominent firm offers the lowest price.

¹²For asymmetric firms, we focus on the triopoly case; we allow for more firms under a symmetric specification. As noted already, Armstrong and Vickers (2019) present a comprehensive analysis of a triopoly with single-stage pricing. Their formal result does not cover our specification, in which the audiences of non-prominent firms are distinct. However, they discuss the possibility of multiple mixed-strategy equilibria in such cases. In contrast, our approach offers a unique prediction for prices played as pure strategies.

Our second extended setting builds upon classic models of informative advertising (Butters, 1977; Grossman and Shapiro, 1984) in which buyers are randomly and independently aware of each firm. This generates the full set of buyer consideration sets: captive consumers, those who see two prices, shoppers who see all prices, and so on. Adopting our two-stage list-prices-then-discounts approach, we find that entirely distinct prices are set using pure strategies. Firms with broader advertising exposure charge higher prices.

We endogenize costly advertising decisions via a three-stage model: firms choose advertising (the breadth of awareness), followed by our pricing game. This adds a list-price stage to the models of Ireland (1993) and McAfee (1994). Our predictions for equilibrium advertising choices coincide with theirs. A distinct largest-spend firm emerges, while rivals employ “puppy-dog ploy” strategies: each (endogenously smaller) firm advertises to at most half of potential buyers. By limiting its exposure, a firm makes it less tempting for a higher-priced competitor to undercut, which allows that firm to list a higher price. Under the “random mailbox postings” technology of Butters (1977), the leading firm advertises at exactly twice the intensity of all its rivals. We predict a distinct pattern with one (near) universally known supplier (perhaps a direct sales channel by the product manufacturer) charging the highest feasible price, and a set of progressively cheaper retailers, each known to only a minority of customers.

Our first two extensions allow the price-awareness of buyers to depend on the decisions of firms. In our third and final extended setting, awareness is chosen by buyers. We build upon the fixed-sample search technology of Burdett and Judd (1983) and Janssen and Moraga-González (2004): buyers choose how many (costly) price quotations to request and then select the best available price. Firms set prices using our two-stage approach. We predict that firms choose a distinct set of prices. Search behavior and the comparative-static properties differ from those of Janssen and Moraga-González (2004): we find (for reasonable parameters) that buyers obtain either one or two quotations, and that the expected price charged falls with entry.

In summary, our two-stage approach predicts a unique pattern of stable price dispersion in models of sales, product prominence, advertising, and costly buyer search.¹³ Our applications illustrate that two-stage pricing can easily replace a standard single-stage game in richer models. In some settings (such as the symmetric model of sales, and the Butters-Ireland-McAfee model of advertising) we see no change to firms’ profits or to their non-price choices; in others (such as the models prominence and of consumer search) differences do arise.

Section 2 studies our two-stage model of sales à la Varian (1980), and presents new comparative-static results. Sections 3 to 5 develop the aforementioned extensions to include product prominence, informative advertising, and costly buyer search. Section 6 highlights the broad applicability of our approach by citing several studies that use a clearinghouse pricing stage.

¹³For some symmetric single-stage specifications there are many equilibria (Baye, Kovenock, and de Vries, 1992), and the literature does not offer a complete picture of what happens under asymmetric specifications. Notable exceptions to this include the aforementioned studies of duopoly (Narasimhan, 1988), triopoly (Armstrong and Vickers, 2019), and consideration sets with independent awareness (Ireland, 1993; McAfee, 1994).

2. A MODEL OF SALES

Here we modify the classic model of sales to allow for two stages of pricing: the posting of list prices followed by the opportunity to offer discounts. A main result (Proposition 1) reports a unique set of prices that are chosen as pure strategies along the equilibrium path.

A Two-Stage Pricing Game. The two-stage game is played by n firms. At the first stage firms simultaneously post list prices, where \bar{p}_i is the list price of firm $i \in \{1, 2, \dots, n\}$. These prices are observed by all firms. At the second stage the firms simultaneously set final retail prices which satisfy $p_i \leq \bar{p}_i$. Firm i faces a constant marginal cost $c_i \geq 0$.

Buyers are all willing to pay v , which exceeds the marginal cost of every firm. A mass $\lambda_i > 0$ of buyers are “captive” or “loyal” to firm i . A mass $\lambda_S > 0$ of “shoppers” buy from the cheapest firm. If there is a lowest-price tie then we assume (for convenience only) that the shoppers buy from the firm (or firms) with the lowest marginal cost; it is straightforward to accommodate other tie-break rules.¹⁴ Ignoring tied prices for now, the profit (and payoff) of firm i is $(p_i - c_i)(\lambda_i + \lambda_S \mathcal{J}[p_i < p_j \forall j \neq i])$, where “ $\mathcal{J}[\cdot]$ ” is the indicator function.

In the absence of constraining first-stage prices (if, for example, $\bar{p}_i = v$ for all i) the second stage becomes the setting of Varian (1980, 1981), generalized to allow for asymmetries in costs and captivities. Any equilibrium of a single-stage symmetric game involves mixing by at least two firms, and generates profits equal to those earned by serving captive customers at the maximum price v (Baye, Kovenock, and de Vries, 1992). In contrast, we seek an equilibrium (of our two stage game) in which firms choose pure strategies. (We will show that in such an equilibrium the second-stage prices equal the first-stage list prices; each firm sets and maintains one price.)

Definition. *A profile of prices generates an equilibrium in pure strategies if there is a subgame perfect equilibrium in which those prices are chosen as pure strategies on the equilibrium path.*

We do not insist that pure strategies are used off the equilibrium path.¹⁵ In fact, our equilibria involve the play of mixed equilibria in some off-path subgames.¹⁶

¹⁴This tie-break rule easily establishes the existence of Nash equilibria in all possible subgames. If equilibria exist in all possible subgames, then all of our claims hold even using other tie-break rules. If equilibria do not exist in some subgames, then we can weaken our solution concept (as described in the next footnote) and yet still obtain a unique profile of prices that generate an equilibrium in pure strategies.

¹⁵We can also work with a weaker solution concept: we do not require equilibria in subgames that are reached following a multi-player deviation or following a single-player deviation that is equilibrium-dominated. Under this (less stringent) definition of equilibrium, a profile of prices generates an equilibrium in pure strategies if there is a Nash equilibrium in which in these prices are chosen as pure strategies on the equilibrium path, and where the equilibrium profile specifies Nash play in any subgame following a single-player first-stage deviation.

¹⁶Our approach is related to some Bertrand-Edgeworth models with capacity constrained firms. Kreps and Scheinkman (1983) considered a game in which first-stage capacity choices are followed by second-stage price competition. They found an equilibrium which replicates a Cournot outcome in pure strategies on the equilibrium path. Just as it is here, this is supported by mixed-strategy play in some off-path pricing subgames. In a duopoly model with list prices, discounts and fixed capacities, Díaz, González, and Kujal (2009) also found pure strategies on-path for a class of residual demand functions, with the possibility of off-path mixing. We thank Mark Armstrong and Dan Kovenock for suggesting these comparisons. More generally, capacity models may produce less-rich pricing patterns and comparative statics compared to models of limited consumer information

A Unique Equilibrium Outcome in Pure Strategies. In the Varian (1980) model, a firm captures shoppers by undercutting the lowest competing price. This force walks the firms down a staircase of prices, until prices are so low that firms elevate prices upward to exploit captive customers. The undercutting process then resumes; there is no pure-strategy equilibrium.

In our model a firm's first-stage choice acts as a price cap that, if set sufficiently low, stops competitors from undercutting in the second stage. The equilibrium structure involves all but one firm pricing high while the remaining firm posts a low limit price to dissuade any second-stage discounts. (Our extensions involve a full set of entirely distinct prices.)

Turning to our formal analysis, firm i guarantees a profit of at least $\lambda_i(v - c_i)$ by setting $p_i = \bar{p}_i = v$ and exploiting captive customers, even if shoppers go elsewhere. A strictly lower price can at best win the business of all shoppers and generate a profit of at most $(\lambda_i + \lambda_S)(p_i - c_i)$. It follows that firm i will never set a list price (and final sales price) where this falls below $\lambda_i(v - c_i)$: list prices $\bar{p}_i < p_i^\dagger$ are strictly dominated, where

$$p_i^\dagger \equiv \frac{\lambda_i v + \lambda_S c_i}{\lambda_i + \lambda_S}. \quad (1)$$

Eliminating strictly dominated prices, firm i chooses $\bar{p}_i \in [p_i^\dagger, v]$. The minimum undominated price p_i^\dagger is increasing in c_i and λ_i .¹⁷ If these firm-specific parameters are lower then a firm can be more aggressive, in the sense that it is more willing (lower λ_i) and able (lower c_i) to compete for shoppers' business. To reflect this, we label the firms in order of increasing aggressiveness. The statements of our results are simplified if this order is strict: $p_1^\dagger > \dots > p_n^\dagger$.

Definition. *The competing firms are strictly asymmetric if their minimum undominated prices are strictly ordered: $p_1^\dagger > \dots > p_n^\dagger$. A higher-indexed firm is described as more aggressive.*

Henceforth we often assume (with very little loss of generality) that the firms are strictly asymmetric. We also cover situations in which firms are exactly symmetric, and our results extend appropriately to other situations in which subsets of firms are the same.¹⁸

Any pure-strategy equilibrium of a second-stage subgame satisfies two properties. Firstly, the cheapest firm must be unique: if two (or more) firms tie for the lowest price, then one faces an incentive to undercut. Secondly, all firms charge their list prices: given that the lowest-price firm is unique, it has no incentive to discount; a higher-priced firm sells only to captive customers, and so can profit by raising any discounted price all the way up to its list price.

It follows that any equilibrium with on-path pure strategies involves a unique lowest list price. This cheapest firm subsequently captures all shoppers. Given that higher-price firms sell only

(see e.g., Armstrong and Vickers, 2019, Section 5). A possible root of this is that the capacity model has n variables (each firm's capacity) while the limited-information setup offers $2^n - 1$ non-empty information sets.

¹⁷Setting $v = 1$ (without loss of generality) and $c_i = 0$ for all i (which imposes symmetry of costs) the minimum undominated price $p_i^\dagger = \lambda_i / (\lambda_i + \lambda_S)$ for firm i is equal to the "captive to reach" ratio emphasized by Armstrong and Vickers (2019) in the context of a single-stage pricing model.

¹⁸Accommodating fully those other situations (in which firms are not strictly asymmetric) lengthens and complicates the statements of our results without generating any new insights.

to their captive customers, their list prices must be as high as possible. We conclude that some firm j charges a list price $\bar{p}_j < v$, whereas all other firms $i \neq j$ set $\bar{p}_i = v$.

In the second stage no firm is able to raise price. The lowest-price firm has no incentive to lower its price. We must check, however, whether one of the high-price firms wishes to offer a second-stage discount and undercut \bar{p}_j . Doing so is unprofitable if and only if $\bar{p}_j \leq p_i^\dagger$. We conclude that $\bar{p}_j \leq \min_{i \neq j} p_i^\dagger$. If this inequality holds strictly then firm j could safely raise its price at the first stage, hence $\bar{p}_j = \min_{i \neq j} p_i^\dagger$. For firm j , any list price below p_j^\dagger is strictly dominated, and so $p_j^\dagger \leq \bar{p}_j = \min_{i \neq j} p_i^\dagger$. This implies that the lowest-price is offered by the most aggressive firm. Lemma 1 summarizes.¹⁹

Lemma 1 (Necessary Properties of Prices). *If a profile of prices generates an equilibrium in pure strategies then the most aggressive firm sets $\bar{p}_n = p_{n-1}^\dagger$ and captures shoppers, while less aggressive firms $i < n$ set $\bar{p}_i = v$ and sell only to captives. Final prices satisfy $p_i = \bar{p}_i$ for all i .*

Lemma 1 characterizes the (unique) profile of list prices that can form the equilibrium play of pure strategies. However, it does not establish that such an equilibrium exists. Consider a strategy profile that satisfies Lemma 1: $\bar{p}_n = p_{n-1}^\dagger$ and $\bar{p}_i = v$ for $i < n$. For the high-price firms, the only possible first-stage deviation is a price cut. Given that firm n is guaranteed to price at or below p_{n-1}^\dagger , any downward deviation by $i < n$ leaves firm i strictly worse off. Similarly, firm n serves all shoppers and cannot gain by deviating downward. The remaining first-stage deviation is an increase in \bar{p}_n . This leads to a subgame in which there is no pure-strategy Nash equilibrium. The next lemma characterizes the profits of firms in any mixed-strategy equilibrium of such a subgame.

Lemma 2 (Second-Stage Subgame). *Consider a subgame in which firm n sets a list price satisfying $v \geq \bar{p}_n > p_{n-1}^\dagger$ and others are unconstrained, so that $\bar{p}_i = v$ for all $i < n$. There is at least one mixed-strategy Nash equilibrium of this subgame. In any such equilibrium, firm n earns expected profit $(\lambda_S + \lambda_n)(p_{n-1}^\dagger - c_n)$ while each firm $i < n$ earns expected profit $\lambda_i(v - c_i)$.*

For example, if firm n deviates to a list price satisfying $p_{n-2}^\dagger > \bar{p}_n > p_{n-1}^\dagger$ then in the subgame there is a unique Nash equilibrium: firms $i < n - 1$ maintain their list prices ($p_i = \bar{p}_i = v$), while firms $n - 1$ and n mix continuously over the interval $[p_{n-1}^\dagger, \bar{p}_n)$ with distribution functions

$$F_{n-1}(p) = 1 - \frac{\lambda_S(p_{n-1}^\dagger - c_n) - \lambda_n(p - p_{n-1}^\dagger)}{\lambda_S(p - c_n)} \quad \text{and} \quad F_n(p) = 1 - \frac{\lambda_{n-1}}{\lambda_S} \frac{v - p}{p - c_{n-1}}, \quad (2)$$

and place remaining mass at \bar{p}_{n-1} and $\bar{p}_n = v$, respectively. In fact, under some relatively weak parameter restrictions this is an equilibrium for any $\bar{p}_n > p_{n-1}^\dagger$.²⁰ The profits reported in Lemma 2 are the same as those earned when firms use the list prices described in Lemma 1. This means that an upward deviation in list price by firm n is not profitable. Finally, within (off-path) subgames following any other choices of list prices, any equilibrium may be played. Together, this leads us to our first main result.

