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// ATABEK ATAYEV

Information Asymmetry and Search Intensity

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Information Asymmetry and Search Intensity *

Atabek Atayev[†]

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Abstract

In markets where sellers' marginal costs of production have a common component, they have informational advantage over buyers regarding those costs. This information asymmetry between sellers and buyers is especially relevant in markets where buyers have to uncover prices through costly search. We propose a theoretical model of simultaneous search that accounts for such information asymmetry. Our main finding is that informing buyers about marginal costs may harm them by deterring search and, hence, softening competition. This result has important implications on policy regulations and voluntary information sharing.

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[†]Market Design, ZEW—Leibniz Centre for European Economic Research, L 7, 1, 68161 Mannheim, Germany. E.: atabek.atayev@zew.de

1 Introduction

While it is well-established that information asymmetry on product quality harms consumers,[1] a similar conclusion has found support in homogeneous goods markets, where information asymmetry pertains to the production marginal cost (MC). The detrimental impact of this information asymmetry has been stressed in markets possessing two features. One is that sellers' MCs have a common component. This allows an individual seller to have a good knowledge about production costs of its competitors. The other feature is that consumers have to uncover prices through costly search, and in particular through *sequential search*. It is then natural that consumers do not know production costs if they are poorly informed about prices.

But how plausible is sequential search? Although sequential search permits a buyer to learn more of sellers' production costs with each round of searching and prevents excessive search, it is time-inefficient. This is especially so if a buyer wishes to gather information quickly and the search outcome is observed with a delay. In such markets *simultaneous search* outperforms sequential search (Morgan and Manning, 1985). Observations from real-world markets support this argument. For instance, a procurement agency simultaneously solicits multiple bidders to submit their offers because bidders need time to prepare offers. A consumer applies for a mortgage credit at multiple banks simultaneously, as it takes time for banks to review applications and quote interest rates.

In this paper we study simultaneous search markets with information asymmetry on the MC. Contrary to common wisdom, we demonstrate that resolving this information asymmetry may harm buyers.

We develop this insight within a canonical model of simultaneous search as in Burdett and Judd (1983), which we present in Section 2. In a one-shot game, sellers simultaneously set prices and consumers choose how many sellers to search. Goods are homogeneous. Since our focus is on markets where sellers' marginal costs of production have a common component, we assume that sellers have the same constant MC. This cost is a random draw from a commonly known distribution. Sellers observe the cost realization but buyers do not, which results in information asymmetry. To assess the impact of resolving

[1] On the problem of adverse selection see, e.g., Akerlof (1970), Spence (1973), Rothshchild and Stiglitz (1976), and on that of moral hazard see, e.g., Wilson (1968), Mirrlees (1976), Holmström (1979), Grossman and Hart (1983)).

the information asymmetry, we compare the outcome of a market with the information asymmetry to that of a market where buyers observe the production cost.

After establishing the existence of an equilibrium with positive trade in Section 3, we report our main result in Section 4. We demonstrate that eliminating the information asymmetry on the production cost may harm buyers. This is mainly due to buyers' search behavior. In expectation consumers search less intensely when they observe the production cost than when they do not, which we elaborate on in the next paragraph. Less intense search means that buyers are less able to compare prices. This, in turn, softens competition. The consumer surplus declines even though reduced search intensity causes buyers to incur less search cost.

To explain why informing buyers about the production cost mitigates their search incentive, we delve into the relationship between the MC and search intensity when buyers observe the production cost. We demonstrate that buyers' search intensity is decreasing and concave in the MC. Noting a positive relationship between search intensity and the level of price dispersion, we show that this concavity arises from two negative effects of the production cost on the level of price dispersion. The direct effect is that, with buyers' search behavior being fixed, high prices become more profitable to sellers than low prices. Specifically, the support of the equilibrium price distribution narrows with the lowest price in the support moving closer to the monopoly price. There is also an indirect effect as sellers take into account buyers' search strategy when setting prices. Sellers expect the share of price-comparing buyers to drop owing to the above-described direct effect. Sellers then have incentive to charge prices closer to the monopoly price. This further reduces price dispersion and mitigates buyers' incentive to search. Because both the direct- and indirect-effects are negative, buyers' search intensity declines with an increasing rate in the MC, creating a concave relationship. By Jensen's inequality it follows that the expected search intensity when buyers observe the production cost is lower than the search intensity given the expected production cost. However, the latter search intensity is one wherein buyers do not observe the production cost.

In Section 5 we demonstrate robustness of our main result to various model extensions. Besides generalizing the main model in ways common in the search literature, we analyze two important cases which naturally arise from our main result. In one of these cases we allow sellers to truthfully disclose information on the production cost to buyers. We show that in equilibrium sellers choose to reveal their production cost. The reasoning is similar to "full-unraveling" in Grossman and Hart (1980). In the other case we permit buyers to observe or ignore the production cost before engaging in search. We demonstrate that it is individually optimal for a buyer to observe the MC. This is so despite the fact that consumers are better-off if they collectively choose to ignore information on the production cost. This consumer behavior is driven by an incentive that resembles a free-riding incentive in a public goods game.

In Section 6 we discuss several empirical application of our model. We first consider the Italian competition authorities' policy of setting so-called *reference prices* in a procurement market for medical devices. The regulation had been effective for approximately one year. A references price had been informative of sellers' (which produce fairly homogeneous goods such as syringes and needles) production costs. In line with the prediction of our model, the dispersion of prices shrank when the reference prices were in place. Contrary to expectations of the authorities, reference prices did not lower market prices. We also present a couple of observations that support our model's prediction that the decentralized market has a tendency to naturally resolve the information asymmetry (as implied in the previous paragraph). One of the observations pertains to the establishment of benchmarks by market participants in the over-the-counter markets. The other observation is voluntary information sharing of retailers on demand forecast with suppliers in vertical markets.

We believe that our paper makes an important contribution to the literature. For one reason, it provides new insights into the role of information asymmetry, as our key finding is diametrically opposite to those reached by the existing studies on consumer search (see Section 7). For another reason, it calls for further exploration of simultaneous search markets. We suggest potential avenues for future research in the final section.

2 Model

In this section we first present the model and then discuss its assumptions.

2.1 Assumptions, Timing, and Equilibrium Concepts

The model is based on the simultaneous search model of Burdett and Judd (1983).[2] $N \geq 2$ identical sellers, or *firms*, supply homogeneous goods to a unit mass of buyers, or *consumers*. The industry MC is a random draw from $\{c_1, c_2, ..., c_K\}$, where $0 \leq c_1 < ... < c_K < \infty$, according to probability mass function f, so that f_k is the probability that the MC equals c_k for $k \in \{1, ..., K\}$. Sellers observe the MC and compete on prices. As we allow for mixed strategies, we let $x_j(p|c_k)$ be the probability that seller j charges a price above p when the MC is c_k. We denote by $\underline{p}_k$ and $\overline{p}_k$ respectively the lowest and highest prices in the support of the price distribution, given c_k.

Each buyer wishes to consume a unit of the product which she values at $v(> c_K)$. In a model with the information asymmetry, buyers do not observe the MC. In the model without the information asymmetry, buyers observe the MC. In both models buyers do not know prices. To make a purchase a buyer has to learn at least one price through costly search. Search is simultaneous, also known as *non-sequential search* or *fixed-sample-size search*. A searching buyer requests price information from m number of sellers, after which the search is terminated. It costs $s > 0$ to obtain a price quote. Therefore, searching m sellers entails a total cost of $m \times s$. Since mixed-strategies are allowed, we denote by q_m the probability that a representative buyer searches m sellers—so that $\sum_{m=0}^{N} q_m = 1$—in a model version where buyers do not observe the production cost.[3] In the other version of the model, consumers condition their search intensities on the realized production cost. There we let $q_m(c_k)$ represent the probability of searching m firms when the MC is c_k.

Two different explanations of q are possible. One is that q_m represents the share of consumers that search m sellers. The other explanation is that q represents a consumer's search intensity. We say that a consumer searches more intensely if the probabilities of her searching higher numbers of sellers increase and, correspondingly, the probabilities of

[2]This model has been extended to theoretically study price competition (e.g., Anderson et al., 1992; McAfee, 1995; Janssen and Moraga-Gonzalez, 2004; Moraga-Gonzalez et al., 2021; Atayev, 2022), price dynamics (e.g., Fershtman and Fishman, 1992; Yang and Ye, 2008) and labor markets (e.g., Burdett and Mortensen, 1998; Acemoglu and Shimer, 2000). The model has proven to be a convenient framework for empirical studies employing structural estimation techniques (e.g., Hong and Shum, 2006; Moraga-González and Wildenbeest, 2008; De los Santos et al., 2012; Honka, 2014; Galenianos and Gavazza, 2022).

[3]We use this notation for simplicity, while acknowledging that the proper notation is $q_m(\mathbb{E}[c_k])$ as buyers condition their search strategies on the expected MC.

her searching lower numbers of sellers decrease. Similar explanations apply for $q(c_k)$.

The timing of the game is as follows. First, the MC is realized. Second, sellers observe the MC and simultaneously set prices. Depending on our model, buyers may or may not observe the MC. Third, buyers—without knowing prices—search. Finally, buyers who observe at least one price may make purchases.

The solution concept is Bayesian-Nash equilibrium (BNE) in our model with the information asymmetry. In a BNE each player maximizes her payoff given her belief about other players' strategies and the MC, which are correct in equilibrium. We employ Nash equilibrium (NE) as a solution concept for our model where consumers observe the MC.

2.2 Discussion of Assumptions

We now discuss the model's following assumptions: identical MCs, homogeneous goods, and simultaneous search. We assume that sellers face the same MC for two reasons. First, it is a convenient way to model markets where sellers' MCs are subject to common industry shocks. Second, it is a simple method to emphasize the information asymmetry between buyers and sellers in the sharpest way possible.

