Monopoly, Competition and Information Acquisition

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Abstract

An incumbent monopolist is uncertain about its linear demand, but can acquire public information at a cost. We determine how an entry threat affects the firm's information acquisition. If returns to scale are constant and the state-contingent demands become more dispersed as output increases, then entry reduces information acquisition. If, however, either the incumbent or entrant has increasing returns; or if the state-contingent demands are nonlinear or fail increasing dispersion, then entry can increase information.

Finally, entry can hurt consumers. Although entry always increases output, it can decrease information. Consumers sometimes prefer a better informed monopoly to a duopoly.

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1 Introduction

A monopolist is uncertain about its demand but can acquire information at a cost. How does an entry threat affect its information acquisition? How are consumers affected if the firms are better informed? Can consumers prefer a monopoly to an oligopoly?

These questions are related to long-standing debates about how market structure affects investment and welfare. Intuitively, two forces determine how entry affects information acquisition. First, entry reduces the incumbent's profit. This compression of profit *tends* to reduce information acquisition–an argument which recalls Schumpeter's (1942, ch. VIII) assertion long ago that competition discourages innovation by reducing its rewards. Second, there is a strategic effect: acquiring more information changes the behavior of the entrant. Since the value of information is sometimes negative for duopolists, this strategic effect must sometimes reduce information acquisition.

We assume that firms produce identical goods and compete in quantities. The firms face a linear demand with parameters unknown to both. One firm, the incumbent, can acquire information in stage 1. In the monopoly benchmark, that firm is the only producer during stage 2. In the duopoly model, another firm considers entry in stage 2.

If returns to scale are constant and the state-contingent demands become more spread out as output increases–a condition we call *increasing dispersion*–then an entry threat reduces information acquisition (Proposition 1). If, however, either the entrant or the incumbent has increasing returns to scale; or if the demands fail increasing dispersion or are nonlinear, then entry can increase information acquisition.

Most oligopoly models of information with demand uncertainty assume that returns to scale are nonincreasing and that demand is linear with only the intercept being random (see Vives [1999, ch. 8] for a survey of this literature).[1] This demand specification automatically satisfies increasing dispersion. Our examples of information-increasing entry illustrate that this commonly used model obscures the effect of competition on information acquisition.

We also show that entry can hurt consumers. Although entry increases output, it can decrease information. For some preference specifications, consumers prefer a better informed monopolist to a duopoly.

We assume throughout that information is public: the entrant has the same information as the incumbent. We make three observations on this assumption. First, it might be defensible if the incumbent monopolist acquires information from market experience. In particular, suppose that the incumbent is a monopoly producer at stage 1 who uses the market outcome as a signal of future demand, and can vary how much it learns about demand by varying its output–in other words, it can *experiment*. If the stage-1 market outcome is observable by the entrant, then information is public.[2] Second, some industries share their

[1]Malueg and Tsutsui (1996) consider slope uncertainty.

[2]Aghion, Espinosa and Jullien (1993), Harrington (1995) and Mirman, Samuelson and Schlee (1994) study duopoly experimentation models with public information.

private information in public forums, such as trade publications (Vives, 1990: 409-11). Doyle and Snyder (1999) find that production-plan annoucements of U.S. automobile producers are consistent with the hypothesis that such annoucements convey information about common demand parameters. In such a case the public information assumption is natural. (In the U.S. auto industry, entry might result from lowering a trade barrier.) Although we assume that there is only one incumbent, our results are a first step toward understanding how entry affects information acquisition of oligopolists (when it must be conveyed publicly).[3] Third, one of our main messages is how increasing returns and the failure of increasing dispersion can lead to information-increasing entry. This message continues to hold when information is private, a point we return to in our concluding remarks.

Besides assuming linear demand and public information, our proofs use two other strong assumptions: firms choose outputs, rather than prices; and the uncertainty is about a common value (market demand), rather than a private value (such as a firm's idiosyncratic cost). Our results are largely unchanged if we relax these assumptions. This robustness contrasts with results on information sharing in oligopoly, which are sensitive to these assumptions (Vives, 1999: 252).