¹⁹Versions of this lemma hold when firms are not strictly asymmetric. For example, if firms are symmetric then any one of them can play the role of the lowest-list-price competitor that captures all of the shoppers.

²⁰For example, if firms share a common marginal cost then this is an equilibrium for any $\bar{p}_n > p_{n-1}^\dagger$.

Proposition 1 (Pure Strategies on the Equilibrium Path). *There is a unique profile of prices that generates an equilibrium in pure strategies. Final prices satisfy $p_i = \bar{p}_i$ for all i . The most aggressive firm sets a price $\bar{p}_n = p_{n-1}^\dagger$ that dissuades others from undercutting, and serves all shoppers. Others sell only to captives at the monopoly price: $\bar{p}_i = v$ for $i < n$.*

Recall that firms are strictly asymmetric. If firms are symmetric then there are n equilibrium price profiles that differ only via the identity of the shopper-capturing low-price firm. (We note again that we obtain a full set of n distinct prices when we move to richer specifications.)

Prices, Profits and Welfare. The symmetric equilibrium of Varian (1980) generates (via the realization of mixed strategies) generically distinct prices. Baye, Kovenock, and de Vries (1992) showed that all (of the uncountably-many) equilibria require at least “two to tango” by randomizing over the range of undominated prices.²¹ In our equilibrium “one firm dances alone” and so the extent of price dispersion consists of only two distinct prices, a feature we return to discuss at the end of this section.²²

The strategies of Proposition 1 yield a profit of $\lambda_i(v - c_i)$ to each firm $i < n$ (the monopoly profit from serving only captive buyers) and a profit of $(\lambda_S + \lambda_n)(p_{n-1}^\dagger - c_n)$ for the aggressive firm n . From Lemma 2, these profits equal those from the mixed-strategy equilibria of a pricing game when firm n deviates to a higher list price $\bar{p}_n > p_{n-1}^\dagger$. One such deviation is to $\bar{p}_n = v$. Following this deviation, no firm is constrained in the second stage, and so the subgame is equivalent to the single-stage pricing game studied (for symmetric firms) by Varian (1980) and (more generally) by Baye, Kovenock, and de Vries (1992). Formalized by the following Corollary, this implies that a Varian (1980) pricing stage of any model can be replaced with our two-stage version without upsetting early-stage behavior of profit-seeking firms.

Corollary 1 (Profits). *The unique profile of prices that generates an equilibrium in pure strategies yields profits equal to those earned in a standard single-stage model of sales.*

The switch to two-stage pricing does not influence profits, but it can matter for welfare. This is because output is allocated differently. In our model, shoppers are served by a single firm. In contrast, a mixed-strategy equilibrium allocates shoppers randomly. If costs are heterogeneous and if the most aggressive firm has the lowest marginal cost then our equilibrium is more efficient. Of course, if the most aggressive firm achieves that status because of a small mass of captive customers, then our two-stage setting’s pure strategies can result in lower welfare.

Corollary 2 (Welfare and Consumer Surplus). *If the asymmetry of firms is driven by heterogeneity of costs, so that the most aggressive firm has the lowest marginal cost, then an equilibrium with on-path pure strategies in our two-stage model generates higher welfare and higher consumer surplus than in any equilibrium of a single-stage pricing game.*

²¹In a generalized single-stage model with random and symmetric information sets, Johnen and Ronayne (2019) show there is a unique and completely mixed equilibrium if and only if some buyers see exactly two prices.

²²Our subsequent sections depart from the captives-and-shoppers setting and predict entirely distinct prices.

Comparative-Static Results. The effect of the composition of consumers and the number of firms has been of interest to many authors (Varian, 1980; Rosenthal, 1980; Stahl, 1989; Janssen and Moraga-González, 2004; Morgan, Orzen, and Sefton, 2006; Armstrong, 2015). Most restricted attention to a symmetric industry, and so set (without loss of generality, given that symmetry is assumed) marginal cost to zero. To maintain comparability, we do this too.

The literature uses various assumptions about how the number of captive consumers depends on entry: either they are divided evenly between firms (Varian, 1980) or new entrants bring their own captive customers (Rosenthal, 1980). We use the former specification: $\lambda_i = \lambda_L/n$ for some total mass λ_L of captive buyers. (Later we discuss the latter specification.)

Under symmetry, we pick the low-price supplier to be firm n and we consider prices that generate an equilibrium in pure strategies. Applying Proposition 1,

$$\bar{p}_i = v \text{ for } i < n \quad \text{and} \quad \bar{p}_n = p^\dagger = \frac{\lambda_L v}{\lambda_L + n\lambda_S}. \quad (3)$$

The shopper-capturing lowest price p^\dagger combines the two forces highlighted by Janssen and Moraga-González (2004). The *business stealing* incentive to set a low price to capture shoppers is increasing in λ_S , while the *surplus appropriation* incentive to exploit captives with a high price is increasing in λ_L/n . The shoppers exert a search externality (in the spirit of Armstrong, 2015) by driving down the price paid by the captive customers of the low-priced firm n .²³

Entry to the industry reduces the lowest price, which is paid by shoppers and by the mass λ_L/n of customers who are captive to firm n . However, it also re-allocates the captive buyers toward the other high-priced firms. Two definitions of the average price are of interest:

$$\frac{\sum_{i=1}^n \bar{p}_i}{n} = \frac{(\lambda_L + (n-1)\lambda_S)v}{\lambda_L + n\lambda_S} \quad \text{and} \quad \frac{\sum_{i=1}^{n-1} (\lambda_L/n)\bar{p}_i + [\lambda_S + (\lambda_L/n)]\bar{p}_n}{\lambda_L + \lambda_S} = \frac{\lambda_L v}{\lambda_S + \lambda_L}. \quad (4)$$

The first expression is the simple average of the prices charged across firms. It is also the average price paid by a captive buyer. The second expression (an appropriately weighted average) is the average price paid overall. These expressions generate a further corollary to Proposition 1.

Corollary 3 (Consumer Composition and Entry to a Symmetric Industry). *Consider the unique profile of prices that generates an equilibrium in pure strategies for a zero-cost industry in which a mass λ_L of captive customers is divided equally amongst n firms. The average price (both charged and paid) rises with λ_L , but falls with λ_S . Entry to the industry raises the average price charged by suppliers, but does not influence the average price paid by buyers.*

The final claim (the average price paid is independent of n) holds because symmetric firms earn the same profit as they would from selling only to their captive customers at the maximal price v . This means that industry profit equals $\lambda_L v$. Changing n while keeping both λ_L and λ_S fixed does not change industry profit and so does not change the average price paid.

²³In the symmetric equilibrium of a single-stage model, shoppers lower the expected price paid by captives.

This logic also applies if, following Rosenthal (1980), an entrant brings new captive customers. We set $\lambda_i = \lambda_L$ for all i , so that the total mass of captive buyers is $n\lambda_L$, and the total mass overall is $\lambda_S + n\lambda_L$. Each firm earns a profit equal to that earned by charging v to captives. Industry profit is $n\lambda_L v$ which increases with entry. The average price paid by buyers is (as an accounting identity) equal to the average profit per consumer, $n\lambda_L v / (\lambda_S + n\lambda_L)$. By inspection, entry raises the average price paid. Entry itself has no direct effect on industry profitability; in essence suppliers earn monopoly profits on captives and compete away profits (for any n) corresponding to shoppers. What matters for profitability is the balance between captives and shoppers. The specification of Rosenthal (1980) links that balance to the entry of new competitors, generating the result that entry raises the average price paid.

The results so far also hold in single-stage models of sales (a firm earns a profit equal to that from focusing on the exploitation of captives) and so, under symmetry, we add support for established comparative-static predictions. We now discuss results in asymmetric industries.

The profitability of an asymmetric industry can depend on the distribution of captives across the n firms. Each of the $n - 1$ largest firms ($i < n$) earns profit $\lambda_i v$. The most aggressive firm (with the smallest captive customer base) serves the shoppers at the price p_{n-1}^\dagger . So

$$\text{profit of firm } n = (\lambda_S + \lambda_n) p_{n-1}^\dagger = \frac{(\lambda_S + \lambda_n) \lambda_{n-1} v}{\lambda_{n-1} + \lambda_S} = \lambda_n v + \frac{\lambda_S (\lambda_{n-1} - \lambda_n) v}{\lambda_{n-1} + \lambda_S}. \quad (5)$$

Adding in the profits for the first $n - 1$ firms, and dividing by the total mass of customers $\lambda_L + \lambda_S$ yields the average price paid or (equivalently) the industry's profitability. This is

$$\text{average price paid} = \frac{\text{industry profit}}{\lambda_L + \lambda_S} = \frac{\lambda_L v}{\lambda_L + \lambda_S} \left(1 + \frac{\lambda_S (\lambda_{n-1} - \lambda_n)}{\lambda_L (\lambda_{n-1} + \lambda_S)} \right). \quad (6)$$

This average price is higher in an asymmetric industry than in a symmetric industry with the same captives-to-shoppers ratio. The effect is determined by the ratio $(\lambda_{n-1} - \lambda_n) / (\lambda_{n-1} + \lambda_S)$, and requires a gap in the sizes of the two smallest firms. Profitability is larger when the smallest firm is smaller (fewer captives buy at the aggressive low price) and when the second-smallest firm is larger (this firm is less tempted to undercut firm n , and so firm n can select a higher limit price). Industry profitability is maximized by moving captive customers away from the smallest firm, away from the largest $n - 2$ firms, and toward the second-smallest firm. The best configuration (for profitability) is for firm n to have no captive customers, and for the remaining firms to share them equally: $\lambda_n = 0$ and $\lambda_i = \lambda_L / (n - 1)$ for $i < n$.

Based on these observations, it is easy to see that adding an extra competitor to the industry (while keeping fixed the mass of captive buyers, and so redistributing some to the new entrant) can either raise or lower the average price paid. Beginning from a symmetric industry configuration, adding a smaller new firm (and so creating a gap between the smallest two firms) raises the average price. Adding a further firm with an identical size to the existing smallest firm then lowers the average price back to its original level.

List Prices as a Stackelberg Commitment. Our two-stage specification allows firms to make a commitment in the first stage of play. This can induce other firms to set higher final retail prices. In essence, the most aggressive firm n acts as a Stackelberg leader, setting a price just low enough to ensure that no other firm wishes to undercut in the second-stage. The same effect occurs as the equilibrium outcome of a fully specified two-stage Stackelberg game in which all firms are given a full commitment opportunity in the first stage.²⁴

To explore this idea briefly, suppose that the first-stage choice of a list price is a Stackelberg commitment to a final retail price that can be neither raised or lowered, but that every firm has the option to remain unconstrained. In the second stage, all unconstrained firms proceed to select (without constraint) their own final retail prices. Just as before, we look for an equilibrium in which pure strategies are chosen along the equilibrium path.²⁵

There is a subgame perfect equilibrium in which firm n commits (as the unique Stackelberg leader) to $\bar{p}_n = p_{n-1}^\dagger$ in the first stage, while other (follower) firms remain unconstrained. In the second stage, firms $i < n$ charge $p_i = v$ and sell to captives, while firm n serves the shoppers.

It is easy to see that no firm $i < n$ has a profitable first-stage or second-stage deviation (to capture shoppers requires a dominated price) and that firm n loses strictly with a lower first-stage price choice (this firm already serves all available shoppers). If firm n deviates to a higher price in the first stage, then it loses the shoppers to (at least) firm $n - 1$ in the second stage. If firm n deviates to remain unconstrained in the first stage then we revert to a subgame in which Lemma 2 applies, and so firm n does not gain from this deviation.

With a little more work we can show that there is no other equilibrium outcome with the play of pure strategies. Briefly, only one Stackelberg price can ever be used, and this must capture the business of all shoppers.²⁶ Firm n is uniquely able to choose such a price that is sufficiently low to dissuade price cuts from others at either the first or second stage.

Price Dispersion and the Pattern of Sales. The mixed strategies of Varian (1980) were intended to capture the use of discounted “sales” prices. The realized prices may be either close or far apart, and the identity of the cheapest shopper-capturing firm is uncertain. With asymmetric firms these claims apply to two firms who “tango” for the shoppers while $n - 2$ others maintain the “regular” monopoly price (Baye, Kovenock, and de Vries, 1992). In contrast, we predict a profile of $n - 1$ regular prices alongside one starkly lower “on sale” price. Of course, with symmetric firms the identity of the on-sale firm can switch from time to time, and so our model is consistent with at least some amount of temporal variation in pricing positions. Similarly, any changes in the ordering of asymmetric firms can also flip the identity of the on-sale firm. In these senses, we retain the spirit of sales, while providing new insights.

²⁴We thank Mark Armstrong for suggesting that we flesh out this connection here.

²⁵For technical reasons, we retain a free choice of how to break ties when two firms charge the same price.

²⁶Any higher price commitment than the lowest Stackelberg price does not win any shoppers, and so the relevant firm would prefer to exploit fully its captives. If more than one firm charges the Stackelberg price then there is either an incentive for a firm to undercut or for one of the Stackelberg firms to revert to the monopoly price.

3. A MODEL OF PROMINENCE

Moving beyond the captives-and-shoppers setting, we now set, à la Armstrong, Vickers, and Zhou (2009), one prominent firm to be visible to everyone. Buyers also see at most one other firm.²⁷ The prominent firm might correspond to a national sales channel, whereas other firms might be local suppliers. This simple specification generates entirely distinct prices. Moreover, it can be incorporated into a deeper model: inspired by papers in which suppliers pay for prominence or for placement (Armstrong and Zhou, 2011; Chen and He, 2011) we add a preliminary stage in which a prominence provider sells the prominence position.