Markets with fairly homogeneous goods are widespread. In mortgage markets, the primary difference across banks is the interest rate. In a procurement market for medical devices, products, such as syringes and needles, are fairly homogeneous across sellers. Similarly, there is not much quality variation of agricultural products.[4]

Simultaneous search, as demonstrated by Morgan and Manning (1985), is optimal in markets where buyers need to gather price information fast and sellers quote prices with a delay. This holds true even though buyers learn through search not only of prices but also of market-fundamentals, such as the MC. To illustrate this argument, we consider a mortgage market. Suppose that on average, it takes a bank around two weeks (or ten working days) to review a buyer's application and quote an interest rate. If a buyer searches sequentially, she first applies for a mortgage in one of the banks, waits around two weeks for a reply, and only then decides whether to contact another bank. Although with sequential search a buyer can better evaluate banks' lending costs with each search, it is time-consuming. In our example, it takes around three months to learn of offers of

[4] Generally, there are two types of agricultural products: organic and non-organic. However, within each type the products are fairly homogeneous.

six banks. However, the buyer can expedite the process by simultaneously submitting applications to all six banks and learning their offers within just two weeks.

The time-efficiency of simultaneous search is especially relevant if a buyer faces external deadlines for their purchases. In many countries, regulations dictate public procurement agencies to set deadlines for bid submission. The impact of such deadlines is apparent in the public procurement of medicines in the Russian Federation, where more than a quarter of the procurement in 2019 was declared unsuccessful as no bid was submitted within the announced deadlines (Cursor, 2019). Implying a sharp rise in the search cost, deadlines are also consistent with the argument that the search cost is convex in the number of searches in sequential search markets (e.g., Ellison and Wolitzky, 2012; Carlin and Ederer, 2019). It can be shown that under certain conditions, predictions of sequential search models with convex search coincide with those of simultaneous search models with linear search costs.

Finally, empirical studies show that the predictions of simultaneous search models align more closely with consumers' search behavior in real-world markets compared to those of sequential search models. De los Santos et al. (2012) and Honka and Chintagunta (2017) demonstrate this in the case of online markets for books and car insurance, respectively.

3 Equilibrium

Equilibrium analysis consists of two parts. We first examine the model in which consumers do not observe the MC and later the model in which consumers observe the MC.

In both cases we restrict our attention to equilibria where some consumers search and make a purchase. Although in both models exist the *Diamond paradox* equilibria (Diamond, 1971) with no trade—where consumers do not search and sellers charge a price higher than $v - s$—these equilibria are fragile. For instance, the equilibrium is ruled out if we introduce a positive share of consumers who observe multiple offers to our models. In contrast, equilibria with search and positive trade are robust to such assumptions, as we show in Sections 5.4 and 5.5. We will refer to such a BNE (and an NE in the case with no information asymmetry) simply as an *equilibrium*.

3.1 Unobserved MC

We begin by characterizing an equilibrium and then establish its existence. This equilibrium has similar characteristics as that in the model of Burdett and Judd (1983) where buyers observe the production cost. Specifically, in equilibrium buyers randomize between searching one seller and searching two sellers. Meanwhile, sellers set their prices according a unique price distribution that is monotone in its compact support with the highest price equal to the monopoly price v for any realization of the MC. The following lemma formalizes the players' strategies.

Lemma 1. *If an equilibrium exists when buyers do not observe the MC, it must be that*

(i) $0 < q_1, q_2 < 1$ *and* $q_1 + q_2 = 1$*, and*

(ii) $x_j(p|c_k) = x(p|c_k)$ *for all* $j \in \{1, ..., N\}$*, where for all* $k \in \{1, ..., K\}$ $x(p|c_k)$ *has no atoms or flat regions in its compact support* $[\underline{p}_k, \overline{p}_k]$ *with* $\overline{p}_k = v$*.*

We establish by contradiction the reasoning for why a strictly positive share of buyers search only one seller in equilibrium. If all buyers search at least two prices, they will buy at the lowest observed price. No seller, then, wishes to have the highest price. If two or more sellers tie at some price higher than the MC, it pays off for one of them to slightly undercut the price. As a result of these two arguments, the optimal price must be equal to the MC. However, if prices are equal to the MC, buyers do not want to search more than one seller, a contradiction.

The argument in the previous paragraph helps us understand why price-comparing buyers search exactly two sellers in equilibrium. First, note that sellers play mixed-strategy pricing for any realization of the MC. This is because each seller faces a trade-off between ripping-off buyers who observe only its price and attracting price-comparing buyers. The share of the former type of buyers must be positive as we argued in the previous paragraph. The share of the latter type buyers must be positive as follows. For contradiction, suppose that all buyers search one firm and hence there is no price comparison. Then, the optimal price is the monopoly price. However, an individual buyer has incentive to not search, as doing so yields a payoff equal to zero while searching yields a negative payoff, leading to contradiction.

Next, notice that the added benefit of searching an additional seller decreases with the number of searched sellers for any non-degenerate price distribution. Formally, if we let $X(p)$ be the *ex-ante* probability that a buyer expects a seller to charge a price above p, then $1-(1-X(p))^m$ is the distribution of the minimum of m prices. Call it the mth order statistic. The difference between the mth and $m+1$th order statistics is given by $X^m(p)(1-X(p))$. This difference is clearly decreasing in m, which implies that the added benefit of searching an additional, $m+1$th, seller decreases with m. As the cost of searching an additional seller is constant, it must be that either all buyers search the same number of sellers or they randomize over searching two adjacent numbers of sellers. Since in equilibrium some buyers discover only one price, price-comparing buyers must search exactly two sellers.

Knowing consumers' equilibrium search behavior allows us to determine properties of the equilibrium price distribution(s) for each realization of the MC. First, the existing literature has established that for any given MC, sellers draw prices from the same unique price distribution if the share of consumers who observe exactly two prices is strictly positive (e.g., Baye et al., 1992; Johnen and Ronayne, 2021).[5] From the previous paragraph we know that the share of such consumers is indeed positive. Next, the price distribution cannot not have atoms. If it had an atom at some price, sellers would tie at that price with a strictly positive probability. Then, an individual seller would have an incentive to slightly undercut the price as doing so leads to a discontinuous increase of its demand from price-comparing consumers (e.g., Rosenthal, 1980; Varian, 1980). Third, the price distribution cannot have flat regions in the support. If it did, an individual seller would strictly prefer the highest price in that flat region to the lowest price in the same region, as its expected demand would be the same at those prices. Fourth, the highest price in the support of the equilibrium price distribution must be equal to the monopoly price v. If the highest price were greater than v, a seller would not make any sales at that price.

[5]The full proof is given by Johnen and Ronayne (2021). To understand the intuition, consider a case where price-comparing buyers observe three prices instead of two prices. This means that each seller competes with two other sellers for the price-comparing buyers. It is then possible to show that in equilibrium one of the sellers always charge the monopoly price, while the other two compete head-to-head by drawing prices from the same distribution that continuously increases in its support. However, if price comparing buyers observe exactly two random prices, then each seller has to compete head-to-head with every other seller. This eliminates a seller's incentive to always charge the monopoly price in equilibrium, as its rivals will always undercut.

If the highest price were lower than v, a seller could profitably deviate to the monopoly price as in both cases it would sell only to consumers who observe its price only.

It is now left to establish equilibrium existence. As in the model of Burdett and Judd (1983), an equilibrium exists if the search cost is not very high. To show that, we need to derive the equilibrium price distributions and buyers' search intensity.

The equilibrium price distribution for any given MC can be derived based on its properties presented in Lemma 1. If seller j charges price p while facing c_k, its expected profit equals

$$\left(\frac{1-q_2}{N}+\frac{2q_2}{N}x(p|c_k)\right)(p-c_k),$$

where we substituted $q_1 = 1 - q_2$ to simplify the notation. The first term in the large brackets represents the share of consumers who search one seller and happen to visit seller j. These consumers make a purchase at any price below the monopoly price. The second term in the large brackets stands for the share of consumers who search two sellers and happen to visit the seller under question as well as another competitor. These consumers buy seller j's product if its price is lower than the rival seller's price, as well as the monopoly price.

In equilibrium an individual seller is indifferent of choosing any price in the support of the equilibrium price distribution and prefers these prices to ones which are not in the support. Therefore, we equate the above expected profit to the expected profit generated by the monopoly price to obtain

$$x(p|c_k)=\frac{1-q_2}{2q_2}\left(\frac{v-c_k}{p-c_k}-1\right) \text{ with support } \left[\underline{p}_k, v\right], \tag{1}$$

where $\underline{p}_k$ solves $x(\underline{p}_k|c_k) = 1$. It is useful to work with inverse function $p(x|c_k)$, which in equilibrium satisfies $p(x|c_k) = (1 - q_2)(v - c_k)/(1 - q_2 + 2q_2x) + c_k$.

We next use the fact that an individual buyer is indifferent between searching one seller and searching two sellers to derive the equilibrium search intensity. Given the price distributions in (1), searching one seller yields an expected payoff equal to

$$v+\sum_{k=1}^{K} f_k \int_{\underline{p}_k}^{v} px'(p|c_k)dp - s = v - \sum_{k=1}^{K} f_k \int_0^1 p(x|c_k)dx - s,$$

where $x'(p|c_k) := \partial x(p|c_k)/\partial p$ and we changed the variable of integration to obtain the equality. Similarly, searching two sellers yields an expected payoff equal to $v - 2\sum_{k=1}^{K} f_k \int_0^1 p(x|c_k)xdx - 2s$. These two payoffs must be equal for an individual buyer in equilibrium. Equalizing the payoffs renders

$$\sum_{k=1}^{K} f_k \int_0^1 p(x|c_k)(1-2x)dx = s, \tag{2}$$

where the left-hand side (LHS) and the right-hand side (RHS) represent the added benefit and cost of searching the second firm. The challenge is then to show that there exists $0 < q_2 < 1$ that solves this equation. The following proposition demonstrates that such q_2 exists for small search costs.