A Triopoly with a Prominent Firm. Firm $i \in \{1, 2, 3\}$ has access to a base of ϕ_i customers who each see firm i 's final retail price. Additionally, all potential customers are informed of one, prominent, firm's price. Let that be firm $i = 1$. Potential customers are partitioned into three types with consideration sets $\{1\}$, $\{1, 2\}$, and $\{1, 3\}$. Only the first type is truly captive; the others compare the price of their "local" supplier $i \in \{2, 3\}$ to that of the prominent firm.²⁸ We set symmetric marginal costs to zero, and we label the non-prominent firms so that $\phi_2 \geq \phi_3$. (For symmetric firms we also report a solution for an oligopoly with $n > 3$ competitors.)

Other aspects of our model are as before: firms post list prices in a first stage, and are free to discount (but not raise) those prices in a second stage. We seek prices that are chosen as pure strategies along the equilibrium path of a subgame perfect equilibrium.

Equilibrium Prices. The prominent firm charges the maximum possible price and sells only to captives, while the non-prominent firms charge strictly less. The reason is that a non-prominent firm has no captive customers, and so always undercuts the (strictly positive, because it has captive customers and so is strictly profitable) price of the prominent firm. Given that the prominent firm loses comparison sales to its non-prominent competitors, it is optimal to exploit fully the captive customers who only see the prominent price, by setting $p_1 = \bar{p}_1 = v$.

A non-prominent firm sets a list price just low enough to dissuade the prominent firm from undercutting it. Suppose that $j \in \{2, 3\}$ offers the lowest list price. The prominent firm earns $\phi_1 v$ by exploiting captives, but captures everyone, a mass $\phi_1 + \phi_2 + \phi_3$, by undercutting \bar{p}_j . It follows that the critical list price satisfies $(\phi_1 + \phi_2 + \phi_3)\bar{p}_j = \phi_1 v$. The solution for \bar{p}_j does not depend on which non-prominent firm $j \in \{2, 3\}$ posts this lowest list price.

²⁷In ongoing work (Myatt and Ronayne, 2019) we study a model of nested prominence: the audience of any firm is contained within that of any more prominent supplier. We think here of an ordered list of search results, where a buyer of type i examines only the first i listings. In this "listed prominence" setting, we again find a unique profile of entirely distinct prices supported by the play of pure strategies. Such a situation, referred to as a "nested reach" specification, was studied by Armstrong and Vickers (2019) under single-stage pricing. They imposed a (reasonable) monotonicity condition on the incremental reach of progressively larger firms. Under this condition they characterize an interesting mixed-strategy equilibrium in which firms mix over successive overlapping intervals. Any price lies within the support of two firms. The expected profits of firms are different from (and strictly higher than) those from the pure-strategy play of our two-stage pricing game. A related single-stage model was considered by Inderst (2002), although he did not fully characterize equilibrium play.

²⁸Armstrong and Vickers (2019) provide an extensive analysis of single-stage price competition in a triopoly with a full range of consideration sets. Their main formal result excludes this situation considered here.

Next, consider the other non-prominent firm $i \neq j$. It can lift its list price above \bar{p}_j (an undercut to $\bar{p}_i > \bar{p}_j$ by the prominent firm would only capture $\phi_1 + \phi_i$ customers, and so is less tempting if \bar{p}_i is not too high) and so $\bar{p}_i > \bar{p}_j$. The maximum list price which prevents the undercut satisfies $(\phi_1 + \phi_i)\bar{p}_i = \phi_1 v$. The solution for this intermediate list price \bar{p}_i depends on the identity of the firm $i \in \{2, 3\}$ that offers it; it is higher if ϕ_i is smaller.

These arguments pin down two candidates for a profile of prices:

$$\bar{p}_1 = v, \quad \bar{p}_i = \frac{\phi_1 v}{\phi_1 + \phi_i}, \quad \text{and} \quad \bar{p}_j = \frac{\phi_1 v}{\phi_1 + \phi_2 + \phi_3} \quad \text{for } i, j \in \{2, 3\} \quad \text{and} \quad j \neq i, \quad (7)$$

such that $\bar{p}_1 > \bar{p}_i > \bar{p}_j$. If the non-prominent firms are symmetric (so that $\phi_2 = \phi_3$) then there is a unique profile of distinct prices, although the two firms can take alternative positions in that profile. If $\phi_2 > \phi_3$, there are two candidate price profiles.

From either set of retail prices, no firm can profitably deviate downwards: non-prominent firms have nothing to gain and the construction of those list prices removes the incentive for the prominent firm to undercut. To construct a subgame perfect equilibrium, we need to check whether any non-prominent firm wishes to deviate to a higher list price.

The proof of Proposition 2 establishes that the larger non-prominent firm chooses the lowest list price, so that the price profile satisfies $\bar{p}_1 > \bar{p}_3 > \bar{p}_2$. For such a profile we prove a version of Lemma 2: an upward deviation by either non-prominent firm results in no gain in any equilibrium of the relevant subgame. However, there is a profitable upward deviation from the list-price profile where $\bar{p}_1 > \bar{p}_2 > \bar{p}_3$.²⁹ This means that (if firms are asymmetric) we pin down a unique profile of distinct list prices.³⁰

If firms are symmetric then our arguments so far define a unique candidate profile, although they do not establish the order of the firms in the pricing sequence. For symmetric firms we also report the unique profile for a larger oligopoly with $n > 3$ firms.

Proposition 2 (Pure Strategies in a Model of Prominence). *If the non-prominent firms are asymmetric, so that $\phi_2 > \phi_3$, then the unique profile of distinct prices*

$$\bar{p}_1 = v, \quad \bar{p}_3 = \frac{\phi_1 v}{\phi_1 + \phi_3}, \quad \text{and} \quad \bar{p}_2 = \frac{\phi_1 v}{\phi_1 + \phi_2 + \phi_3} \quad (8)$$

generates an equilibrium in pure strategies. Final prices satisfy $p_i = \bar{p}_i$ for all firms. The prominent firm sets the monopoly price. The larger non-prominent firm sets the lowest price.

If firms are symmetric, so that $\phi_i = \phi$ for all $i \in \{1, \dots, n\}$ for general n , then there is a unique profile of distinct prices which generates an equilibrium in pure strategies:

$$\bar{p}_i = \frac{v}{i} \quad \text{for all } i \in \{1, \dots, n\}, \quad (9)$$

so that the list (and final retail) price of a firm declines inversely to its position in the sequence.

²⁹Specifically, the smallest firm $i = 3$ has an incentive to deviate to a list price strictly above \bar{p}_2 .

³⁰The single-stage game with these information sets produces multiple equilibria (Armstrong and Vickers, 2019).

Unlike the model of sales (in Section 2) and the model of advertising (in Section 4) firms with larger reach are cheaper: a larger reach makes a non-prominent firm's price more attractive to undercut, pushing down that firm's price. It remains the case that the profit of a non-prominent firm is increasing in its own size. However, the larger non-prominent firm can make a smaller profit than the other. This is true whenever their sizes are sufficiently close.

As the prominent firm's position strengthens (an increase in ϕ_1) then price cuts (which sacrifice revenue from captives) hurt it more. As a result, its non-prominent rivals can sustain higher prices without being undercut. It follows that non-prominent firms' prices and profits are increasing in ϕ_1 . This implies that consumers are worse off with a larger prominent firm.

Selling Prominence. The prominent firm is advantaged relative to others. We now extend our model to an environment in which this advantage is conferred by a prominence provider.

Suppose that all firms in the triopoly begin with exclusive local customer bases, so that firm $i \in \{1, 2, 3\}$ charges v to ϕ_i buyers within its locality. A unique (monopolist, labeled as M) prominence provider offers, in an initial stage, to elevate one firm to national prominence. For example, a provider may be a department store that chooses a product to display in the window, or a website that shows a product on its home page or highlights it at the top of search results.

Specifically, M makes a take it or leave it offer to one firm, and commits to give prominence to a specified competitor if the offer is refused. We label the firms so that $\phi_1 > \phi_2 > \phi_3$.

Consider an offer to the largest firm. This firm earns $\phi_1 v$ from a prominent position. If it loses prominence then it will (Proposition 2) take the lowest-price position and so earn $\phi_1 \phi_i v / (\phi_1 + \phi_2 + \phi_3)$ where $i \in \{2, 3\}$ is the firm that rises to prominence otherwise. The harshest threat is for the provider to declare that $i = 3$. Thus, M can make the offer

$$\text{prominence fee} = \phi_1 v - \frac{\phi_1 \phi_3 v}{\phi_1 + \phi_2 + \phi_3} = \frac{\phi_1 (\phi_1 + \phi_2) v}{\phi_1 + \phi_2 + \phi_3} \quad (10)$$

to the largest firm, and this offer will be accepted. Of course, the prominence provider could make an offer to a smaller firm. The proof of Proposition 3 proves that this generates a lower fee than dealing with the largest firm, the worst choice from consumers' perspective.

Proposition 3 (Prominence Provision). *If firms play pure strategies in the two price-setting stages, then there is a unique outcome from a subgame perfect equilibrium in which (i) the prominence provider offers prominence to the largest firm in exchange for a fee equal to $\pi_M = \phi_1 (\phi_1 + \phi_2) v / (\phi_1 + \phi_2 + \phi_3)$; (ii) this firm accepts; and (iii) firms price as reported in Proposition 2. The prominence fee satisfies*

$$\frac{\partial \pi_M}{\partial \phi_1} > \frac{\partial \pi_M}{\partial \phi_2} > 0 > \frac{\partial \pi_M}{\partial \phi_3}, \quad (11)$$

and so is largest when customers move from away from the smallest firm.

The final claim holds because non-prominent firms do worse when the prominent firm is smaller; a small prominent firm has fewer captive customers to exploit and so is more willing to undercut any non-prominent competitors. In essence, a small non-prominent rival has a threatening lean and hungry look, which strengthens the ability of the prominence provider to extract a fee from a large firm. As such, the prominence provider profits from and compounds firm asymmetries, to the detriment of consumers.

4. A MODEL OF ADVERTISING

In this section, we expand buyers' consideration sets via a specification that builds upon Butters (1977), Grossman and Shapiro (1984), Ireland (1993), McAfee (1994), and Eaton, MacDonald, and Meriluoto (2010): each price is exposed to an independent fraction of potential buyers. We find a unique profile of distinct prices supported by the equilibrium play of pure strategies.

We then evaluate the choice of advertising strategies, endogenizing consumers' information. Here we replicate results (when advertising exposure is costless) from Ireland (1993) and (with costly advertising) from McAfee (1994): one firm chooses relatively high exposure for a high list price, while others cap their exposures to prevent the use of revenue-eroding lower list prices.

A Two-Stage Pricing Game with Independent Awareness. The game played by n firms is as before: firms post list prices, and then follow by setting weakly lower final sale prices. To simplify exposition we assume symmetry of the marginal costs of production, and then simplify again (without further loss of generality) by setting the common marginal cost to zero.

On the demand side, an independent fraction α_i of buyers is aware of firm i so the proportion of buyers aware of firms i and j but no others is $\lambda_{ij} = \alpha_i \alpha_j \prod_{k \notin \{i,j\}} (1 - \alpha_k)$, and the masses of shoppers and captives to firm i are $\lambda_S = \prod_{i=1}^n \alpha_i$ and $\lambda_i = \alpha_i \prod_{j \neq i} (1 - \alpha_j)$, respectively.

Definition. *The firms are strictly asymmetric if $1 \geq \alpha_1 > \dots > \alpha_n > 0$. A lower-indexed firm, with greater pricing awareness or advertising reach, is described as a larger firm.*

Just as before, we can accommodate ties (so that subsets of firms share the same type) but our results can be stated much more cleanly and clearly when firms are distinct.

A Unique Equilibrium Outcome in Pure Strategies. We again seek a unique outcome in pure strategies. Necessarily, this involves a pure-strategy Nash equilibrium in the second-stage pricing subgame. In the captives-and-shoppers model we noted that the lowest-price firm must be unique. Here similar logic yields something stronger: all final retail prices must be unique. Suppose any subset of firms post the same price: there is a positive mass of buyers with exactly this consideration set of suppliers and so every member of that set has an incentive to undercut.

Given that prices must be distinct, any otherwise-unconstrained firm could locally raise price without losing sales. This implies that all firms must be constrained: in the second stage all firms maintain their list prices, and so each firm sets one price on the equilibrium path.

We now characterize the necessary properties of first-stage list prices. For now, suppose that $\bar{p}_1 > \dots > \bar{p}_n$ so that larger firms list higher prices. (We will confirm that this is the so.) The largest firm only sells to its own captive customers, and so sets the maximum list price: $\bar{p}_1 = v$. The next price must be low enough to dissuade the larger firm from undercutting in the second stage. That largest firm sells to a fraction $\alpha_1 \prod_{i>1} (1 - \alpha_i)$ of buyers: those who are aware of the price p_1 but unaware of the $n - 1$ cheaper firms. In contrast, charging slightly below p_2 means that only the $n - 2$ cheapest firms provide competition; the undercut sells to a fraction $\alpha_1 \prod_{i>2} (1 - \alpha_i)$ of buyers. There is no incentive to undercut the next list price if

$$\bar{p}_1 \alpha_1 \prod_{i>1} (1 - \alpha_i) \geq \bar{p}_2 \alpha_1 \prod_{i>2} (1 - \alpha_i) \quad \Leftrightarrow \quad \bar{p}_2 \leq (1 - \alpha_2) \bar{p}_1. \quad (12)$$

If this “no undercutting” inequality holds strictly then the second firm can locally raise \bar{p}_2 without any loss of sales, and so we conclude that $\bar{p}_2 = (1 - \alpha_2) \bar{p}_1$. It remains, however, to check whether the second firm wishes to raise \bar{p}_2 still further. One possibility would be to match \bar{p}_1 . The worst-case scenario is that this higher price sells only to captives of this second firm. Assuming this worst-case scenario, such an upward deviation must be unprofitable, and so

$$\bar{p}_2 \alpha_2 \prod_{i>2} (1 - \alpha_i) \geq \bar{p}_1 \alpha_2 (1 - \alpha_1) \prod_{i>2} (1 - \alpha_i) \quad \Leftrightarrow \quad \bar{p}_2 \geq \bar{p}_1 (1 - \alpha_1) \quad \Leftrightarrow \quad 1 - \alpha_2 \geq 1 - \alpha_1, \quad (13)$$

which holds if $\alpha_1 \geq \alpha_2$. This shows that the higher price must be charged by the larger firm.

We have dealt here with the two highest list prices. The same logic applies as we move down the sequence, which allows us to characterize fully the list prices that must be charged if pure strategies are played along the equilibrium path. Lemma 3 summarizes.

Lemma 3 (Necessary Properties of Advertised Prices). *If a profile of list prices generates an equilibrium in pure strategies then $\bar{p}_1 = v$ and $\bar{p}_i = (1 - \alpha_i) \bar{p}_{i-1}$ for $i > 1$.*

We proceed as before. Consider any strategy profile in which the firms charge list prices which satisfy Lemma 3. By construction, and on the equilibrium path, no firm has a profitable deviation in the second stage. In the first stage, no firm wishes to deviate to a lower list price: such a firm could (in any case) choose such a price in the second stage, while lowering the first-stage list price can only serve to push down the prices of competing firms. It follows that the only possible profitable first-stage deviation is for a firm to raise its list price.

The largest firm already charges the maximum price $\bar{p}_1 = v$. For other firms, an increased list price necessarily violates the “no undercutting” constraint in the relevant subgame, which is resolved by the play of a mixed-strategy Nash equilibrium in that subgame. Such an equilibrium, however, generates payoffs that offer no improvement over the equilibrium path.

Consider, for example, an upward deviation by the second-largest firm to $\bar{p}_2 > (1 - \alpha_2)v$. In the second-stage subgame, there is an equilibrium in which all other prices are maintained (so that

$p_i = \bar{p}_i$ for $i > 2$) while the top two firms continuously mix over $[(1 - \alpha_2)v, \bar{p}_2]$ via distributions

$$F_1(p) = \frac{1}{\alpha_1} \left[1 - \frac{(1 - \alpha_2)v}{p} \right] \quad \text{and} \quad F_2(p) = \frac{1}{\alpha_2} \left[1 - \frac{(1 - \alpha_2)v}{p} \right] \quad (14)$$

with all remaining mass placed at v and \bar{p}_2 respectively. For price-setting purposes these firms ignore the existence of other competitors and play the mixed-strategy equilibrium of a standard captives-and-shoppers game (as analyzed in Section 2). They enjoy expected profits equal to $v\alpha_i \prod_{j=2}^n (1 - \alpha_j)$ for each $i \in \{1, 2\}$. These are equal to the payoffs received on the equilibrium path. Examining upward list-price deviations for other firms yields Lemma 4.

Lemma 4 (Second-Stage Following a Price Deviation). *Consider a subgame in which: (i) all firms other than i maintain list prices which satisfy Lemma 3 and (ii) firm i deviates upward to a higher list price. There is a mixed-strategy Nash equilibrium of this subgame in which firms earn the same profit as they did with the original list prices.*

Lemma 4 establishes that the remaining deviations in the first stage are not profitable. For any other subgames we can pick any Nash equilibrium. Doing so we can construct a subgame perfect equilibrium that supports the play of pure strategies.

Proposition 4 (Pure Strategies on the Equilibrium Path). *A unique profile of prices generates an equilibrium in pure strategies. If firms are strictly asymmetric then distinct list prices are higher for larger firms. These prices are*

$$\bar{p}_1 = v \quad \text{and} \quad \bar{p}_i = v \prod_{j=2}^i (1 - \alpha_j) \quad \text{for } i > 1. \quad (15)$$

Moving from larger to smaller firms, prices become closer: \bar{p}_i/\bar{p}_{i-1} is decreasing in i . Across the industry, profits are proportional to firms' sizes: $\pi_i = v\alpha_i \prod_{j=2}^n (1 - \alpha_j)$.

This proposition considers the case with completely asymmetric firms. With symmetric firms ($\alpha_i = \alpha$ for all i) we can characterize prices that are unique apart from the labelling of the firms: $\bar{p}_i = v(1 - \alpha)^{i-1}$ and $\pi_i = v\alpha(1 - \alpha)^{n-1}$. These outcomes are also obtained if we take the unique outcome for a fully asymmetric specification and allow the asymmetries to disappear.

The expressions for firms' profits in Proposition 4 are identical to those reported by Ireland (1993) and McAfee (1994). They considered a single stage of pricing and characterized mixed-strategy Nash equilibria. As in the captives-and-shoppers setting, we establish stable price dispersion (entirely distinct prices chosen as pure strategies) without impacting firms' profits.

Endogenous Advertising. Firms' (expected) profits have the feature that the awareness parameters α_i enter symmetrically for $i > 1$ but not for the largest firm $i = 1$. This suggests that the endogenous choice of advertising may be asymmetric. We confirm this next.

The firms participate in three stages of play. At the first stage they simultaneously choose their advertising policies: firm i chooses the (independent) proportion $\alpha_i \in [0, 1]$ of buyers that are aware of its final price. The second and third stages follow our two-stage-pricing specification.

Firm i 's advertising cost $C_i(\alpha_i)$ is smoothly increasing, convex, $C_i(0) = 0$, and $C_i'(0) < v$. When firms are asymmetric we order them so that $C_1'(\alpha) < \dots < C_n'(\alpha)$ for all $\alpha \in (0, 1)$. This differs from the specification of McAfee (1994) by allowing for asymmetric firms.³¹ In contrast, Ireland (1993) assumed that firms face no costs of advertising.

Our solution concept is as before. We seek a profile of pure strategies (for both advertising choices and subsequent list and retail prices) along the equilibrium path, and we also look for the play of pure strategies following any first-stage deviations of advertising choices.

Definition. *A profile of advertising strategies generates an equilibrium in pure strategies if there is a subgame perfect equilibrium in which pure strategies are played both on the equilibrium path, and within any second-stage subgame.*

Proposition 4 characterizes firms' expected profits. Given that firms are not yet ordered by their (now endogenous) choice of advertising exposure, we can write these expected profits as

$$\pi_i = \begin{cases} v\alpha_i \prod_{j \neq i} (1 - \alpha_j) & \alpha_i > \max_{j \neq i} \{\alpha_j\} \text{ and} \\ v\alpha_i (1 - \alpha_i) \prod_{j \notin \{i, k\}} (1 - \alpha_j) & \alpha_i < \alpha_k \text{ where } \alpha_k = \max_{j \neq i} \{\alpha_j\}, \end{cases} \quad (16)$$

and where both expressions apply when firm i ties to be the largest firm.

An equilibrium (in the sense of our definition above) is generated by a pure-strategy Nash equilibrium of the simultaneous-move game in which each firm i maximizes $\pi_i - C_i(\alpha_i)$.

A firm's sales revenue reacts differently to its advertising reach depending on whether that firm is the largest. The largest firm sets the highest (monopoly) price and so does not worry about another firm undercutting them. Therefore for the largest firm, an increase in α_i increases its expected revenue linearly. In contrast, smaller firms' prices must be set to deter undercutting by larger firms. For such smaller firms, there are two competing effects: fixing second-period prices, an increase in α_i scales up sales; however, it also forces its second-period price down (and that of any smaller firms because of the recursive nature of prices). In fact,

$$\frac{\partial \pi_i}{\partial \alpha_i} = \begin{cases} v \prod_{j \neq i} (1 - \alpha_j) & \alpha_i > \max_{j \neq i} \{\alpha_j\} \text{ and} \\ v(1 - 2\alpha_i) \prod_{j \notin \{i, k\}} (1 - \alpha_j) & \alpha_i < \alpha_k \text{ where } \alpha_k = \max_{j \neq i} \{\alpha_j\}. \end{cases} \quad (17)$$

For a smaller firm, revenue is decreasing in advertising exposure when a firm reaches a majority of buyers. Revenue kinks upward as α_i passes through through the maximum advertising exposure of competing firms. Specifically,

$$\frac{\lim_{\alpha_i \downarrow \max_{j \neq i} \alpha_j} \partial \pi_i / \partial \alpha_i}{\lim_{\alpha_i \uparrow \max_{j \neq i} \alpha_j} \partial \pi_i / \partial \alpha_i} = \frac{1 - \max_{j \neq i} \alpha_j}{1 - 2 \max_{j \neq i} \alpha_j} > 1, \quad (18)$$

where the inequality is strict because (once dominated strategies have been eliminated) every firm chooses positive exposure. This implies that no firm chooses its advertising reach to be exactly equal to the maximum of others, and so there is a unique largest firm.

³¹McAfee (1994) also related his paper to that of Robert and Stahl (1993), who specified the simultaneous (rather than sequential) choice of advertising exposure and price.

For smaller firms, advertising increases sales revenue only if $\alpha_i < \frac{1}{2}$. This implies that firms other than the largest restrict awareness to a minority of potential buyers.

Lemma 5 (Properties of Advertising Choices). *In any pure-strategy equilibrium of the advertising game, there is a unique largest firm. Other firms advertise to a minority of buyers.*

On the revenue side, the largest firm always faces an incentive to increase its exposure. Labelling this firm as k , it is straightforward to confirm that, in equilibrium, $\partial\pi_k/\partial\alpha_k \geq 1/2^{n-1}$. Hence, if $C'(1) < 1/2^{n-1}$ then firm k chooses $\alpha_k = 1$ and advertises to everyone.

An advertising equilibrium is characterized by the specification of a leading (and largest) firm k and n advertising choices which satisfy the $n - 1$ first-order conditions

$$\frac{C'_k(\alpha_k)}{v} = \prod_{j \neq k} (1 - \alpha_j) \quad \text{and} \quad \frac{C'_i(\alpha_i)}{v} = (1 - 2\alpha_i) \prod_{j \notin \{i, k\}} (1 - \alpha_j) \quad \forall i \neq k. \quad (19)$$

To fully characterize an equilibrium we also need to check for any non-local deviations. For example, one of the smaller firms $i \neq k$ has the option to deviate and choose $\alpha_i > \alpha_k$ and become the largest firm. The proof of Proposition 5 checks such remaining details.

Proposition 5 (Pure-Strategies on Path: Endogenous Advertising). *There is at least one equilibrium of the advertising-then-pricing game in which firms choose pure strategies along the equilibrium path, and also do so following any first-stage deviation in advertising choice.*

In any such equilibrium, one firm chooses a strictly higher advertising level than all the others, sets a list price equal to the monopoly price, and only sells to buyers who are uniquely aware of its product. Other firms advertise to at most half of potential buyers and set lower prices.

In equilibrium a leading firm advertises distinctly more than others. Proposition 5 does not identify this firm. If the advertising cost functions are not too different then any firm can play this role.³² If they are different then the leading firm enjoys relatively lower advertising costs.³³ The other minority-audience firms can, however, be ordered given the structure of the advertising cost functions. For example, if $k = 1$ then advertising choices satisfy $\alpha_1 > \dots > \alpha_n$.

If firms are symmetric ($C_i(\alpha_i) = C(\alpha_i)$ for all i) then the first-order conditions simplify appreciably. Writing α for the common advertising choice of the smaller firms,

$$\frac{C'(\alpha_k)}{v} = (1 - \alpha)^{n-1} \quad \text{and} \quad \frac{C'(\alpha)}{v} = (1 - 2\alpha)(1 - \alpha)^{n-2}. \quad (20)$$

These are precisely the equilibrium conditions stated by McAfee (1994).

A special case is when advertising is free (Ireland, 1993) where there is a pathological equilibrium in which multiple firms choose $\alpha_i = 1$ and subsequent prices are competed down to marginal cost. Putting this aside (or by allowing costs to be close to free) the “free advertising” case yields $\alpha = \frac{1}{2}$ for $n - 1$ firms, and complete coverage for one firm.

³²This is true for the specifications of Ireland (1993) and McAfee (1994), under which costs are symmetric.

³³Formally: there is some k^* such that there is an equilibrium in which any $k \in \{1, \dots, k^*\}$ leads the industry.

Another case of interest is the cost specification derived from the random mailbox postings technology suggested by Butters (1977).³⁴ Equivalently, this is what McAfee (1994) called constant returns to scale in the availability of a firm's price.³⁵ This specification is obtained by setting $C(\alpha) = \gamma \log[1/(1 - \alpha)]$, so that the marginal cost of increased advertising satisfies $C'(\alpha) = \gamma/(1 - \alpha)$. Setting $\gamma = 1$ without loss of generality (this cost coefficient only matters relative to the valuation v of buyers for the product) and requiring $v > 1$ (otherwise all firms choose zero advertising) the relevant first-order conditions become

$$\frac{1}{v(1 - \alpha_k)} = (1 - \alpha)^{n-1} \quad \text{and} \quad \frac{1}{v} = (1 - 2\alpha)(1 - \alpha)^{n-1}. \quad (21)$$

These equations solve recursively. Substituting the second into the first, we find that $\alpha_k = 2\alpha$: no matter what the level of cost, the large firm has twice the advertising reach of all smaller firms. The solution for α satisfies the natural comparative-static property that α is increasing in the product valuation v , and so is decreasing in the advertising cost parameter γ .³⁶

Proposition 6 (Equilibrium with Symmetric Advertising Costs). *If advertising is free, as it is under the specification of Ireland (1993), then, in an equilibrium in which firms earn positive profits, the largest firm chooses maximum advertising exposure, while others advertise to half of potential buyers. The largest firm earns twice the profit of each smaller firm.*

If the cost of advertising reach is determined by a random mailbox postings technology, as it is under the constant returns case of McAfee (1994), so that $C(\alpha) = -\gamma \log(1 - \alpha)$, then the largest firm chooses advertising awareness equal to double that of the competing small firms. Advertising is increasing in buyers' willingness to pay.

For both cases, with firms labelled appropriately, final retail prices satisfy $\bar{p}_i = v/2^{i-1}$.

The ‘‘independent awareness’’ advertising technology and its endogenous selection are not new to this paper: Ireland (1993) and McAfee (1994) both report that the leading firm is twice the size (in terms of advertising reach) and earns twice profit of other firms. Other authors have, more recently, studied versions of the single-stage model but with a pre-pricing stage in which firms determine their captive shares and have also found asymmetric equilibrium advertising outlays (Chioveanu, 2008; Ronayne and Taylor, 2019). In contrast to these papers, our result maintains the prediction of asymmetric advertising intensities while allowing for the on-path play of pure strategies. Moreover, we identify (as the final claim of Proposition 6) an interesting pricing pattern: the margin of each firm in the pricing ladder is half that of the firm above.