Proposition 1. *Suppose buyers do not observe the MC. Then, for $N \geq 2$, $v > 0$ and non-degenerate f there exists $\overline{s} \in (0, \sum_{k=1}^{K} f_k(v - c_k)/4]$ such that for $s < \overline{s}$ two equilibria exist. Each equilibrium is given $\left((x(p|c_k))_{k=1}^{K}, q_2\right)$ where $x(p|c_k)$ is determined by (1) for each $c_k \in \{c_1, ..., c_K\}$ and q_2 by (2).*

The proof is in the appendix and the intuition is as follows. In the appendix we show that the added benefit of searching the second seller, expressed by the LHS of (2), is positive and concave in the search intensity $q_2 \in (0, 1)$. Moreover, the added benefit of searching the second seller vanishes as the share of price-comparing consumers either disappears or converges to one. This is not surprising as sellers have incentive to charge the monopoly price if the share of price-comparing consumers vanishes (recall the Diamond paradox) and the price equal to the MC if all consumers compare prices. These facts imply that the expected benefit of searching the second seller is inverse U-shaped with respect to the search intensity as illustrated by the solid curve in Figure 1. Then, for small search costs there exist two equilibria if consumers prefer searching some firms to not searching at all. We show that this is true. In the figure those two equilibria are represented by the intersections of the solid curve and the dashed horizontal line representing the search cost.

One can argue that only one of those two equilibria is stable in a sense that if the actual search intensity is in the neighborhood of the stable-equilibrium search intensity, then buyers optimally adjust their search intensity to the equilibrium one.[6]

[6]Formally, let $N_\varepsilon = \{\widetilde{q} \in \mathbb{R} : |\widetilde{q} - q_2| < \varepsilon\}$ be the neighborhood of an equilibrium q_2 for arbitrarily

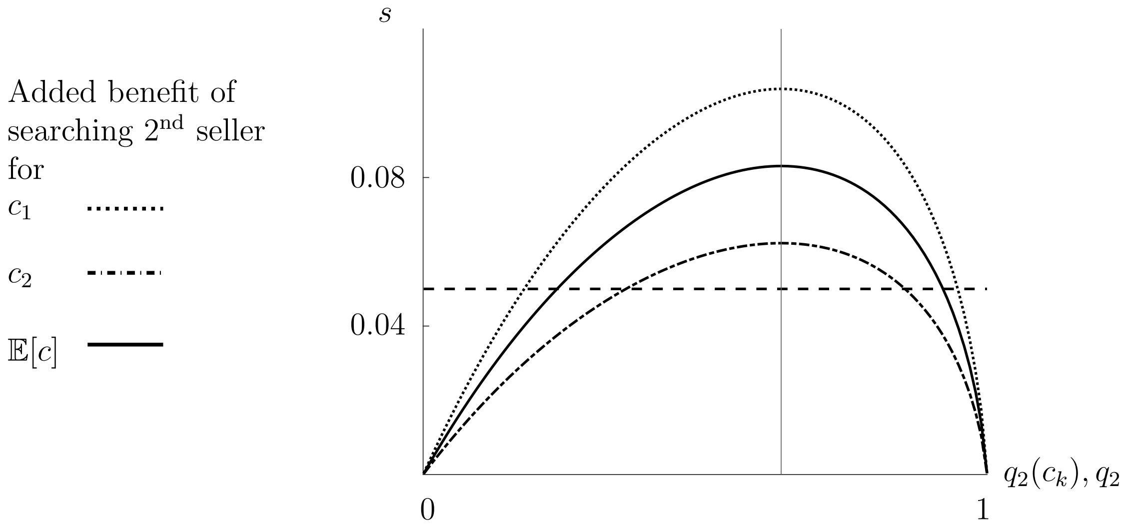

Figure 1: Illustration of BNEs for $N = 2$, $v = 1$, $s = 0.05$, $K = 2$, $c_1 = 0$, $c_2 = 0.4$ and $f_1 = 0.5$.

Corollary 1. *Of the two BNEs in Proposition 1, one characterized by a higher search intensity is stable.*

To understand the reasoning, consider an equilibrium given by a higher search intensity, which is represented by the right-most intersection of the solid curve and the dashed line in Figure 1. If the actual search intensity falls slightly short of the equilibrium level, the added benefit of searching the second seller is higher than the cost of doing so. As a result, buyers have an incentive to search more intensely. If, in contrast, the actual search intensity is slightly higher than the equilibrium level, the added benefit of searching the second seller is lower than the cost of doing so. As a result, buyers have an incentive to search less intensely. Therefore the equilibrium is stable. By applying similar arguments, it can be easily verified that the equilibrium characterized by a lower search intensity is unstable.

3.2 Observed MC

We now turn to examining a case where buyers, just like sellers, observe the production cost. This enables buyers to condition their search strategies on the realized MC. If the

small $\varepsilon > 0$. Then a perturbed search intensity q' is any search intensity in that neighborhood, i.e., $q' \in N_\varepsilon$. If q_2 is a part of a stable equilibrium and the actual search intensity is q', the search intensity converges to the equilibrium one. See Atayev (2022), Section 4.4 for discussion of why this notion of stability is desirable.

MC is c_k, the resulting *ex-interim* game is a special case of our model with information asymmetry but with $f_k = 1$. Therefore we can apply our analysis in the previous subsection to examine the current version of the model. To avoid repetition we omit parts of the analysis which can be directly inferred from Subsection 3.1.

Let $q_2(c_k)$ represent the probability that consumers search two sellers when the MC is c_k, and so the probability that consumers search one seller is $1 - q_2(c_k)$. Then, the equilibrium consists of $(x(p|c_k), q_2(c_k))$ for each c_k. Following the line of argument presented in the previous subsection, we can establish that

$$x(p|c_k) = \frac{1 - q_2(c_k)}{2q_2(c_k)} \left(\frac{v - c_k}{p - c_k} - 1 \right) \text{ with support } \left[\underline{p}_k, v \right], \tag{3}$$

where $\underline{p}_k$ solves $x(\underline{p}_k|c_k) = 1$. Using inverse function $p(x|c_k)$ that satisfies $p(x|c_k) = (1 - q_2(c_k))(v - c_k)/(1 - q_2(c_k) + 2q_2(c_k)x) + c_k$ in equilibrium, we write an equation that determines the equilibrium search intensity as

$$\int_0^1 p(x|c_k)(1 - 2x)dx = s. \tag{4}$$

We are now ready to state the main result of this subsection in the following corollary, which is a direct consequence of Proposition 1 and Corollary 1.

Corollary 2. *Suppose buyers observe the MC.*

(i) For each $k = \{1, ..., K\}$, there exists $\overline{s}_k \in (0, (v - c_k)/4]$ such that for $s < \overline{s}_k$ there exist two equilibria given by $(x(p|c_k), q_2(c_k))$ which are determined by (3) *and* (4).

(ii) Of the two equilibria for each $k \in \{1, ..., K\}$, one with a higher search intensity is stable.

Two questions arise naturally. One is, how $\overline{s}_k$s are related to each other? The other is, how $\overline{s}_k$s are related to $\overline{s}$ in Proposition 1? The following corollary answers to both questions.

Corollary 3. *We have (i) $\overline{s}_1 > \overline{s}_2 > ... > \overline{s}_K$ and (ii) $\overline{s} = \sum_{k=1}^{K} f_k \overline{s}_k$.*

The proof is in the appendix. To understand the intuition, consider a case where buyers observe the production cost, and rewrite the added benefit of searching the second seller in (4) by using the expression for $p(x|c_k)$ as[7]

$$(v-c_k)\int_0^1 \frac{(1-q_2(c_k))(1-2x)}{1-q_2(c_k)+2q_2(c_k)x}dx = s.$$

Recall from the discussion of Proposition 1 that the added benefit of searching the second seller, represented by the left-hand side of the equation, is concave in the search intensity (also observe Figure 1). This means that there is a unique value of the search intensity which maximizes the added benefit of searching the second seller. Note that this unique value of the search intensity is independent of the MC. Moreover, the maximum value of the added benefit of searching the second seller is linearly decreasing in the MC. This last observation implies the first part of the corollary.

We can rewrite equation (2) for the case with the information asymmetry in a similar manner as in the previous paragraph:

$$\sum_{k=1}^{K} f_k(v-c_k)\int_0^1 \frac{(1-q_2)(1-2x)}{1-q_2+2q_2x}dx = s.$$

Now we can see that the unique value of search intensity, which maximizes the added benefit of searching the second seller, must be the same as in the case without the information asymmetry. It directly follows that the second part of the corollary must be true.

Figure 1 illustrates the two points of the corollary. The dotted and dash-dotted curves represent the additional benefits of searching the second seller when the MC is low (i.e., $c_1 = 0$) and when it is high (i.e., $c_2 = 0.4$), respectively, and when consumers observe them. The vertical line stands for the search intensity at which the added benefit of searching the second seller is maximized in these two cases, as well as in the case with the information asymmetry. Notice that the values of these search intensities are identical for all three cases.

[7] We make the following changes:

$$\begin{aligned}\int_0^1 \left[\frac{(1-q_2(c_k))(v-c_k)}{1-q_2(c_k)+2q_2(c_k)x}+c_k\right](1-2x)dx &= \int_0^1 \left[\frac{(1-q_2(c_k))(v-c_k)}{1-q_2(c_k)+2q_2(c_k)x}(1-2x)+c_k(1-2x)\right]dx \\ &= \int_0^1 \frac{(1-q_2(c_k))(v-c_k)}{1-q_2(c_k)+2q_2(c_k)x}(1-2x)dx.\end{aligned}$$

4 Elimination of Information Asymmetry

We are now ready to evaluate the impact of informing consumers about the MC on market outcomes. We will first consider markets with trade and then markets where trade may be absent with a positive probability.