³⁴Suppose that buyers are divided into $1/\Delta$ segments each of size Δ . Each segment corresponds to a mailbox. An advertisement costs $\gamma_i \Delta$ for firm i , and randomly hits one of the segments. Hence, with a total spend of $C_i(\alpha_i)$, a firm is able to distribute $C_i(\alpha_i)/(\gamma_i \Delta)$ advertisements. It follows that $\alpha_i = 1 - (1 - \Delta)^{C_i(\alpha_i)/(\gamma_i \Delta)}$. Taking the limit as $\Delta \rightarrow 0$, we observe that $(1 - \Delta)^{C_i(\alpha_i)/(\gamma_i \Delta)} \rightarrow \exp(-C(\alpha_i)/\gamma_i)$. Solving suggests a cost specification $C_i(\alpha_i) = \gamma_i \log[1/(1 - \alpha_i)]$ where (for asymmetric firms) we assume that $0 < \gamma_1 < \dots < \gamma_n$.

³⁵The idea behind the ‘‘constant returns’’ terminology is that two merging firms do not save when achieving the same aggregate exposure. The probability that a buyer sees an offer from one of firms i and j is $1 - (1 - \alpha_i)(1 - \alpha_j)$. There are constant returns if $C(\alpha_i) + C(\alpha_j) = C(1 - (1 - \alpha_i)(1 - \alpha_j))$.

³⁶An explicit solution is easily obtained when $n = 2$: $\alpha = \frac{3}{4} - \frac{1}{4}\sqrt{1 + \frac{8}{v}}$.

5. A MODEL OF BUYER SEARCH

For all three settings considered so far, the access of buyers to prices has been either exogenous or determined by firms' marketing choices. Here we allow for endogenous consumer search.

We pair our two-stage pricing approach with the model of Janssen and Moraga-González (2004), henceforth JMG, in which buyers pay for costly price quotations. Our predictions differ from those with single-stage pricing. Under reasonable parameters, buyers obtain either one or two price quotations and so are, endogenously, either captive to a single firm or are pairwise shoppers, bringing the analysis closer to that in Burdett and Judd (1983). Using pure strategies, firms post a unique and distinct sequence of prices.³⁷ Under the equivalent model with single-stage pricing, there can also be equilibria in which buyers obtain no more than one quotation. We show that, under two-stage pricing, such equilibria exist only for a narrow range of parameter values, and involve no search at all if there are no exogenous shoppers.

Our comparative-static predictions also differ from those that hold under single-stage pricing (cf. JMG). Fixing the search strategies of buyers, we find that the average price charged by the firms (this is equal to the average price paid by captive buyers) does not rise with entry to the industry. We also find that the average price paid across all buyers is independent of the number of competitors, and is equal to the median price posted. Allowing for endogenous search, increases in either the number of firms or the search cost raise the fraction of pairwise shoppers, lower the average price charged and average price paid.

A Pricing Game with Costly Fixed-Sample Search. On the supply side, we follow the specification of earlier sections. There are n symmetric firms with constant marginal cost normalized to zero. They post list prices, and then set (weakly lower) final retail prices.

On the demand side, a fraction $\lambda_S \in [0, 1]$ of buyers are shoppers who see all n prices. Following JMG, others are "searchers" who use a fixed-sample technology to obtain price quotations.³⁸ Moving simultaneously, each searcher pays κq to obtain $q \in \{0, 1, \dots, n\}$ quotations, where $0 < \kappa < v$. This randomly reveals (without replacement) q out of the n price offers. The buyer selects the cheapest offer.

We imagine a situation in which buyers search at the same time as firms engage in pricing. Such a game has no proper subgames. We seek a solution, however, which would be supported by a subgame perfect equilibrium of the pricing game if the search strategies of buyers were known. To do this formally, we specify a game in which buyers move first and simultaneously choose search policies. These policies are observed by firms, before they begin their own stages of play. The first pricing stage is now the start of a proper subgame. Any individual buyer

³⁷Our prices have a closed-form solution, unavailable in the single-stage framework (see e.g., JMG p. 1103).

³⁸We can allow for $\lambda_S = 0$ so that there are no exogenous shoppers, and so all buyers are searchers. In the original studies of costly search, the assumption that $\lambda_S > 0$ was justified by appealing to the fact that some people enjoy shopping (Stahl, 1989) or have no opportunity cost of time (JMG).

has no measurable influence on future play and so acts as though moving simultaneously. This enables us to continue to use subgame perfection as a solution concept.

Our notation follows JMG: μ_q is the proportion of searchers who pay for q quotations. Using a single-stage specification for firms' pricing, they identified three possibilities for equilibria: (i) a low search intensity equilibrium in which $\mu_0, \mu_1 > 0$ and $\mu_0 + \mu_1 = 1$; (ii) a moderate search intensity equilibrium in which $\mu_1 = 1$; and (iii) a high search intensity equilibrium in which $\mu_1, \mu_2 > 0$ and $\mu_1 + \mu_2 = 1$.³⁹

Expanding notation further, for this third case the fractions of potential buyers who see only a price quotation from firm i (and so are captive) or compare the prices of firms i and j are

$$\lambda_i = \frac{\mu_1(1 - \lambda_S)}{n} \quad \text{and} \quad \lambda_{ij} = \frac{2\mu_2(1 - \lambda_S)}{n(n - 1)}. \quad (22)$$

We seek subgame perfect equilibria in which prices are chosen as pure strategies. Specifically, we identify a search strategy (which specifies that a fraction μ_q of buyers request q price quotations) and a set of prices such that it is optimal for a buyer to request q quotations when $\mu_q > 0$, and the set of prices meet our earlier definition of equilibrium.

Low and Moderate Intensity: Searching Once or Never. A familiar property of costly search is that, in any equilibrium, buyers obtain at most two quotations, and some obtain only one. The rough logic is that there are (at least weakly) decreasing returns to search, and so there is either a single optimal sample size q (so that $\mu_q = 1$ for this q) or two neighboring sample sizes q and $q + 1$ are both optimal (so that $\mu_q + \mu_{q+1} = 1$).⁴⁰ If all buyers obtain at least two price quotations ($q \geq 2$) then every firm is sure to face head-to-head competition with at least one other firm. This forces prices (also in our two-stage game) to zero. However, if prices are zero then consumers optimally obtain only a single quotation; a contradiction.

Lemma 6 (Number of Quotations in Equilibrium). *In equilibrium $\mu_{q>2} = 0$ and $\mu_1 > 0$: searchers gather at most two quotations, and some gather exactly one.*

Here we consider buyers who obtain one quotation or none, so that $\mu_2 = 0$. This combines the cases of low search intensity ($0 < \mu_1 < 1$: some buyers never search) and moderate search intensity ($\mu_1 = 1$: everyone obtains one quotation) from JMG. This is a world of captives and shoppers, where the mass of buyers captive to i is $\lambda_i = \mu_1(1 - \lambda_S)/n$. We know (Proposition 1) that $n - 1$ firms fully exploit captives while the n th firm chooses a list price p^\dagger low enough to dissuade discounts from others. From (1),

$$p^\dagger = \frac{\lambda_i v}{\lambda_i + \lambda_S} = \frac{\mu_1(1 - \lambda_S)v}{\mu_1(1 - \lambda_S) + \lambda_S n} \quad \Leftrightarrow \quad \frac{v - p^\dagger}{n} = \frac{\lambda_S v}{\mu_1(1 - \lambda_S) + \lambda_S n}. \quad (23)$$

Turning to optimal search, a quotation costs κ and earns surplus $v - p^\dagger$ if the ‘‘limit price’’ firm n supplies the quotation, which happens with probability $1/n$; this generates the expression on the right. The fact that a buyer is searching for a single lowest price means that the gains from

³⁹The low-intensity equilibrium, $\mu_0 > 0$, would not exist if the first search were free, as in Stahl (1989).

⁴⁰When $n = 2$ we can also construct situations in which buyers are indifferent between three options $q \in \{0, 1, 2\}$.

search (just like the costs) are linearly increasing in the number of quotations q ; the probability that q searches without replacement find the cheapest firm is q/n . This means that if it is strictly preferred to search for one quotation rather than none, then it is strictly optimal to search for quotations from all n suppliers. To construct an equilibrium in which $\mu_1 > 0$ but $\mu_2 = 0$ requires a searcher to be exactly indifferent between searching and not. Solving for μ_1 and checking that $\mu_1 \in (0, 1]$ yields the following result.

Proposition 7 (Searching Once or Never). *If $n < v/\kappa \leq n - 1 + (1/\lambda_S)$ then there is an equilibrium in which buyers search for a single quotation with probability*

$$\mu_1 = \frac{\lambda_S}{1 - \lambda_S} \left(\frac{v}{\kappa} - n \right) \quad (24)$$

but otherwise do not search. Firms play pure strategies on the equilibrium path. One firm sets a low list price $p^\dagger = v - n\kappa$, while all others charge v . Final prices satisfy $p_i = \bar{p}_i$ for all i .

JMG defined a “moderate search intensity” equilibrium as one in which every buyer obtains exactly one quotation, so that $\mu_1 = 1$. For generic parameters (the exception is when $n - 1 + (1/\lambda_S) = v/\kappa$) there is no such equilibrium.⁴¹ Therefore, our solution corresponds to their “low search intensity” equilibrium. Interestingly, they (in their Propositions 4–5) established the existence of such an equilibrium when n is large. In contrast, we also require n to be sufficiently small.⁴² The equilibrium property that only one firm chooses a price lower than v means that buyers are searching for the proverbial needle in the haystack. When n is large enough, even for low cost-to-value ratios, buyers prefer not to search at all.

More generally the fraction of those who search is decreasing in n . An increase in n also pushes down the lowest price while making the highest prices (equal to v) more frequent, and so makes the distribution of prices riskier while the average price remains constant.⁴³

However, perhaps the most important observations concern the fraction of shoppers who exogenously see all prices. Suppose $n < v/\kappa$, so that a buyer would search if at least one firm gives the product away. If λ_S is small, then the inequality $v/\kappa < n - 1 + (1/\lambda_S)$ required for existence holds. However, as this fraction becomes negligible trade collapses: $\mu_1 \downarrow 0$ as $\lambda_S \downarrow 0$ i.e., endogenous search falls to zero as the exogenous search is removed from the model. In essence this says that a low search intensity equilibrium is a no search equilibrium.

⁴¹Our game (with pure-strategy play) rules out Propositions 1–3 of JMG (Section 3, pp. 1094–1098) which correspond to their moderate-intensity equilibrium. In their world, the use of single-stage pricing means that firms choose mixed strategies, and so there are many different possible prices. This implies that there are decreasing returns to search, which contrasts with the linearity here. One way to recover existence for a non-degenerate set of parameters would be to assume that search costs are strictly increasing, rather than constant.

⁴²The number of firms cannot be too small (because of the second inequality in Proposition 7): if $v/\kappa > (1 + \lambda_S)/\lambda_S$ then that second inequality fails for n small enough. This is because too few firms can make the probability that a searcher finds the low price so high that all searchers wish to search. The fact that the low price rises as n falls tempers this effect, but does not undo it.

⁴³These results reinforce those reported in Proposition 5 of JMG.

High Intensity: Searching Once or Twice. We have shown that lower (at most one quotation) search intensities either are not chosen in equilibrium or involve negligible search. The more interesting case is when some searchers ask for two price quotations so that each firm faces a positive probability of going head-to-head with any other firm. This ensures that any equilibrium with the on-path play of pure strategies must involve n distinct prices. We order the firms such that $\bar{p}_1 > \dots > \bar{p}_n$.

Fixing buyers' search strategies, we now characterize the staircase of prices that satisfy "no undercutting" constraints: firm $i < n$ with price \bar{p}_i does not wish to undercut (at the second stage) the price \bar{p}_{i+1} and so capture those additional searchers who see quotations from both firms i and $i + 1$. For $i < n - 1$, this constraint is

$$\left(\lambda_i + \sum_{j < i} \lambda_{ij}\right) \bar{p}_i \geq \left(\lambda_i + \lambda_{i(i+1)} + \sum_{j < i} \lambda_{ij}\right) \bar{p}_{i+1}. \quad (25)$$

On the left-hand side, maintaining price \bar{p}_i wins sales from the mass λ_i of customers who see only this price, and also wins sales $\sum_{j < i} \lambda_{ij}$ from comparisons with higher-priced rivals. On the right hand side, undercutting \bar{p}_{i+1} grabs extra sales of $\lambda_{i(i+1)}$ (the searchers who compare i 's price against the next cheapest firm). If this constraint held as a strict inequality then firm $i + 1$ could safely raise \bar{p}_{i+1} , and so (25) holds with equality. For firm $n - 1$, there is an additional incentive to undercut firm n : by charging below \bar{p}_n this firm can also capture the shoppers (who see all prices).⁴⁴ The presence of shoppers only influences the lowest price \bar{p}_n in the sequence. We simplify exposition (with no real loss of insight) by setting $\lambda_S = 0$. Finally, the highest price is $\bar{p}_1 = v$ as this firm sells only to captives. These equations pin down a unique profile of prices that are part of an equilibrium with the on-path play of pure strategies. The terms λ_i and λ_{ij} are, in turn, determined endogenously by the search strategies of buyers.

Just as before, there is no incentive (by construction) for any firm to undercut at either stage. Checking for any profitable deviation upwards at the list-price stage (by constructing equilibria in the appropriate subgames) yields Proposition 8.

Proposition 8 (Equilibrium Prices with Search for Two Quotations). *Set $\lambda_S = 0$. Suppose that the search strategy satisfies $\mu_1 > 0$, $\mu_2 > 0$ and $\mu_1 + \mu_2 = 1$. For the two-stage pricing game, there is a unique profile of list prices*

$$\bar{p}_i = \frac{\mu_1(n-1)v}{\mu_1(n-1) + 2(1-\mu_1)(i-1)} \quad (26)$$

played as pure strategies as part of a subgame perfect equilibrium. Each firm sets $p_i = \bar{p}_i$. The (distinct) prices are decreasing in the proportion $\mu_2 = 1 - \mu_1$ of buyers who search for a second price quotation. If n is odd, then the median price is equal to $\mu_1 v$.

The average price charged is lower in an industry with $n > 2$ competitors than in a duopoly.

Each firm earns profit of $\mu_1 v/n$, and so the average paid by a buyer is equal to $\mu_1 v$.

⁴⁴For firm $n - 1$ and $\lambda_S > 0$: $(\lambda_{n-1} + \sum_{j < n-1} \lambda_{j(n-1)})\bar{p}_{n-1} = (\lambda_{n-1} + \lambda_{n-1(n)} + \sum_{j < n-1} \lambda_{j(n-1)} + \lambda_S)\bar{p}_n$.

The final claims concern profitability and so (equivalently) the average price paid. A fraction of μ_1/n of customers are effectively captive to each firm. A fraction $1 - \mu_1$ are pairwise shoppers. The most expensive firm loses any comparisons, and so earns the profit from exploitation of captive customers. The price construction means that all firms earn equal expected profit. The average price paid does not depend directly on the number of competitors. Instead, it depends on the strategy of buyers: more intensive search lowers the distribution of prices posted.

Although the average price paid is independent of n , the distribution of prices is not. Notably (cf. JMG) the average price posted is not increasing in n . Beyond the statement made in the proposition, we can also show that this average is decreasing for $n \in \{2, 3, 4, 5\}$ before calculations become cumbersome.⁴⁵

Now we consider endogenous search. From Proposition 8 we can work out the expected gain to acquiring one or two price quotations. An equilibrium is obtained when the gain from the second quotation (this is weakly lower than from the first quotation) equals κ .

Consider, for example, the the duopoly case ($n = 2$) for which the two prices are $\bar{p}_1 = v$ and $\bar{p}_2 = \mu_1 v / (2 - \mu_1)$. A single quotation finds the cheaper firm with probability $1/2$ and generates consumer surplus $v - \bar{p}_2$. Two quotations find this consumer surplus with certainty. For this special case of $n = 2$, the marginal benefit of both the first and second quotations is equal to $(v - \bar{p}_2)/2$.⁴⁶ Equating this to the quotation cost κ yields an equilibrium. The case where $n = 3$ is also tractable. We report both the duopoly and triopoly cases here.

Proposition 9 (Equilibrium Search in a Duopoly and Triopoly). *Set $\lambda_S = 0$. Consider an equilibrium in which potential buyers acquire either one or two price quotations.*

For a duopoly with $v > 2\kappa$, there is a unique equilibrium which satisfies

$$\mu_2 = 1 - \mu_1 = \frac{\kappa}{v - \kappa}, \quad \frac{\bar{p}_1 + \bar{p}_2}{2} = v - \kappa, \quad \text{and average price paid} = \mu_1 v = \frac{v(v - 2\kappa)}{v - \kappa}. \quad (27)$$

Buyers are indifferent between searching once, twice, or never; they earn zero expected payoff.

For a triopoly with $v > 3\kappa/2$, there is a unique equilibrium which satisfies

$$\mu_2 = \frac{\kappa}{(2/3)v - \kappa}, \quad \frac{\bar{p}_1 + \bar{p}_2 + \bar{p}_3}{3} = v - \kappa - \frac{\kappa v}{2v - 3\kappa}, \quad \text{and av. price paid} = \frac{v(2v - 6\kappa)}{2v - 3\kappa}. \quad (28)$$

A move from duopoly to triopoly or an increase in the search cost κ raises the intensity of search and lowers the average price charged and the average price paid.

⁴⁵Proposition 6 of JMG, which says that the average price charged increases with n , does not hold. Under the symmetric mixed strategies of the single-stage game it is uncertain whether a particular firm will win shoppers. As the number of firms grows, the probability of being the cheapest falls exponentially. Firms react to this exponential fall in equilibrium by shifting mass to higher prices. This force is not present under our equilibrium price profile: the lowest price \bar{p}_n internalises this force completely.

⁴⁶We can construct an equilibrium in which some buyers do not search at all. Formally, for any equilibrium in which $\mu_1 + \mu_2 = 1$ and any $\tilde{\mu}_0 > 0$ there is an equilibrium in which all three search sizes $q \in \{0, 1, 2\}$ are used, satisfying $\tilde{\mu}_q = \mu_q(1 - \tilde{\mu}_0)$ for $q \in \{1, 2\}$. A slight change to our model eliminates this multiplicity. If we assume that the second quotation is slightly more expensive than the first then once again any equilibrium can only involve two adjacent search strategies.

Proposition 9 reports that search increases as it becomes more costly. This follows from the equilibrium requirement that searchers must be indifferent between one and two quotations: greater intensity pushes prices down, compensating searchers for their increased costs.⁴⁷

Many Suppliers. Given the search strategy of buyers, we have equilibrium prices for any n . However, various expressions become cumbersome for larger oligopolies. To make progress, we consider the limiting case where there are large number of suppliers. Given a search strategy across one or two quotations from potential buyers, the distribution satisfying Lemma 7 ensures that firms are indifferent between prices across the relevant support.

Lemma 7 (Equilibrium Price Distribution with Many Suppliers). *Fix the search strategy of buyers, and allow the number of firms to grow large. The unique profile of prices converges to a continuous distribution with support on $[\mu_1 v / (2 - \mu_1), v]$. Writing $F(\cdot)$ for this distribution, and $F_{\min}(\cdot)$ for the distribution of the minimum $\min\{p', p''\}$ of two randomly drawn prices,*

$$F(p) = 1 - \frac{\mu_1}{1 - \mu_1} \frac{v - p}{2p} \quad \text{and} \quad F_{\min}(p) = 1 - \left(\frac{\mu_1}{1 - \mu_1} \frac{v - p}{2p} \right)^2. \quad (29)$$

The expected payments from (i) a single quotation and (ii) two quotations are

$$E[p] = \frac{v}{2} \frac{\mu_1}{1 - \mu_1} \log \left(\frac{2 - \mu_1}{\mu_1} \right) \quad (30)$$

$$E[\min\{p', p''\}] = \frac{v}{2} \left(\frac{\mu_1}{1 - \mu_1} \right)^2 \left(\frac{2(1 - \mu_1)}{\mu_1} - \log \left(\frac{2 - \mu_1}{\mu_1} \right) \right). \quad (31)$$

Here we highlight an important connection between the equilibria of our model and those in the literature. The mixed equilibria of single-stage models are not ex post Nash for finite n . But as $n \rightarrow \infty$, the equilibria of a large class of games become ex post Nash (Kalai, 2004, Theorem 1). The mixed-strategy equilibria of the single-stage pricing models we have examined are no exception. In fact, as $n \rightarrow \infty$ in our model, prices organize themselves in such way as to asymptotically produce the exact same distribution, F of (29), as reported in those studies.⁴⁸ Hence both paradigms are robust to ex post deviations in the limit, but only there. The difference is that our equilibrium is ex post Nash for all n , not only when $n \rightarrow \infty$.

Given the equivalence of our equilibrium with that in the literature for a large number of firms, we derive optimal search and give our final result by following previous papers closely, e.g., Burdett and Judd (1983, Section 3.2) and (JMG, pp. 1104–1109). The cost of an additional

⁴⁷The indifference condition is artefact of there being one level of search cost for everyone. Suppose instead there were two searcher types: low-cost and high-cost with respective marginal costs of search κ_H and $\kappa_L < \kappa_H$. It is then straightforward to construct an equilibrium for a non-degenerate set of parameters in which: (i) prices are played with pure strategies; (ii) low-cost (high-cost) searchers strictly prefer to gather two (one) quotation i.e., there are no indifference conditions; and (iii) prices and search intensities are independent of search costs.

⁴⁸In JMG, the mixed strategy they derive for their high search intensity's equilibrium (see their equation 8) is ex post Nash only when $n \rightarrow \infty$. The same expression (without exogenous shoppers) can also be found in Burdett and Judd (1983, equation 2) where n is large throughout.

quotation must be equal to the expected reduction in price:

$$\kappa = E[p] - E[\min\{p', p''\}] = \frac{v}{2} \frac{\mu_1}{1 - \mu_1} \left(\frac{1}{1 - \mu_1} \log \left(\frac{2 - \mu_1}{\mu_1} \right) - 2 \right). \quad (32)$$

The right-hand side is single-peaked, rising from zero at $\mu_1 = 0$ and falling back to zero at $\mu_1 = 1$. This implies that if κ is large there is no solution; but if κ is sufficiently small there are two equilibrium values for μ_1 .

Proposition 10 (Equilibrium Search with Many Suppliers). *Consider an equilibrium with a continuum of suppliers and endogenous search. There is some $\bar{\kappa}$ such that if $\kappa < \bar{\kappa}$ then there are two equilibria. Both involve greater buyer search for two quotations (and so lower industry profit, lower average price charged, and lower average price paid) than in a duopoly.*

As discussed, our predictions depart markedly from the literature for finite n , and coincide only as $n \rightarrow \infty$. Proposition 10 establishes that the incentive to acquire a second quotation lies everywhere below the incentive when $n = 2$. This means that equilibria in the two cases are distinct, involving a higher search intensity (and so lower prices) when the number of competitors is very large rather than very small. This prediction is distinct from the single-stage model of JMG (see their Proposition 8) who find that the expected price charged is the same with a duopoly and with many firms.

6. CONCLUDING REMARKS

Our two-stage model predicts a unique profile of distinct prices played with pure strategies. We therefore generate stable price dispersion, in line with a substantial part of empirical evidence.

The model is highly portable and conducive to deeper analyses as demonstrated by our applications, where we generate new insights in models of sales, prominence, advertising, and search. The traditional single-stage framework has been applied to many other research areas too, including: price discrimination (Armstrong and Vickers, 2018; Fabra and Reguant, 2018); product substitutability (Inderst, 2002); sequential consumer search (Stahl, 1989); switching costs (for a review, see Farrell and Klemperer, 2007); strategic clearing-houses such as comparison websites (Baye and Morgan, 2001, 2009; Moraga-González and Wildenbeest, 2012; Ronayne, 2019; Shelegia and Wilson, 2017); and competition with boundedly-rational consumers (Carlin, 2009; Chioveanu and Zhou, 2013; Heidhues, Johnen, and Kőszegi, 2018; Inderst and Obradovits, 2018; Piccione and Spiegler, 2012). In all of these contexts, we suggest that our novel pricing game can (by avoiding the on-path play of mixed strategies) better match stylized empirical observations, while facilitating and enriching a broad portfolio of inquiry.

OMITTED PROOFS

Proof of Lemma 1. This follows from the argument in the main text. \square

Proof of Lemma 2. The conditions of Theorem 5 of Dasgupta and Maskin (1986, p. 14) are met, and guarantee the existence of a mixed-strategy Nash equilibrium.⁴⁹

Suppose that $p_i \sim F_i(\cdot)$, and write \bar{s}_i for the upper bound to the support of this mixed strategy.

Claim (i). No firm places an atom strictly below its list price. This absence of atoms implies that the expected profit of a firm is continuous in its price except at others' list prices.

An atom at $p_i < \bar{p}_i$ is justified only if it can capture the shoppers. No other firm $j \neq i$ prices just above p_i ; it would be better for j to capture the atom. The only firms that might set $p_j = p_i$ are strictly more efficient ($c_j < c_i$) because they (by our tie-break rule) can win at tied prices; but that means that firm i loses against them. We conclude that firm i can raise p_i locally without losing sales, and yet increasing the profit from captives; a contradiction.

Claim (ii). Firm n performs strictly better than by selling to captives at the monopoly price.

For $i < n$ prices strictly below p_{n-1}^\dagger are strictly dominated. No firm places an atom at p_{n-1}^\dagger . This means that firm n can capture all shoppers by setting $p_n = p_{n-1}^\dagger$, and so n 's expected profit weakly exceeds $(p_{n-1}^\dagger - c_n)(\lambda_S + \lambda_n) > (p_n^\dagger - c_n)(\lambda_S + \lambda_n) = (v - c_n)\lambda_n \geq (\bar{p}_n - c_n)\lambda_n$.

Claim (iii). A firm's pricing mixture includes its list price: $\bar{s}_i = \bar{p}_i$ for all i .

If $\bar{p}_j < \bar{s}_i < \bar{p}_i$ then firm i would never choose $p_i \in (\bar{p}_j, \bar{p}_i)$: sales are only to captives (firm j is guaranteed to be cheaper) and firm i would do better to raise price further. Suppose instead that $\bar{p}_j > \bar{s}_i$ for all j . For the same reason, firm j never chooses $p_j \in (\bar{s}_i, \bar{p}_j)$. From claim (i) there is no atom at \bar{s}_i . Firm i could again raise price from \bar{s}_i without losing sales. We conclude that $\bar{s}_i < \bar{p}_i$ can be optimal only if some j places an atom at $\bar{p}_j = \bar{s}_i$. This must be firm n (all others satisfy $\bar{p}_j = v > \bar{s}_i$). Firm i does not place an atom at \bar{s}_i , from claim (i). Hence firm n sells only to captives with an atom at \bar{p}_n . This contradicts claim (ii).

Claim (iv). Firm $i < n$ earns an expected payoff of $\lambda_i(v - c_i)$.

Suppose that $\bar{p}_n < v$. From claim (iii), the mixed strategy of $i < n$ includes its maximum price at which no shoppers buy and so firm i earns $\lambda_i(v - c_i)$ from sales to captive customers.

Suppose instead that $\bar{p}_n = v$. If every firm were to place an atom at v then at least one firm would undercut the others. Hence some firm j places no atom at v . Other firms $i \neq j$ are willing to price at or close to v , and are always beaten on price by firm j . These firms earn

⁴⁹A condition is that the sum of payoffs (here, aggregate profit) is upper semi-continuous in actions (here, prices). Industry revenue is continuous. Consider costs when the allocation of output changes discontinuously as prices change. For upper semi-continuity we require the allocation to maximize industry profit, and so minimize aggregate cost, at any tied prices. This is achieved by breaking ties in favor of efficient suppliers.