4.1 Markets with Trade

It is commonly expected that eliminating information asymmetry, wherein buyers have an informational disadvantage, should benefit them. However, the next proposition shows that the opposite is true if the search cost is small so that trade always wakes place.

Proposition 2. *Suppose $s \leq \overline{s}_K$ and consider stable equilibria. Then, ex-ante*

(i) buyers search less intensely,

(ii) the consumer surplus is lower,

(iii) the seller profit is higher, and

(iv) the total surplus is higher,

when buyers observe the MC than when they do not.

The proof is in the appendix. To understand the intuition behind (i), it is useful to consider consumers' search intensity when they observe the production cost. In the appendix we show that this search intensity is decreasing and concave in the MC, which we also illustrate in Figure 2. This happens because of two negative effects of an increase in the MC on the level of price dispersion, which in turn mitigates search incentives. The direct effect is that as the MC rises, while consumers' search behavior remains fixed, the level of price dispersion shrinks. This is because charging high prices becomes more profitable than charging low prices, with the lowest price in the price distribution getting closer to the monopoly price. The indirect effect is due to the fact that sellers take into account consumers' search intensity when setting their prices. Sellers expect the share of price-comparing consumers to drop because of the direct effect. If the share of price-comparing consumers falls, sellers have an incentive to charge prices closer to the monopoly price. As a result, price dispersion shrinks even more, which in turn causes even less search. This explains why consumers' search intensity falls at an increasing rate as the MC rises, i.e., why it is concave in the MC.

By Jensen's inequality it then follows that the expected search intensity when buyers observe the MC is lower than the search intensity given the expected MC. Formally we have that $\mathbb{E}[q_2(c_k)] < q\left(\mathbb{E}[c_k]\right)$ where the expectation is with respect to the MC. However, we know that in our model with information asymmetry, buyers take into account the expected production cost when deciding on their search intensity. Then, the search intensity under the information asymmetry equals $q\left(\mathbb{E}[c_k]\right)$, which means that buyers search more intensely with the information asymmetry than without it.

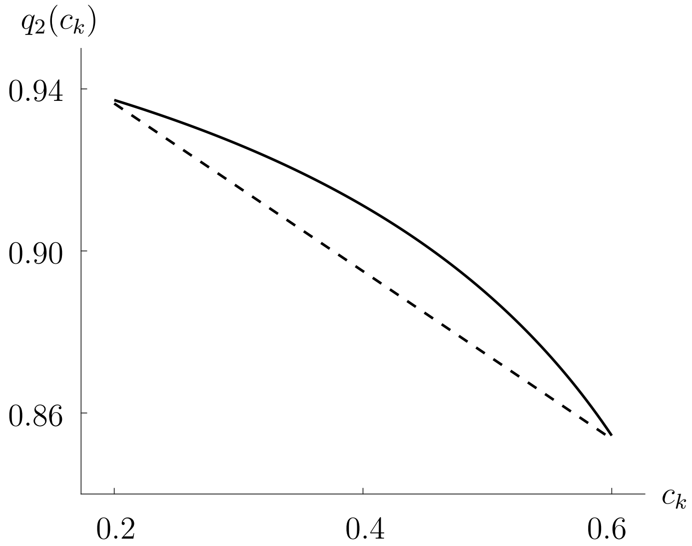

Figure 2: Concavity of $q_2(c_k)$ with respect to c_k

Figure 2 illustrates the concavity of the equilibrium search intensity in the MC when observed by consumers. We varied the MC from 0.1 to 0.4, while keeping the rest of the parameter values the same as in Figure 1. The solid curve represents the search intensity and the dashed straight line connects the highest and lowest search intensities in the figure.

Intuition behind (ii) and (iii) is easily understood together. Recall that the equilibrium seller profit equals $\sum_{k=1}^{K} f_k(1 - q_2)(v - c_k)/N$ when consumers do not observe the production cost and $\sum_{k=1}^{K} f_k(1 - q_2(c_k))(v - c_k)/N$ when they observe it. Notice that these equilibrium profits decrease with the respective search intensities. This is not surprising, as competition becomes stronger when the share of price-comparing consumers rises. From (i) we know that $q_2 = q\left(\mathbb{E}[c_k]\right)$, and thus the expected search intensity with the information asymmetry is higher than that without it. Since competition is more intense with higher search intensity, the equilibrium seller's profit is lower with the information asymmetry than without it. Weaker competition resulting from elimination of the information asymmetry harms consumers through higher prices. This effect dominates the positive effect of less search, i.e., lower search costs incurred.

The reasoning behind (iv) follows directly from (i). Notice that if all consumers make purchases, the total surplus depends only on the total costs spent on search. Changes in the price distribution have only a distributive effect. The total surpluses with and without the information asymmetry are, respectively, $\sum_{k=1}^{K} f_k(v - c_k - (1 + q_2)s)$ and $\sum_{k=1}^{K} f_k(v - c_k - (1 + q_2(c_k))s)$. From (i) we know that consumers search more intensely and, hence, incur higher total search cost when they do not observe the MC than when they do. Therefore, the total surplus is lower in the former case than in the latter.

4.2 Beyond Markets with Trade

We next provide some insights into the impact of resolving information asymmetry pertaining the MC on market outcomes when search costs may be high. Three exhaustive cases are possible. We will begin with high search costs, which we call Case (i), where $s > \overline{s}_1$. This implies that there cannot be an equilibrium with trade. Case (ii) arises when $\overline{s} < s < \overline{s}_k$ for some $\overline{s}_k > \overline{s}$. In this case, a stable equilibrium with active trade exists only if the production cost is lower than its expected value and consumers observe its realization (recall from Corollary 3 that for any $0 < q_2(c_k) < 1$, $\overline{s}_k$ is linearly decreasing in c_k). Case (iii) is where $\overline{s}_k < s \leq \overline{s}$ for some $\overline{s}_k < \sum_{k=1}^{K} f_k s_k$. This implies that buyers do not search, and consequently there is no trade, if they observe the production cost that is higher than its expected value, namely, $c_k > \sum_{k=1}^{K} f_k c_k$ for some k.

Case (i) is the simplest. The condition $s > \overline{s}_1$ means that there only exist equilibria without trade. This holds true for any realization of the production cost and regardless of whether consumers observe it. Therefore, information asymmetry on the production cost does not play any role.

Proposition 3. *If $s > \overline{s}_1$, the only equilibria that exist entail no trade independent of whether consumers observe the MC.*

We continue with Case (ii). In contrast to Proposition 2, the following proposition shows that informing consumers about the production cost leads to Pareto improvement.

Proposition 4. *Suppose $\overline{s} < s < \overline{s}_k$ for some $\overline{s}_k > \overline{s}$ and consider stable equilibria. Then, ex-ante*

(i) buyers search more intensely,

(ii) the consumer surplus is higher,

(iii) the seller profit is higher, and

(iv) the total surplus is higher,

when buyers observe the MC than when they do not.

The reasoning is simple. Consider first a case with information asymmetry on the production cost. As the search cost is higher than the cutoff value, namely $\overline{s}_k > \overline{s}$, the unique equilibrium outcome involves no search and no trade. Consider now a case where buyers observe the production cost. There is a (stable) equilibrium with active search and positive trade for small value realizations of the production cost as $s < \overline{s}_k$ for some $\overline{s}_k > \overline{s}$. Since for these values of the production cost buyers receive a positive surplus by searching, they are better off than in the case where they do not observe the production cost. Similarly, sellers earn positive profits in expectation when the information asymmetry is resolved. As a result, the total surplus increases owing to the elimination of the information asymmetry.

We now turn our attention to Case (iii). We restrict our analysis to the impact of eliminating information asymmetry pertaining the MC on the social surplus. While it is important to examine the reaction of the equilibrium search intensity, consumer surplus and seller profit to the elimination of the information asymmetry, such analysis turns out to be extremely difficult. Recalling a negative linear relationship between $\overline{s}_k$ and c_k in Corollary 3 and denoting by c_L the highest production cost that is lower than $\sum_{k=1}^{K} f_k c_k$, we report our result in the following proposition.

Proposition 5. *Suppose that $\overline{s}_k < s \leq \overline{s}$ for some $\overline{s}_k < \sum_{k=1}^{K} f_k s_k$. The total surplus is lower when consumers observe the MC than when they do not if $s > \overline{s}_k$ for all $\overline{s}_k < \sum_{k=1}^{K} f_k s_k$ and $s \leq \sum_{k=L}^{K} f_k (v - c_K)/2 \sum_{k=L+1}^{K} f_k$.*

To understand the reasoning, we first establish that $q_c(c_k) \lesseqqgtr q_2$ for $c_k \gtreqqless \sum_{k=1}^{K} f_k c_k$. This indicates that the search intensity when buyers observe the MC is above (lower than) that when they do not, if the production cost is below (higher than) its expected value. To establish that, we rewrite equations (2) and (4) as

$$\int_0^1 \frac{(1-q_2)(1-2x)}{1-q_2+2q_2 x} dx = \frac{s}{\sum_{k=1}^{K} f_k(v-c_k)}, \qquad \int_0^1 \frac{(1-q_2(c_k))(1-2x)}{1-q_2(c_k)+2q_2(c_k)x} dx = \frac{s}{v-c_k}.$$

The LHSs of the equations represent the normalized added benefit of searching the second firm, whereas the RHSs stand for the corresponding normalized costs. Notice that when consumers observe the production cost, the normalized cost of searching the second firm is decreasing in c_k. Also in a stable equilibrium, the normalized added benefit of searching the second firm decreases with the search intensity $q_2(c_k)$. Consequently, it follows that $q_2(c_k)$ is decreasing in c_k and the comparison of the above two equations implies that $q_c(c_k) \lesseqqgtr q_2$ for $c_k \gtreqqless \sum_{k=1}^{K} f_k c_k$.

On the basis of that result, we will now derive the sufficient conditions which cause the result of the proposition. The social surplus with the information asymmetry is higher than without it if $\sum_{k=1}^{K} f_k(v - c_k - (1+q_2)s) > \sum_{k=1}^{L-1} f_k(v - c_k - (1+q_2(c_k))s)$. We can simplify the inequality as

$$\sum_{k=L+1}^{K} f_k(v - c_k - (1+q_2)s) > \sum_{k=1}^{L} f_k(q_2 - q_2(c_k))s.$$

The inequality certainly holds if its LHS is positive and RHS is negative. The LHS of the inequality is positive for certain if $\sum_{k=L}^{K} f_k(v - c_K - 2s) \geq 0$. The RHS of the inequality is certainly negative if $q_2 < q_2(c_k)$ for all $1 \leq k \leq L$. The discussion in the previous paragraph implies that this is definitely the case if $s > \overline{s}_L$. However, the last inequality means that $s > \overline{s}_k$ for all $\overline{s}_k < \sum_{k=1}^{K} f_k s_k$.

5 Extensions

With this section we show that our main result in Proposition 2—consumers being harmed by transparency on the production cost—is robust to different model extensions. In the next two subsections, we allow sellers to publicly reveal the production cost and consumers to observe or ignore it. In Subsection 5.3 we assume that the distribution of the MC is continuously increasing in its compact support. Subsection 5.4 incorporates search cost heterogeneity into the main model. Finally, Subsection 5.5 considers *noisy search*, wherein a searching consumer obtains prices of unknown number of sellers.

We relegate extensive analysis of the final two subsections to the online appendix in order to avoid repetition. In our analysis we do not establish the uniqueness of a stable equilibrium akin to that in Proposition 1, but we focus on such an equilibrium.

5.1 Information Disclosure

As Proposition 2 implies that sellers are better-off when buyers observe the production cost, it is important to analyze sellers' incentive to reveal the MC. The next proposition shows that sellers will disclose their cost if doing so is not (very) costly.

Proposition 6. *Suppose that $s \leq \overline{s}_K$ and information disclosure is not costly, and consider stable equilibria. If buyers do not observe the MC, seller have an incentive to disclose it.*

The reasoning is fairly simple. It is clear that sellers choose to disclose the production cost if they can commit to do so *before* the realization of the MC. If, however, sellers cannot make such commitment, we can employ the following algorithm, in spirit of Grossman and Hart (1980), to show "full unraveling." Consider a case where the MC obtains its highest value. If this information is not disclosed to buyers, their search intensity is given by q_2 as in Proposition 1. If sellers inform buyers about the production cost, we know that buyers search less intensely than q_2. In particular, the new search intensity will discontinuously decrease from q_2, leading to a discontinuous increase of the sellers' market power. Then, if revealing the MC to buyers is not costly (or in this case of discrete distribution of the production cost, not very costly), these sellers choose to do so. Consider next a case where the MC obtains its second highest value. Just like in the previous case, sellers have incentive to disclose this information to mitigate search. We can continue the argument in a similar manner to see that sellers have incentive to disclose information for all but the lowest value-realization of the MC. In equilibrium buyers correctly conjecture that if there is no information disclosure, the MC must have obtained its lowest value.

5.2 Incentive to Observe the MC

Whereas Proposition 6 informs us that information about the production cost is likely to be provided to buyers by sellers, Proposition 2 seems to suggest that buyers may have an incentive to ignore such information. However, we demonstrate that in equilibrium it cannot be the case that some buyers choose not to observe the production cost.

Proposition 7. *Suppose that $s \leq \overline{s}_K$ and the MC can be freely observed, and consider stable equilibria. Then, all buyers choose to observe the MC.*

The reasoning is by contradiction. Suppose that some consumers observe the production cost. As we consider a stable equilibrium akin to that in Proposition 1, we can employ arguments similar to those in Lemma 1 to verify that $x(p|c_k)$ must be non-degenerate, while the share of consumers who observe one price and that of price-comparing consumers must be strictly positive. We know from Section 4 that the share of price-comparing consumers must be higher among consumers who do not observe the MC than that among consumers who observe the MC.

Next, consider an individual buyer who does not observe the production cost. Her equilibrium surplus is $v - \sum_{k=1}^{K} \int_0^1 p(x|c_k) x dx$. If the buyer deviates to observing the MC, she adjusts her search intensity to maximize her surplus. Specifically, she chooses to definitely search only one seller (two sellers) if the observed MC is lower (higher) than the expected MC, as the search intensity is decreasing in MC (recall the discussion in Section 4). Formally, if, with a slight abuse of notation, we let c_L be the highest MC that is below the expected MC, it must be that $\int_0^1 p(x|c_k)(1-2x)dx \lesseqgtr s$ for $k \gtreqless L$ so that searching more (less) intensely is beneficial for $c_k \leq (>) c_L$, while $L \geq 1$. As the deviating buyers' payoff is no less than $v - \sum_{k=1}^{L} f_k \left(2\int_0^1 p(x|c_k)xdx - s\right) - \sum_{k=L+1}^{K} f_k \int_0^1 p(x|c_k)dx$, the deviation is beneficial if

$$\sum_{k=1}^{L} f_k \left(\int_0^1 p(x|c_k)(1-2x)dx - s \right) > 0.$$

However, this is true as discusses above. Then, an individual buyer has incentive to deviate to observing the MC, which leads to a contradiction.

This behavior is reminiscent of free-riding behavior in a public-goods game. Consumers who do not observe the production cost create a positive externality by searching "very" intensely and triggering competition. An individual consumer has an incentive to exploit this externality by observing the production cost and, on average, searching less intensely.

5.3 Continuous Distribution of MC

In this subsection we extend the discrete distribution of the MC to a continuous distribution. We assume that F has no mass points or gaps in its compact support $[\underline{c}, \overline{c}]$ where $0 \leq \underline{c} < \overline{c} < v$. The rest of the model remains unchanged.

For equilibrium analysis we can employ the same line of argument as in Section 3. Correspondingly, we can also employ the same techniques to prove the welfare result. The only inconsequential difference we need to take care of is a replacement of a summation sign with a corresponding integral sign whenever we wish to take an expectation with respect to the MC. As a result, all our results in the main model follow: a stable equilibrium exists for small search costs both when consumers observe the MC and when they do not, and the elimination of information asymmetry on the MC harms consumers.

5.4 Search Cost Heterogeneity

In this subsection we address consumer heterogeneity by introducing a small share of consumers that exogenously compare multiple prices. Empirical papers suggest that consumers may differ in their search costs (e.g., Hong and Shum, 2006; De los Santos et al., 2012). Moreover, as in the German mortgage market, consumers can delegate search to a middleman who receives fixed fee, independent of the credit amount, so that the middleman's main aim is to find a deal that the consumer will accept. In this case, we can think of middlemen as consumers with very low search costs. To account for such heterogeneity in search costs, we assume that a positive share of consumers observes all prices at zero search cost and buys at the lowest of the observed price as in traditional models of Varian (1980) and Stahl (1989).

In the online appendix, we prove the existence of stable equilibria where consumers with positive search costs randomize between searching one firm and searching two firms. We also show that informing consumers about the production cost reduces their surplus.

5.5 Noisy Search

In this final subsection, we consider a search protocol known as *noisy search* (Wilde, 1977). There are N different search technologies: $1, 2, ..., N$. Search technology n entails cost of $n \times s$ and reveals prices of at least n sellers. Noisy search can be used to describe search behavior of a procurement agency. An agency, which solicits bidders through various platforms (e.g., a newspaper, an online platform such as Linkedin), does not know how many bidders it can attract through each platform. But the more platforms the agency employs to announce an auction, the more bidders it will solicit.

In the online appendix, we demonstrate that qualitatively our key result generalizes to a setting with noisy search. We establish the existence of stable equilibria similar to those in Proposition 1 and Corollary 2. Furthermore, we show that elimination of information asymmetry on the MC harms buyers by deterring search and softening competition.

6 Applications

In this section we discuss a few empirical applications of our model.

6.1 Reference Prices in Public Procurement

Evidence by Bucciol et al. (2020) on the introduction of reference prices in public procurement of medical devices in Italy supports our main mechanism. In Italy, a public hospital wishing to purchase medical devices invites sellers to participate in a tender. Each seller is required to submit a description of its product and a price. If medical devices are homogeneous, the tender is awarded to the seller with the lowest price. In this setting we can regard a hospital's investment in advertising a tender as its search intensity, with higher investment in advertising implying higher search intensity.

Between July 1st, 2012 and May 2nd, 2013, the Italian authorities adopted a policy wherein they would set reference prices for fairly homogeneous medical devices, such as needles and syringes. The aim of the policy was two-fold: to homogenize prices paid by different hospitals for the same medical device and to reduce the average price paid. As a result, a reference price was set equal to 25th percentile of the prices paid for similar products before the adoption of the policy. If all sellers participating in a tender submitted prices higher than a reference price, a new auction was held where the reference price would be disregarded.