$\lambda_i(v - c_i)$. If $n \neq j$, then firm n would earn $\lambda_n(v - c_n)$, which contradicts claim (ii). Hence $j = n$, and all firms $i < n$ earn $\lambda_i(v - c_i)$ as claimed. Note that all firms $i < n$ must place an atom at v . If some $i < n$ were to join n by omitting the atom, then once again firm n 's expected profit would fall to $\lambda_n(v - c_n)$, in contradiction to claim (ii).

Firm i 's profit can exceed $\lambda_i v$ only if all other more efficient firms have an atom at v .

Claim (v). Firm n earns an expected payoff of $(\lambda_S + \lambda_n)(p_{n-1}^\dagger - c_n)$.

Suppose that firm n never prices below some $p > p_{n-1}^\dagger$. Firm $n - 1$ could price within the interval $(p_{n-1}^\dagger, \min\{p, p_{n-2}^\dagger\})$ and sell to all shoppers, at a price yielding a profit that strictly exceeds $(\lambda_S + \lambda_{n-1})p_{n-1}^\dagger = \lambda_{n-1}v$. This contradicts claim (iv). Hence the mixed strategy of firm n extends down to p_{n-1}^\dagger , which captures all shoppers and yields the claimed profit. \square

Proof of Proposition 1 and Corollaries. By construction, no high-priced firm has an incentive to undercut firm n in the second stage, and so no incentive to post a lower price. The only other first-stage deviation is an increase in the price of firm n . This yields no change in payoff, given the play in that subgame described in Lemma 2.

The three corollaries all follow from the accompanying discussions in the main text. \square

Proof of Proposition 2. Consider a strategy profile in which the three firms post the list prices as stated, and then (on the equilibrium path) choose $p_i = \bar{p}_i$ in the second stage.

In the second stage, no firm is able to raise price. Non-prominent firms serve all available customers, and so face no incentive to discount. Finally, the stated list prices ensure that the prominent firm has no incentive to undercut any competitors. In the first stage, the same arguments ensure that nothing can be gained from advertising a lower first-stage list price.

It remains to check for an upward deviation in the list prices of non-prominent firms.

Recalling that $v = \bar{p}_1 > \bar{p}_3 > \bar{p}_2$, consider a deviation by firm 3 to a higher list price $\hat{p}_3 > \bar{p}_3$. The following strategies constitute a Nash equilibrium in such a subgame. Firm 2 charges $p_2 = \bar{p}_2$. Firms 1 and 3 mix continuously over the interval from \bar{p}_3 up to \hat{p}_3 using the distributions

$$F_1(p) = \frac{p - \bar{p}_3}{p} \quad \text{and} \quad F_3(p) = \frac{(\phi_1 + \phi_3)p - \phi_1 v}{\phi_3 p}, \quad (33)$$

placing any residual mass at \bar{p}_1 and \hat{p}_3 , respectively. It is straightforward to confirm that firms 1 and 3 earn profits $\phi_1 v$ and $\phi_3 \bar{p}_3$ respectively; no firm gains relative to the equilibrium path.

Suppose that firm 2 deviates upward to \hat{p}_2 where $\bar{p}_3 \geq \hat{p}_2 > \bar{p}_2$. These strategies constitute a Nash equilibrium. Firm 3 charges $p_3 = \bar{p}_3$. Firms 1 and 2 mix from \bar{p}_2 to \hat{p}_2 via

$$F_1(p) = \frac{p - \bar{p}_2}{p} \quad \text{and} \quad F_2(p) = \frac{(\phi_1 + \phi_2 + \phi_3)p - \phi_1 v}{\phi_2 p}, \quad (34)$$

placing residual mass at \bar{p}_1 and \hat{p}_2 , respectively. Firms 1 and 2 earn ϕv and $\phi_2 \bar{p}_2$.

Finally, if $\hat{p}_2 > \bar{p}_3$ then the following strategy profile constitutes a Nash equilibrium. Firm 1 mixes via $F_1(\cdot)$ from (34). Firm 3 mixes from \bar{p}_2 up to $\pi_1 v / (\phi_1 + \phi_2)$ using the distribution

$$F_3(p) = \frac{(\phi_1 + \phi_2 + \phi_3)p - \phi_1 v}{\phi_3 p}. \quad (35)$$

Firm 2 mixes from $\pi_1 v / (\phi_1 + \phi_2)$ up to \hat{p}_2 using the distribution

$$F_2(p) = \frac{(\phi_1 + \phi_2)p - \phi_1 v}{\phi_2 p}, \quad (36)$$

with residual mass placed at \hat{p}_2 . Firm 2 earns $\phi_2 \bar{p}_2$ just as on the equilibrium path. Hence, following each possible deviation we have specified a Nash equilibrium of the subgame in which there is no gain for the player deviating at the first stage.

This shows that the prices in the proposition are supported in a subgame perfect equilibrium.

In the text, we reported a second profile of list prices (in which the larger non-prominent firm posts an intermediate price) which satisfied the necessary conditions discussed in the text:

$$\bar{p}_1 = v, \quad \bar{p}_2 = \frac{\phi_1 v}{\phi_1 + \phi_2}, \quad \text{and} \quad \bar{p}_3 = \frac{\phi_1 v}{\phi_1 + \phi_2 + \phi_3}, \quad (37)$$

We now show that these prices cannot be played as pure strategies on the equilibrium path of a subgame perfect equilibrium. If they were, then on that path each firm i would set $p_i = \bar{p}_i$ (by construction, the prominent firm has no incentive to undercut) and firm 3 would earn a payoff $\phi_3 \phi_1 v / (\phi_1 + \phi_2 + \phi_3)$. We will show that firm 3 has a profitable deviation in the first stage.

Specifically, consider the subgame following a deviation by firm 3 to a list price \hat{p}_3 where

$$\frac{\phi_1 v}{\phi_1 + \phi_3} > \hat{p}_3 > \frac{\phi_1 v}{\phi_1 + \phi_2} = \bar{p}_2 > \bar{p}_3, \quad (38)$$

No firm places an atom strictly below its list price: if a firm did then no competitor would ever price at or just above this atom, and so the firm could safely move the atom upward.

There can be no equilibrium in pure strategies: this would involve prices equal to list prices, and the prominent firm would find it profitable to undercut \bar{p}_2 and so capture all of the business.

The prominent firm uses a mixed strategy: if it were to play the pure strategy $p_1 = \bar{p}_1 = v$ then the opponents would play their list prices. That mixed strategy can place an atom at $\bar{p}_1 = v$, and otherwise mixes continuously over the support of the others' mixed strategies.

For the prominent firm, prices strictly below \bar{p}_3 are strictly dominated, as are prices above \bar{p}_2 but below $\phi_1 v / (\phi_1 + \phi_3)$. A firm $i \in \{2, 3\}$ can secure all customers by charging $p_i = \bar{p}_3$ and so can guarantee a payoff of $\phi_i \bar{p}_3 > 0$. Take the highest price charged by any non-prominent firm. This wins customers with strictly positive probability (as it must to generate a positive expected profit) only if the prominent firm prices above it with strictly positive probability. Thus the prominent firm places an atom at \bar{p}_1 . This implies that payoff of this firm equals $\phi_1 v$.

Excluding the atom at $\bar{p}_1 = v$, consider the support of the prominent firm's (continuous) mixed strategy. This lies within the joint support of the competitors' strategies: any other price can be safely raised (that is, without losing sales) which strictly raises profit. The support of any competitor lies within the support of the prominent firm, and for the same reason. It follows that the two supports (of the prominent firm, and the joint support of the competitors) coincide. At the lower bound of that support, the prominent firm sells to everyone, a mass $\phi_1 + \phi_2 + \phi_3$. This firm's profit is $\phi_1 v$, and so that lower-bound price must equal $\bar{p}_3 = \phi_1 v / (\phi_1 + \phi_2 + \phi_3)$.

Consider the interval $[\bar{p}_3, \bar{p}_2)$. No list price is in this interval, and so there are no atoms. Within this interval there is no gap within the support of the prominent firm: if so then there would be a gap in the support of the competitors' strategies, and so the prominent firm could safely (that is, without losing sales) move a price from the bottom of the gap upward, and so strictly gain. Similarly, there is no gap with the common support of the opponents' strategies. Given that this is so, at least one player $i \in \{2, 3\}$ is willing to set $p_i = \bar{p}_2$ and so earn a payoff of least $\phi_i \bar{p}_3$. Both i and $j \neq i$ face the same relative payoffs when pricing against the prominent firm, and so $j \neq i$ can also guarantee a payoff of at least $\phi_j \bar{p}_3$ by setting $p_j = \bar{p}_2$.

Player 3 earns $\phi_3 \bar{p}_3$ on the equilibrium path, and at least that payoff by playing $p_3 = \bar{p}_2$ in the deviant subgame. Recall that the prominent player never prices just above \bar{p}_2 . Hence, player 3 can safely raise price above \bar{p}_2 without losing sales, and so earn strictly more than $\phi_3 \bar{p}_3$. We conclude that any equilibrium in this subgame yields a profitable deviation.

The remaining claim concerns $n > 3$ where $\phi_1 = \dots = \phi_n$. Order firms inversely to list price. The "no undercutting" arguments yield the list price stated. Consider the list price of \bar{p}_i . The most prominent firm could undercut this and capture the first i customer types. Hence

$$\phi_1 \bar{p}_1 \geq \left(\sum_{j=1}^i \phi_j \right) \bar{p}_i \quad \Leftrightarrow \quad \bar{p}_i \leq \frac{\phi_1 \bar{p}_1}{\sum_{j=1}^i \phi_j} = \frac{\bar{p}_1}{i}. \quad (39)$$

Each firm can safely raise its list price upward until these constraints bind, and so $\bar{p}_1 = v$ and $\bar{p}_i = v/i$ as stated. No player has an incentive to charge a lower list price in the first stage or undercut in the second stage. It remains to check for an upward deviation of list price.

Suppose that firm $i > 1$ raises its list price to $\hat{p}_i > \bar{p}_i$. Consider this strategy profile in the subgame. Firm 1 mixes continuously from \bar{p}_i up to \hat{p}_i using the distribution function

$$F_1(p) = 1 - \frac{\bar{p}_i}{p}, \quad (40)$$

and places all remaining mass at $\bar{p}_1 = v$. Any firm $j > i$ which necessarily satisfies $\bar{p}_j < \bar{p}_i$ sets a price equal to list: $p_j = \bar{p}_j$. Any firm $j < i$ which satisfies $\bar{p}_j \geq \hat{p}_i$ also sets a final retail price equal to list price: $p_j = \bar{p}_j$. Any other firm $j \neq i$ necessarily satisfies $\bar{p}_i < \bar{p}_j < \hat{p}_i$. Such a firm mixes continuously from \bar{p}_{j+1} up to \bar{p}_j using the distribution function

$$F_j(p) = \frac{(j+1)p - v}{p}. \quad (41)$$

Finally, consider the deviant firm i . Take the lowest index k (and so highest list price \bar{p}_k) which satisfies $\bar{p}_k < \hat{p}_i$. Firm i mixes continuously from \bar{p}_k to \hat{p}_i using the distribution function

$$F_i(p) = \frac{kp - v}{p}, \quad (42)$$

and places all remaining mass at the deviant list price \hat{p}_i .

These strategies generate a Nash equilibrium of the subgame. To see this, note that the most prominent firm always prices at \bar{p}_i or above, and so any $j > i$ has no reason to discount below \bar{p}_j . For any other firm j , a price satisfying $\bar{p}_i \leq p \leq \hat{p}_i$, which lies within the support of $F_1(\cdot)$ yields an expected payoff equal to $\phi\bar{p}_i$. If $\bar{p}_j \leq \hat{p}_i$ then a firm can do no better than this, and so optimally plays the prescribed strategy. If $\bar{p}_j > \hat{p}_i$ then j is strictly better off by setting $p_j = \bar{p}_j$ and so does so. It remains to check the optimality of the most prominent firm's price. Consider, for example, a price p satisfying $\bar{p}_{j+1} < p < \bar{p}_j$ for some j satisfying $i < j \leq k$. From the perspective of the most prominent firm, this wins the business of the ϕ customers who see only the most prominent firm, the $(j-2)\phi$ competitors indexed strictly below j , and the customers who see the price of firm i ; a total mass of $j\phi$ customers. Additionally, this price p wins those buyers who see firm j 's price with probability $1 - F_j(p)$. The expected payoff is

$$p\phi [j + (1 - F_j(p))] = p\phi \left[j + 1 - \frac{(j+1)p - v}{p} \right] = \phi v, \quad (43)$$

which is the payoff that the firm obtains by serving only captive customers. Finally, the same argument applies when considering any price $\bar{p}_k \leq p \leq \hat{p}_i$. \square

Proof of Proposition 3. In the text we reported the prominence fee that could be charged to the largest firm. Consider instead the fee that could be charged to the intermediate-sized firm. This firm earns $\phi_2 v$ in a position of prominence. If it loses prominence, then the worst-case scenario is for prominence to be given (just as before) to the smallest firm, in which case firm 2 earns $\phi_2 \phi_3 / (\phi_1 + \phi_2 + \phi_3)$. Taking the difference yields a prominence fee that is strictly less than the fee charged to the largest firm. A related calculation (in which the smallest firm is threatened with the prominence of the intermediate sized firm) also generates a smaller prominence fee. \square

Proof of Lemma 3. For now, label firms so that $\bar{p}_1 > \dots > \bar{p}_n$. (The argument in the text confirms that prices are distinct.) If firms maintain list prices on the equilibrium path then firm i earns a profit $\bar{p}_i \alpha_i \prod_{k>i} (1 - \alpha_k)$. Undercutting a cheaper firm $j > i$ earns (arbitrarily close to) $\bar{p}_j \alpha_i \prod_{k>j} (1 - \alpha_k)$. Comparing these terms yields the inequality $\bar{p}_j \leq \bar{p}_i \prod_{j \geq k > i} (1 - \alpha_k)$. This inequality is satisfied if and only if $\bar{p}_i \leq (1 - \alpha_i) \bar{p}_{i-1}$ for every $i > 1$.