Bucciol et al. (2020) report that the dispersion of prices paid shrank during the time period when references prices were in place. This supports our prediction that informing buyers about marginal production costs reduces price dispersion. We can think of a reference price as informative about sellers' MC, because the reference price was calculated on the basis of previous winning bids.[8]

The authors also show that the introduction of reference prices did not affect the average price paid. This observation, which seems inconsistent with the prediction of our model, can be explained as follows. The Italian authorities regarded a reference price as a *partially-binding* price cap. The reason is that sellers were incentivized to submit prices lower than a reference price, as otherwise a new round of auction would take place. A new auction round would entail costs. First, it would delay potential sales. Second, preparing another round of bidding may involve costly calculation of a new optimal price based on information acquired in the first auction round, e.g., prices of rivals are higher than the reference price. Thus, sellers had an incentive to avoid such costs by submitting low prices, especially those who aimed to bid a price slightly higher than the reference price in the first auction round. This can explain why the average price did not rise when reference prices were in place.

6.2 Benchmarks

Our model provides a novel explanation of the creation of a so-called *benchmark* in a decentralized market. A benchmark aggregates past transaction prices within a given market and publishes them for the market participants. Duffie et al. (2017) view information available on a benchmark as a tool to eliminate information asymmetry on the MC.

It is useful to note some important features of markets where benchmarks were created by market participants. Benchmarks are prevalent in over-the-counter markets for financial products. In these markets, benchmarks were initiated by market participants. For instance, LIBOR was established by its member banks to introduce transparency

[8] Although prices paid for the same device may not fully reflect all prices submitted, paid prices serve as a good approximation of submitted ones.

into an otherwise opaque over-the-counter market for financial products. Importantly, in over-the-counter markets, there is no permanent assignment of market participants into buyers or sellers: a seller today is typically a buyer tomorrow.

Recall that in equilibrium, sellers and individual buyers choose to reveal and observe the MC, respectively. Therefore, it is safe to say that every market participant has an incentive to support creation of a benchmark in the over-the-counter markets.

6.3 Information Sharing in Vertical Markets

Our model provides a novel explanation for information sharing among vertically related sellers. In many industries—such as electronics, medicines, groceries—large retailers have an informational advantage regarding consumer demand over smaller upstream sellers, e.g., manufacturers. Retailers typically have the resources to gather and analyze consumer data. In contrast, upstream sellers have limited opportunities to learn of consumer demand, which leads to information asymmetry. Another feature of these markets is that upstream sellers search for deals from retailers. A good example of such markets is a food supply chain in the EU countries. Numerous small farmers search for deals from few large grocery stores or food-processing companies, which are better informed about consumer demand than farmers (e.g., European Commission (2019)).

As consumer demand is an indicator of the retail market's profitability, it is also indicative of offers that upstream sellers are likely to receive from downstream sellers. Thus, upstream sellers and retailers are respectively what we call buyers and sellers in our model, with consumer demand being represented by what we call the sellers' MC.

Our main results are in line with the evidence indicating that more and more retailers in the USA share their sales forecasts with suppliers (Chain Store Age, 2003). The mechanism—that such information sharing mitigates suppliers incentive to search for and switch retailers—provides a complementary explanation to the ones in the existing literature as for why this happens (e.g., Guo, 2009).

7 Related Literature

In this section we expatiate on why our main result—the elimination of information asymmetry on the MC harming buyers—is opposite to that in the existing theoretical literature on consumer search.[9] As we mentioned earlier, most of the existing studies employ sequential search models (Dana, 1994; Janssen et al., 2011; Duffie et al., 2017). In these models a buyer updates her belief about the production cost every time after observing a new price, as equilibrium prices are informative of the production costs, and then decides whether to buy at the lowest observed price or to search one more seller. The studies show that sellers can deter search and, hence, soften competition by partially inducing buyers into believing that the production cost is high through high prices, even if the production cost is in fact low. In our model of simultaneous search, sellers cannot employ the same method of deterring search as the search essentially terminates before buyers observe the search outcome (and after search requests are made).

Another group of studies employing sequential search focus on vertical markets, where sellers' buy their inputs from manufacturers and, hence, manufacturers' prices determine sellers' MC. Janssen and Shelegia (2015) introduce a monopolist manufacturer to a sequential search model of Dana (1994). Buyers do not observe the contracts between the manufacturer and sellers, i.e., they do not know sellers' production cost. However, in equilibrium buyers have correct beliefs about the wholesale price. Janssen and Shelegia (2015) show that if buyers have arbitrarily small search costs (i.e., when they vanish in the limit) and blame sellers for any deviation from equilibrium retail prices, the manufacturer sets a wholesale price that is higher than the standard monopoly price. Garcia et al. (2017) extend the model by assuming that there are multiple manufactures and sellers, just like buyers, need need to uncover wholesale prices though cost search. Janssen (2020) allows a manufacturer to employ two-part tariffs. Janssen and Reshidi (2023) permit a manufacturer to charge different price to different sellers.

There is a group of studies which suggest that full elimination of information asymmetry on the production cost is better for buyers than its partial elimination, e.g., via informative signals.[10] Tappata (2009) considers a dynamic model of simultaneous search,

[9] The only exception is Janssen et al. (2017) which employ *numerical simulations* to show that resolving information asymmetry on the MC may harm buyers.

[10] Associating the elimination of information asymmetry on MC with more information for buyers, our

where in every period buyers choose their search intensities and purchase decisions. The dynamic element of the model creates a sequential feature of the search. This sequential feature of the model is important, as the industry MCs are correlated across periods and, therefore, buyers condition their current search decisions on past realizations of the production cost and prices. The author demonstrates that prices rise fast as the production cost increases, but fall slowly as the cost decreases—a phenomenon known as *rockets-and-feathers*. However, the downward price adjustment would have been as fast as upward price adjustment if buyers observed the production costs. Yang and Ye (2008) studies a variation of this model where buyers do not observe the past realizations of the production cost. Fishman and Levy (2015) allow for heterogeneity of MCs across sellers.

Also a large body of literature exists on information exchange about production costs among sellers. The closest paper to ours is by Sobolev (2017). In a search market, each seller's MC is an independent random draw. As a seller observes its own production cost and not those of competitors, there is no sharp information asymmetry between sellers and buyers, as we have it in our paper. The author shows that sellers may raise their profits by submitting their production costs to a benchmark that publishes the average of the submitted costs, which is not necessarily observed by buyers. The main driver of this result is a partial resolution of uncertainty on the production costs among sellers.

8 Conclusion

In addition to providing a new insight into the role of information asymmetry—information asymmetry benefiting the side with an informational disadvantage—we believe the paper will initiate research on information asymmetry in simultaneous search markets. Several extensions of our study look promising.

First, it is natural to extend the current work to a setting where production costs across sellers differ, as in real-world markets they are likely to have different production

paper is distantly related to literature on information design. In a standard principal-agent setting (e.g., a principal representing a buyer and an agent, a seller), an agent may have an incentive not to learn the realization of a payoff relevant state (Kessler, 1998). In a market with bilateral trade, the signal structure that maximizes a buyer's payoff may be only partially informative (Roesler and Szentes, 2017). In a similar market but with multiple agents, it may be optimal for agents to ignore informative signals with positive probability (Taneva and Wiseman, 2023).

technologies. One way to model this is to assume that each seller's MC consists of a common industry-wide component and an idiosyncratic shock. Examining this extension is far from trivial. For any given search intensity, sellers are likely to play a pure strategy pricing as in MacMinn (1980). Then, the equilibrium prices, along with consumers' search intensity, are determined by the distribution of the production costs. Analysis of this relationship may require the development of new theoretical tools.

Another natural extension involves introduction of horizontal product differentiation across sellers (as in e.g., Perloff and Salop, 1985; Moraga-Gonzalez et al., 2021). In such markets, buyers have an incentive to compare different deals based on not only prices but also match values. Hence, buyers' search intensity is determined by the distribution of the production costs, which affects prices, and that of match values. Anderson et al. (1992) provide conditions under which all buyers search the same (multiple) number of sellers in equilibrium, if they observe the MC. Moreover, small changes in the production cost is likely to have no effect on search intensity. These observations suggests that analysis of a horizontally-differentiated products market may require conceptually different approach from ours.

In search markets exist information asymmetry not only regarding the production cost but also product availability: buyers may not know which sellers offer the desired product (e.g., Atayev, 2022). For instance, a buyer applying for a mortgage credit does not know whether a bank will approve her application and make an offer. In contrast, sellers may have a good idea about products of their rivals and whether they are currently capacity constrained. Evidence suggests that companies invest in obtaining information about their rivals (e.g., Billand et al., 2010; Gilad, 2015). It is then important to understand the role of information asymmetry concerning product availability.

A Proofs

A.1 Proof of Proposition 1

To show the existence, we rewrite equation (2) by using $p(x|c_k)$ as

$$\sum_{k=1}^{K} f_k \int_0^1 \left(\frac{(1-q_2)(v-c_k)}{1-q_2+2q_2x} + c_k \right) (1-2x)dx = s,$$

or since $\int_0^1 (1-2x)c_k = 0$, as

$$\sum_{k=1}^{K} f_k(v-c_k) \int_0^1 \frac{(1-2x)(1-q_2)}{1-q_2+2q_2x} dx = s. \tag{A.1}$$

It then suffices to show the following facts: (i) that the LHS of (A.1) is positive and below $\sum_{k=1}^{K} f_k(v-c_k)/4$ for any $0 < q_2 < 1$, (ii) is strictly concave in $q_2 \in (0,1)$, (iii) converges to zero both as $q_2 \downarrow 0$ and as $q_2 \uparrow 1$, and (iv) searching one firm yields a positive payoff.

(i) The LHS of (A.1) is indeed positive as

$$\begin{aligned}
\int_0^1 \frac{(1-2x)(1-q_2)}{1-q_2+2q_2x} dx &= \int_0^{1/2} \frac{(1-2x)(1-q_2)}{1-q_2+2q_2x} dx - \int_{1/2}^1 \frac{(1-2x)(1-q_2)}{1-q_2+2q_2x} dx \\
&\geq \int_0^{1/2} (1-2x)(1-q_2)dx - \int_{1/2}^1 (2x-1)(1-q_2)dx \\
&= (1-q_2) \int_0^1 (1-2x)dx = 0.
\end{aligned}$$

The LHS is indeed below $\sum_{k=1}^{K} f_k(v-c_k)/4$ as

$$\begin{aligned}
\int_0^1 \frac{(1-2x)(1-q_2)}{1-q_2+2q_2x} dx &= \int_0^{1/2} \frac{(1-2x)(1-q_2)}{1-q_2+2q_2x} dx - \int_{1/2}^1 \frac{(1-2x)(1-q_2)}{1-q_2+2q_2x} dx \\
&\leq \int_0^{1/2} (1-2x)dx - \int_{1/2}^1 \frac{(2x-1)(1-q_2)}{1+q_2} dx \\
&= \frac{1}{4} - \frac{1-q_2}{4(1+q_2)} \leq \frac{1}{4}.
\end{aligned}$$

(ii) To establish concavity of the LHS of (A.1) in $q_2 \in (0,1)$, we differentiate $(1-q_2)/(1-q_2+2q_2x)$ twice w.r.t. q_2 to obtain $-4x(1-2x)/(1-q_2+2q_2x)^3$. Then, the double derivative of the LHS of (A.1) w.r.t. q_2 is

$$-\sum_{k=1}^{K} f_k (v - c_k) \int_0^1 \frac{4x(1-2x)^2}{(1-q_2+2q_2x)^3} dx,$$

which is strictly negative as the integrand is positive for any $0 < q_2 < 1$. This shows that the LHS of (A.1) is indeed concave in $q_2 \in (0, 1)$.

(iii) We first rewrite the integral on the LHS of (A.1) as

$$\int_0^{1/2} \frac{(1-2x)(1-q_2)}{1-q_2+2q_2x} dx - \int_{1/2}^1 \frac{(2x-1)(1-q_2)}{1-q_2+2q_2x} dx.$$

As integrands of the both terms are positive real-valued decreasing functions of q_2 for their corresponding values of x and bounded below by zero, we employ the monotone convergence theorem to evaluate the limits. Namely as

$$\begin{aligned} \lim_{q_2 \downarrow 0} \int_0^{1/2} \frac{(1-q_2)}{1-q_2+2q_2x}(1-2x)dx &= \int_0^{1/2} \lim_{q_2 \downarrow 0} \frac{(1-q_2)}{1-q_2+2q_2x}(1-2x)dx = \frac{1}{4}, \\ \lim_{q_2 \downarrow 0} \int_{1/2}^1 \frac{(1-q_2)}{1-q_2+2q_2x}(2x-1)dx &= \int_{1/2}^1 \lim_{q_2 \downarrow 0} \frac{(1-q_2)}{1-q_2+2q_2x}(2x-1)dx = \frac{1}{4}, \end{aligned}$$

the LHS of (A.1) indeed converges to zero as $q_2 \downarrow 0$; and as

$$\begin{aligned} \lim_{q_2 \uparrow 1} \int_0^{1/2} \frac{(1-q_2)}{1-q_2+2q_2x}(1-2x)dx &= \int_0^{1/2} \lim_{q_2 \uparrow 1} \frac{(1-q_2)}{1-q_2+2q_2x}(1-2x)dx = 0, \\ \lim_{q_2 \uparrow 1} \int_{1/2}^1 \frac{(1-q_2)}{1-q_2+2q_2x}(2x-1)dx &= \int_{1/2}^1 \lim_{q_2 \uparrow 1} \frac{(1-q_2)}{1-q_2+2q_2x}(2x-1)dx = 0, \end{aligned}$$

the LHS of (A.1) indeed converges to zero as $q_2 \uparrow 1$.

(iv) Finally, a searching buyer obtains an expected payoff not lower than

$$\begin{aligned} &\int_0^1 \frac{1-q_2}{1-q_2+2q_2x} dx \sum_{k=1}^{K} f_k(v-c_k) - s \\ =& \int_0^1 2x \frac{1-q_2}{1-q_2+2q_2x} dx \sum_{k=1}^{K} f_k(v-c_k), \end{aligned}$$

where we obtained the equality by using (A.1). This payoff is clearly positive as the integrand is positive for any $0 < q_2 < 1$, proving that the consumer surplus with search is positive in an equilibrium.

From facts (i), (ii), (iii) and (iv) immediately follows the proof of the proposition.

A.2 Proof of Corollary 3

(i) We start the proof by noting that

$$\begin{aligned} \overline{s}_k &= \max_{q_2(c_k)} \left\{ \int_0^1 \frac{(v-c_k)(1-q_2(c_k))}{1-q_2(c_k)+2q_2(c_k)x}(1-2x)dx \right\} \\ &= (v-c_k) \max_{q_2(c_k)} \left\{ \int_0^1 \frac{1-q_2(c_k)}{1-q_2(c_k)+2q_2(c_k)x}(1-2x)dx \right\}. \end{aligned} \tag{A.2}$$

As the solution to the maximization problem is independent of c_k, it is trivial to see that $\overline{s}_k$ is decreasing in c_k.

(ii) Like in part (i), we start noting that

$$\begin{aligned} \overline{s} &= \max_{q_2} \left\{ \sum_{k=1}^{K} f_k \int_0^1 \frac{(1-q_2)(v-c_k)}{1-q_2+2q_2x}(1-2x)dx \right\} \\ &= \sum_{k=1}^{K} f_k(v-c_k) \max_{q_2} \left\{ \int_0^1 \frac{1-q_2}{1-q_2+2q_2x}(1-2x)dx \right\}. \end{aligned} \tag{A.3}$$

It is easy to see that the solution to the maximization problem is independent of c_ks. Also note that the solution to the maximization problem in (A.2) is the same as that to the maximization problem in (A.3). However, as there is a unique solution to the maximization problems, it follows that $\overline{s} = \sum_{k=1}^{K} f_k \overline{s}_k$. The proof is now complete.

A.3 Proof of Proposition 2

To prove (i) we will first show that $q_2(c_k)$ is decreasing and concave in c_k. Second, letting $\mathbb{E}[c] \equiv \sum_{k=1}^{K} f_k c_k$ and noting that $q(\mathbb{E}[c]) = q_2$, we will employ Jensen's inequality to demonstrate that show that $\mathbb{E}[q(c)] > q(\mathbb{E}[c]) = q_2$.

Letting

$$A := \int_0^1 \frac{(1-q_2(c_k))(1-2x)}{1-q_2(c_k)+2q_2(c_k)x}dx,$$

we observe that the equilibrium $q_2(c_k)$ solves $A(v-c_k) = s$. Next, noting that in equilibrium it must be that $d(v-c_k)A/dc_k = 0$, we obtain

$$\frac{dq_2(c_k)}{dc_k} = \frac{A}{(v-c_k)\dfrac{\partial A}{\partial q_2(c_k)}}, \tag{A.4}$$

which is negative as $\partial A/\partial q_2(c_k) < 0$ in a stable equilibrium. Differentiation of the both sides of the equation by c_k once again yields

$$\frac{d^2 q_2(c_k)}{dc_k^2} = \frac{\left(\dfrac{\partial A}{\partial q_2(c_k)}\right)^2 \dfrac{dq_2(c_k)}{dc_k}(v-c_k) - A\left(-\dfrac{\partial A}{\partial q_2(c_k)} + (v-c_k)\dfrac{\partial^2 A}{\partial q_2(c_k)^2}\dfrac{dq_2(c_k)}{dc_k}\right)}{\left[(v-c_k)\dfrac{\partial A}{\partial q_2(c_k)}\right]^2}. \tag{A.5}$$

This is negative if the numerator of the RHS is negative. Note that the first term in the numerator is negative, as $dq_2(c_k)/dc_k$ is negative. The expression in the large brackets of the second term in the numerator is positive as $\partial A/\partial q_2(c_k) < 0$ and $\partial^2 A/\partial q_2(c_k)^2 < 0$ which follows from proof of Proposition 1 that the expected benefit of searching the second seller is concave in the search intensity, $q_2(c_k)$. This means that the numerator is indeed negative, and therefore $d^2 q_2(c_k)/dc_k^2 < 0$ meaning that $q_2(c_k)$ is concave in c_k.

Concavity of $q_2(c_k)$ implies that $\mathbb{E}[q(c)] > q(\mathbb{E}[c])$. However, as $q(\mathbb{E}[c])$ is independent of actual realization of the MC and solves

$$\int_0^1 \frac{(1-q(\mathbb{E}[c]))(1-2x)}{1-q(\mathbb{E}[c])+2q(\mathbb{E}[c])x}dx(v-\mathbb{E}[c]) = s,$$

it must be that $q(\mathbb{E}[c]) = q_2$. It then follows that $\mathbb{E}[q(c)] < q(\mathbb{E}[c]) = q_2$, which completes the proof of the case where $\overline{s}_K < s$.

To prove (ii) we will show that the *ex-interim* equilibrium consumer surplus, when buyer observe the MC, is concave in c_k. We will then continue by demonstrating that the hypothetical consumer surplus for the MC equal to $\mathbb{E}[c]$ equal to that with the information asymmetry on the MC and greater than the *ex-ante* equilibrium consumer surplus without the information asymmetry.