This holds as an equality. If not then we find the lowest i such that the inequality is strict. Such a firm i can locally raise its list price (and final retail price) without violating any ‘‘no undercutting’’ inequalities in the second stage, and so without losing any sales; a contradiction. We conclude that $\bar{p}_i = (1 - \alpha_i) \bar{p}_{i-1}$ for $i > 1$. The argument in the text shows that $\bar{p}_1 = v$. Repeated substitution of the relevant equality yields $\bar{p}_i = v \prod_{j=2}^i (1 - \alpha_j)$ for $i > 1$.

Finally, we confirm the ordering of the firms. Firm $i > 1$ earns profit $v \prod_{j=2}^i (1 - \alpha_j)$ with probability $\alpha_i \prod_{j>i} (1 - \alpha_j)$, yielding an expected profit of $v \alpha_i \prod_{j=2}^n (1 - \alpha_j)$. Pricing at v would (at worst) yield a profit of $v \alpha_i \prod_{j \neq i} (1 - \alpha_j)$. Comparing these terms, necessarily $1 - \alpha_i \geq 1 - \alpha_1$, or equivalently $\alpha_1 \geq \alpha_i$. We conclude that the largest firm must charge the highest price. \square

Proof of Lemma 4. We write p_i^* for the list prices that satisfy Lemma 3 and generate profits $\pi_i = v \alpha_i \prod_{j=2}^n (1 - \alpha_j)$. Consider an upward deviation in list price by firm $i > 1$. Suppose that this deviant list price satisfies $p_i^* < \bar{p}_i \leq p_{i-1}^*$. Consider the following strategy profile: all firms $j < i - 1$ and $j > i$ charge their list prices, so that $p_j = \bar{p}_j = p_j^*$; firms $j = i - 1, i$ mix continuously over the interval $[p_i^*, \bar{p}_i]$ with distribution satisfying

$$F_j(p) = \frac{1}{\alpha_j} \left[1 - \frac{p_i^*}{p} \right], \quad (44)$$

and $i - 1$ places residual mass at \bar{p}_{i-1} . (It is readily verified that $F_j(p)$ satisfies $F_j(p_i^*) = 0$, is increasing, satisfies $F_j(p) \leq 1$ for $p \leq \bar{p}_j$, and that there are no profitable deviations.) These strategies constitute a Nash equilibrium.

Deviations by i to higher list prices are handled as follows. For example, if i deviates to a list price satisfying $p_{i-1}^* < \bar{p}_i \leq p_{i-2}^* (1 - \alpha_i)^{1/2}$ then players $j = i - 1, i$ mix by (44) and $i - 1$ places residual mass at \bar{p}_{i-1} . If however, $p_{i-2}^* (1 - \alpha_i)^{1/2} < \bar{p}_i \leq p_{i-2}^*$, $j = i - 2, i - 1, i$ mix in the interval $[p_i^*, p_{i-1}^*]$ according to

$$F_j(p) = \frac{1}{\alpha_j} \left[1 - \left(\frac{p_i^*}{p} \right)^{1/2} \right], \quad (45)$$

while firms $j = i - 2, i$ also mix in the interval $[p_{i-2}^* (1 - \alpha_i)^{1/2}, \bar{p}_i]$ according to

$$F_j(p) = \frac{1}{\alpha_j} \left[1 - \frac{p_i^*}{p(1 - \alpha_{i-1})} \right], \quad (46)$$

and place remaining mass at \bar{p}_j . (It is readily checked that these strategies yield the payoffs π_j and there are no profitable deviations.) These strategies constitute a Nash equilibrium. One can then consider all higher list-price deviations by firm i iteratively, concluding in all cases that i 's profit is π_i , and hence that i has no profitable upward deviation in its list price \hat{p}_i . \square

Proof of Proposition 4. This follows from Lemmas 3–4 and the arguments in the main text. \square

Proof of Lemma 5. This follows from the argument in the main text. \square

Proof of Proposition 5. We show there is an equilibrium where firm 1 chooses $\alpha_1^* > \max_{i \neq 1} \{\alpha_i^*\}$. Equilibria of the pricing subgames are those of Proposition 4. Advertising choices satisfy the first-order conditions (19) and so the remaining deviation checks are non-local:

(i) 1 deviates to $\hat{\alpha}_1 \leq \alpha_j^*$ where $j: \alpha_j^* = \max_{i>1} \{\alpha_i^*\}$. Firm j satisfies a first-order condition at α_j^* . Therefore, the best such deviation for 1 is to $\hat{\alpha}_1 = \alpha_j^*$ (1's revenue (cost) curve is the same

(flatter) for $\hat{\alpha}_1 \in [0, \alpha_j^*]$ than j 's over the same interval when $\alpha_i = \alpha_i^*$ for $i \neq j$). By continuity and 1's first-order condition, 1's profit at any $\hat{\alpha}_1 \geq \alpha_j^*$ is less than at α_1^* .

(ii) $i > 1$ deviates to $\hat{\alpha}_i \geq \alpha_1^*$. Firm 1 satisfies their first-order condition at α_1^* . Therefore, the best such deviation for $i > 1$ is to $\hat{\alpha}_i = \alpha_1^*$ (i 's revenue (cost) curve is flatter (steeper) for $\hat{\alpha}_i \in [\alpha_1^*, 1]$ than 1's over the same interval when $\alpha_i = \alpha_i^*$ for $i > 1$). But by continuity and i 's first-order condition, i 's profit at any $\hat{\alpha}_i \leq \alpha_1^*$ is less than at α_i^* . \square

Proof of Proposition 6. We look for equilibria with pure-strategy advertising choices where following any profile of advertising intensities (α_i^* for $i = 1, \dots, n$), the equilibrium of the pricing subgame is that of Proposition 4. We put aside trivial equilibria where more than one firm chooses $\alpha_i = 1$ which lead to marginal cost pricing. All firms have zero costs and are therefore symmetric. It follows that although the profile of equilibrium advertising choices we report is unique, the assignment of firms is not. Subject to this disclaimer, the main text explains that one firm will advertise with the outright highest intensity, and we label this firm 1.

For zero costs, and by (16), the profit of firm 1 is strictly (and linearly) increasing in α_1 for any $\alpha_i < 1$ for $i > 1$, hence $\alpha_1^* = 1$. Given $\alpha_1^* = 1$, (16) shows that the profit of the non-largest firms is maximized at $\alpha_i = 1/2$ for any $\alpha_j < 1$ where $j \neq 1, i$, hence $\alpha_i^* = 1/2$ for $i > 1$.

For positive costs, firms $i, j > 1$ must satisfy their first-order conditions given in (19) but with $C_i = C$. Taking the ratio of i 's and j 's condition yields

$$\frac{C'(\alpha_i)}{C'(\alpha_j)} = \frac{(1 - 2\alpha_i)(1 - \alpha_j)}{(1 - 2\alpha_j)(1 - \alpha_i)}. \quad (47)$$

If $\alpha_i > (<) \alpha_j$ the LHS $> 1 (< 1)$ but the RHS $< 1 (> 1)$. However, if $\alpha_i = \alpha_j$, (47) is satisfied. Hence $\alpha_i^* = \alpha_j^*$. Letting $C(\alpha) = -\log(1 - \alpha)$ gives (21), the solution to which gives the values of α_1^* and α_i^* for $i > 1$, and that $\alpha_1^* = 2\alpha_i^*$. Similar reasoning to that in the proof of Proposition 5 rules out profitable non-local deviations. \square

Proof of Lemma 6. This follows from the argument in the main text. Janssen and Moraga-González (2004, p. 1112) presented in a formal argument in the proof of their Lemma 1. \square

Proof of Proposition 7. Solving (23) yields the expression for μ_1 and for the price p^\dagger . Checking that μ_1 lies in the unit interval generates the inequalities reported. \square

Proof of Proposition 8. Setting $\lambda_S = 0$ for simplicity (it is straightforward to incorporate $\lambda_S > 0$) the fractions of buyers who are captives for firm i and pairwise shoppers between two firms i and j are, from (22), $\lambda_i = \mu_1/n$ and $\lambda_{ij} = 2\mu_2/[n(n-1)]$. For well-rehearsed reasons, the “no

undercutting" constraint of (25) holds as an equality. Hence

$$\begin{aligned} \frac{\bar{p}_{i+1}}{\bar{p}_i} &= \frac{\lambda_i + \sum_{j<i} \lambda_{ij}}{\lambda_i + \lambda_{i(i+1)} + \sum_{j<i} \lambda_{ij}} = \frac{(\mu_1/n) + 2(i-1)\mu_2/[n(n-1)]}{(\mu_1/n) + 2i\mu_2/[n(n-1)]} \\ &= \frac{(n-1)\mu_1 + 2(i-1)(1-\mu_1)}{(n-1)\mu_1 + 2i(1-\mu_1)}. \end{aligned} \quad (48)$$

Setting $\bar{p}_1 = v$ (for the most expensive firm), repeated substitution yields the stated solution for \bar{p}_i . By construction, no firm wishes to choose a lower price in either stage. It remains to check for profitable upward deviations of list price by some firm i . We proceed as before, by constructing a mixed-strategy equilibrium in the deviant subgame which yields a payoff to firm i equal to that received by remaining on the equilibrium path. We omit the details here.

The comparative-static claim regarding the effect of μ_1 (or μ_2) on prices holds by inspection.

For the median price, suppose that n is odd. The median firm i satisfies $i-1 = (n-1)/2$. Applying the pricing solution for this firm yields $\bar{p}_i = \mu_1 v$ as claimed.

The final claims follow because each firm is indifferent between the specified list price and charging v to captives, and because the average price paid equals industry profit. \square

Proof of Proposition 9. For $n = 2$, setting κ equal to the gain from the second quotation:

$$\kappa = \frac{v - \bar{p}_2}{2} = \frac{v(1 - \mu_1)}{2 - \mu_1} \Leftrightarrow \mu_1 = \frac{v - 2\kappa}{v - \kappa}. \quad (49)$$

Regarding the average price charged,

$$\bar{p}_1 = v \quad \text{and} \quad \bar{p}_2 = \frac{\mu_1 v}{2 - \mu_1} = v - 2\kappa \quad \Rightarrow \quad \frac{\bar{p}_1 + \bar{p}_2}{2} = v - \kappa. \quad (50)$$

For $n = 3$,

$$\bar{p}_1 = v, \quad \bar{p}_2 = \mu_1 v, \quad \text{and} \quad \bar{p}_3 = \frac{\mu_1 v}{2 - \mu_1}. \quad (51)$$

Now consider the marginal benefit of the second quotation. With probability $1/3$ the first quotation yielded the highest price, and so the second quotation is sure to yield a saving of $\bar{p}_1 - \bar{p}_2$. With probability $2/3$ the first quotation did not find the cheapest price. The second quotation has probability $1/2$ of moving from the intermediate to the lowest price. Hence

$$\kappa = \frac{\bar{p}_1 - \bar{p}_2}{3} + \frac{1}{2} \frac{2(\bar{p}_2 - \bar{p}_3)}{3} = \frac{\bar{p}_1 - \bar{p}_3}{3} = \frac{2(1 - \mu_1)v}{3(2 - \mu_1)}. \quad \Rightarrow \quad \mu_1 = \frac{2v - 6\kappa}{2v - 3\kappa} < \frac{v - 2\kappa}{v - \kappa}. \quad (52)$$

Substituting back into prices,

$$\begin{aligned} \bar{p}_1 = v, \quad \bar{p}_2 &= \frac{2v - 6\kappa}{2v - 3\kappa}v, \quad \text{and} \quad \bar{p}_3 = v - 3\kappa \quad \Rightarrow \\ \frac{\bar{p}_1 + \bar{p}_2 + \bar{p}_3}{3} &= \frac{2v^2 - 6\kappa v + 3\kappa^2}{2v - 3\kappa} = \frac{(2v - 3\kappa)(v - \kappa) - \kappa v}{2v - 3\kappa} = v - \kappa - \frac{\kappa v}{2v - 3\kappa} < v - \kappa. \quad \square \end{aligned} \quad (53)$$

Proof of Lemma 7. Consider the prices reported in (26). These satisfy $\bar{p}_1 = v$ and $\bar{p}_n = \mu_1 v / (2 - \mu_1)$. Take any price p within the interval bounded by these highest and lowest prices, and write

$F_n(p)$ for the cumulative distribution function of prices. For finite n ,

$$F_n(p) = \frac{n-i}{n-1} \Leftrightarrow \bar{p}_{i-1} > p \geq \bar{p}_i \Leftrightarrow \frac{\mu_1(n-1)v}{\mu_1(n-1) + 2(1-\mu_1)(i-2)} > p \geq \frac{\mu_1(n-1)v}{\mu_1(n-1) + 2(1-\mu_1)(i-1)} \frac{i-2}{n-1} < \frac{\mu_1}{1-\mu_1} \frac{v-p}{2p} \leq \frac{i-1}{n-1} \Leftrightarrow i = \left\lceil (n-1) \frac{\mu_1}{1-\mu_1} \frac{v-p}{2p} \right\rceil + 1, \quad (54)$$

where “[\cdot]” means “the least integer weakly greater than.” Hence

$$F_n(p) = 1 - \frac{1}{n-1} \left\lceil (n-1) \frac{\mu_1}{1-\mu_1} \frac{v-p}{2p} \right\rceil, \quad (55)$$

converges to $F(p)$ (as reported in the lemma) as $n \rightarrow \infty$. The distribution of the minimum of two random draws from $F(\cdot)$ is of course $F_{\min}(p) = 1 - (1 - F(p))^2$ which yields the expression reported. Taking expectations straightforwardly generates the remaining claims. \square

Proof of Proposition 10. (32) in the main text is the equilibrium condition. As noted there, the right-hand side is increasing and then decreasing in μ_1 , hitting zero at the endpoints $\mu_1 \in \{0, 1\}$. Hence (as stated) κ needs to be smaller enough to be below the maximum of this function, and when it is strictly below the maximum there must be two solutions. \square

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