If buyers observe the MC, their equilibrium (*ex-interim*) surplus is

$$\begin{aligned}
CS(c_k) &= v - \int_0^1 p(x|c_k)(1 - q_2(c_k) + q_2(c_k)2x)dx - q_2(c_k)s \\
&= v - \int_0^1 p(x|c_k)dx \\
&= (v - c_k)\int_0^1 \frac{2q_2(c_k)x}{1 - q_2(c_k) + 2q_2(c_k)x}dx \\
&= B(v - c_k),
\end{aligned}$$

where we used (4) to obtain the second equality, simple algebraic manipulations to obtain the third equality, and let $B := \int_0^1 \frac{2q_2(c_k)x}{1-q_2(c_k)+2q_2(c_k)x}dx$ to obtain the last equality. To show that this consumer surplus is concave in c_k we differentiate it twice w.r.t. c_k:

$$\begin{aligned}
\frac{d^2B(v-c_k)}{dc_k^2} &= \frac{d}{dc_k}\left(-B + \frac{\partial B}{\partial q_2(c_k)}(v - c_k)\frac{dq_2(c_k)}{dc_k}\right) = \frac{d}{dc_k}\left(-B + \frac{\partial B}{\partial q_2(c_k)} \times \frac{A}{\frac{\partial A}{\partial q_2(c_k)}}\right) \\
&= \frac{\partial}{\partial q_2(c_k)}\left(-B + \frac{\partial B}{\partial q_2(c_k)} \times \frac{A}{\frac{\partial A}{\partial q_2(c_k)}}\right)\frac{dq_2(c_k)}{dc_k} \\
&= \left(-\frac{\partial B}{\partial q_2(c_k)} + \frac{\left(\frac{\partial^2 B}{\partial q^2(c_k)}A + \frac{\partial B}{\partial q_2(c_k)}\frac{\partial A}{\partial q_2(c_k)}\right)\frac{\partial A}{\partial q_2(c_k)} - \frac{\partial B}{\partial q_2(c_k)}\frac{\partial^2 A}{\partial q^2(c_k)}A}{\left(\frac{\partial A}{\partial q_2(c_k)}\right)^2}\right)\frac{dq_2(c_k)}{dc_k} \\
&= A\frac{\frac{\partial^2 B}{\partial q^2(c_k)}\frac{\partial A}{\partial q_2(c_k)} - \frac{\partial B}{\partial q_2(c_k)}\frac{\partial^2 A}{\partial q^2(c_k)}}{\left(\frac{\partial A}{\partial q_2(c_k)}\right)^2} \times \frac{dq_2(c_k)}{dc_k}.
\end{aligned}$$

where we used (A.4) to obtain the second equality in the first line. Since $dq_2(c_k)/dc_k < 0$, this double derivative is negative if

$$\frac{\partial^2 B}{\partial q^2(c_k)}\frac{\partial A}{\partial q_2(c_k)} - \frac{\partial B}{\partial q_2(c_k)}\frac{\partial^2 A}{\partial q^2(c_k)} > 0. \tag{A.6}$$

As letting $C := 1 - q_2(c_k) + 2q_2(c_k)x$ so that

$$\begin{aligned}
\frac{\partial A}{\partial q_2(c_k)} &= -\int_0^1 \frac{2x(1-2x)}{C^2}dx, \\
\frac{\partial^2 A}{\partial q_2(c_k)^2} &= -\int_0^1 \frac{4x(1-2x)^2}{C^3}dx, \\
\frac{\partial B}{\partial q_2(c_k)} &= \int_0^1 \frac{2x}{C^2}dx, \\
\frac{\partial^2 B}{\partial q_2(c_k)^2} &= \int_0^1 \frac{4x(1-2x)}{C^3}dx,
\end{aligned}$$

the inequality can be rewritten (after some algebraic manipulations) as

$$16\left(\int_0^1 \frac{x^2}{C^2}dx \int_0^1 \frac{x(1-2x)}{C^3}dx - \int_0^1 \frac{x}{C^2}dx \int_0^1 \frac{x^2(1-2x)}{C^3}dx\right) > 0.$$

We further rewrite the inequality by introducing $h := 2x/C \geq 0$ so that $1/C = (1 - q_2(c_k)h)/(1 - q_2(c_k))$:

$$\int_0^1 h^2 dx \int_0^1 h\left(\frac{1-h}{1-q_2(c_k)}\right)\frac{1-q_2(c_k)h}{1-q_2(c_k)}dx - \int_0^1 h\frac{1-q_2(c_k)h}{1-q_2(c_k)}dx \int_0^1 h^2\left(\frac{1-h}{1-q_2(c_k)}\right)dx > 0.$$

However, the inequality simplifies to

$$\int_0^1 h dx \int_0^1 h^3 dx - \left(\int_0^1 h^2 dx\right)^2 > 0.$$

This certainly holds, as rewriting it as

$$\int_0^1 \left(h^{\frac{1}{2}}\right)^2 dx \int_0^1 \left(h^{\frac{3}{2}}\right)^2 dx > \left(\int_0^1 h^{\frac{1}{2}} h^{\frac{3}{2}} dx\right)^2$$

we can see it to be true by Cauchy-Bounjakowsky-Schwarz inequality. This proves that (A.6) is true for any $0 < q_2(c_k) < 1$. This, in turn, means that the double derivative of $B(v - c_k)$ w.r.t. $q_2(c_k)$ is negative, namely that $B(v - c_k)$—the equilibrium (*ex-interim*) buyer surplus—is concave in c_k.

Concavity of the *ex-interim* equilibrium buyer surplus when they observe the MC means that

$$\sum_{k=1}^{K} f_k CS(c_k) = \sum_{k=1}^{K} f_k (v - c_k) \int_0^1 \frac{2q_2(c_k)x}{1 - q_2(c_k) + 2q_2(c_k)x} dx$$
$$< (v - \mathbb{E}[c]) \int_0^1 \frac{2q(\mathbb{E}[c])x}{1 - q(\mathbb{E}[c]) + 2q(\mathbb{E}[c])x} dx = CS(\mathbb{E}[c]).$$

However, we know that $q(\mathbb{E}[c]) = q_2$ and therefore $CS(\mathbb{E}[c])$ equals to the consumer surplus when buyers do not observe the MC. This completes the proof of part (ii).

To prove (iii) we first show that the equilibrium *ex-interim* profit, when buyers observe the MC, is increasing and convex in c_k. This implies that the corresponding equilibrium *ex-ante* profit is lower than the profit given the expected MC, which coincides with equilibrium *ex-ante* profit where buyers do not observe the MC.

Let $\pi(c_k)$ be the equilibrium profit when c_k is realized and buyers observe this realization, and so let $\Pi^O := \sum_{k=1}^{k} f_k \pi(c_k)$ be the expected equilibrium profit. We will show the following facts: $d\pi(c_k)/dc_k > 0$ and $d^2\pi(c_k)/dc_k^2 > 0$. As $\pi(c_k) = (1 - q_2(c_k))(v - c_k)$, we have that

$$\frac{d\pi(c_k)}{dc_k} = -(1 - q_2(c_k)) - (v - c_k)\frac{dq_2(c_k)}{dc_k} = -(1 - q_2(c_k)) - \frac{A}{\frac{\partial A}{\partial q_2(c_k)}},$$

which is positive if $(1 - q_2(c_k))\partial A/\partial q_2(c_k) + A > 0$ as $\partial A/\partial q_2(c_k) < 0$. Substituting the values of $dA/dq_2(c_k)$ and A and applying simple algebraic manipulations, we rewrite the inequality's LHS as $(1 - q_2(c_k)) \left(\int_0^1 (1 - 2x)/C dx - \int_0^1 2x(1 - 2x)/C^2 dx \right)$, which can be reduced to $(1 - q_2(c_k))^2 \int_0^1 (1 - 2x)^2/C^2 dx$ and this is clearly positive. This means that that the inequality holds, which in turn proves that $d\pi(c_k)/dc_k > 0$.

We next note that

$$\frac{d^2\pi(c_k)}{dc_k^2} = \frac{d}{dc_k}\left(-(1 - q_2(c_k)) - \frac{A}{\frac{\partial A}{\partial q_2(c_k)}} \right) = \frac{\partial}{\partial q_2(c_k)}\left(-(1 - q_2(c_k)) - \frac{A}{\frac{\partial A}{\partial q_2(c_k)}} \right)\frac{dq_2(c_k)}{dc_k}$$
$$= \left(1 - \frac{\left(\frac{\partial A}{\partial q_2(c_k)}\right)^2 - A\frac{\partial^2 A}{\partial q_2(c_k)^2}}{\left(\frac{\partial A}{\partial q_2(c_k)}\right)^2} \right)\frac{dq_2(c_k)}{dc_k} = \frac{A\frac{\partial^2 A}{\partial q_2(c_k)^2}}{\left(\frac{\partial A}{\partial q_2(c_k)}\right)^2} \times \frac{dq_2(c_k)}{dc_k},$$

which is positive as $\partial^2 A/\partial q_2(c_k)^2 < 0$ for $0 < q_2(c_k) < 1$, which follows from the proof of

Proposition 1. It is then indeed that $d^2\pi(c_k)/dc_k^2 > 0$, or $\pi(c_k)$ is convex in c_k.

Convexity of $\pi(c_k)$ w.r.t. c_k implies that for any non-degenerate f, it must be that $\sum_{k=1}^{K} f_k \pi(c_k) > \pi(\mathbb{E}[c])$, or

$$\sum_{k=1}^{K} f_k(1 - q_2(c_k)(c_k))(v - c_k) > (1 - q(\mathbb{E}[c]))(v - \mathbb{E}[c]).$$

However, we know that $q(\mathbb{E}[c]) = q_2$ and thus $\pi(\mathbb{E}[c]) = (1 - q(\mathbb{E}[c]))(v - \mathbb{E}[c]) = (1 - q_2)(v - \mathbb{E}[c])$, which is the *ex-ante* equilibrium industry profit when buyers do not observe the MC. This completes the proof of the proposition.

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ZEW – Leibniz Centre for European Economic Research

L 7,1 · 68161 Mannheim · Germany
Phone +49 621 1235-01
info@zew.de · zew.de