In related work, Alepuz and Urbano (1999) and Belleflamme and Bloch (2001) compare experimentation of a monopolist with duopolists in a two-period model with demand uncertainty and public information: firms can affect how much they learn from the period-1 market outcome by varying period-1 choices. Unlike our model, two firms acquire information in their duopoly models. In an experimentation model, the cost of information is just the period-1 profit lost from not maximizing period-1 profit. Since in general the profit lost depends on the number of firms in the market, the cost of information (as well as the benefit) varies with the market structure in their models; in our model, the cost of information is the same across market structures (only the benefit changes). Moreover, these two papers do not focus, as we do, on the total amount of information acquired, but on how much the firms "experiment"–measured as the difference between the period-1 equilibrium actions in a one-period vs. a two-period model.[4]

[3]Of course, if the incumbents are already tacitly colluding on price, output and investment in information, and they share demand information publicly, then our results apply directly. (We can also extend our conclusions to the case in which they collude on price and output, but not investment in information.) Interestingly, Doyle and Synder (1999) cannot reject the hypothesis that U.S. automobile producers behaved collusively in the years 1965-95.

[4]In other related work, Persico (2000) shows that bidders acquire more information about the value of an object in a first-price than in a second-price auction (when information is covertly acquired), and Hwang (1995) compares information acquistion of monopolists and oligopolists (when information is private). Many papers have analyzed information acquisition in oligopolies for a *given* market structure. Fried (1985), Gal-Or (1988), Hwang (1993), Creane (1995) and Patron (2001) are examples.

2 The Model

There are two firms: Firm I is the incumbent and E the potential entrant. Firm j's output cost function is $c_j(q) = qk_j + F_j$ for $q > 0$ with $c_j(0) = 0$ and $(k_j, F_j) \geq 0$ for $j = I, E$. If $F_j = 0$, then firm j has constant returns; otherwise it has increasing returns.[5] The inverse demand function is $p = g(q, \gamma)$, where p is the market price, q the industry output, and γ an unknown parameter. We assume that γ takes on one of $n \geq 2$ values, $\gamma_1, ..., \gamma_n$, and let $\rho_i^0 \in (0, 1)$ denote the common prior belief that $\gamma = \gamma_i$ for $i = 1, ..., n$. As we have mentioned, the information acquisition literature commonly assumes that demand is linear.

Assumption A1 (i) The inverse demand is linear: $g(q, \gamma) = \alpha - \beta q$ for all $q \geq 0$, where $\gamma = (\alpha, \beta)$, and γ takes one of $n \geq 2$ values, $\gamma_1, ..., \gamma_n$, with $\alpha_n \geq \alpha_{n-1} \geq ... \geq \alpha_1$ and no two elements of $\{\gamma_1, ..., \gamma_n\}$ are equal; (ii) $\alpha_1 > k_I$.

Part (ii) ensures that a monopolist with constant returns is always active.

In stage 1 the incumbent acquires information: it chooses one out of a set of real-valued signals indexed by a nonnegative real number x. The cost of information indexed by x is $C(x)$. A signal's distribution depends both on the demand state γ and x and we assume that it is given by a density (or alternatively, a discrete probability mass) function $z \mapsto f(z|\gamma; x)$, which we assume is continuous in x. After choosing x and observing the signal realization z, the incumbent revises beliefs about the state of demand according to Bayes's rule. We let $b_i(\cdot)$ denote the mapping that gives the posterior belief that $\gamma = \gamma_i$ for $i = 1, ..., n$:

$$b_i(z, x) = \frac{\rho_i^0 f(z|\gamma_i; x)}{\sum_j \rho_j^0 f(z|\gamma_j; x)}; \tag{1}$$

and we let $\rho^0 = (\rho_2^0, ..., \rho_n^0)$, $\rho = (\rho_2, ..., \rho_n)$ and $b(z, x) = (b_2(z, x), ..., b_n(z, x))$. From the stage-1 perspective, the posterior belief is random and we let $G(\cdot; x)$ denote the distribution of the posterior for information choice x:

$$G(\rho; x) = \int_{\{z|b(z,x)\leq\rho\}} dH(z, x),$$

where $H(\cdot, x)$ is the prior cumulative distribution function for the signal at each x.[6] We modify Blackwell's (1951) definition of 'more informative' to ensure that higher values of x are *strictly* more informative. Let $S_{n-1} = \{(y_2, ..., y_n) \in \mathbb{R}_+^{n-1} | \, y_2 + ... + y_n \leq 1\}$.

Definition 1 *Experiment x'* ***is strictly more informative than*** *x if and only if $\int \Psi(\rho)dG(\rho; x') > \int \Psi(\rho)dG(\rho; x)$ for every real-valued, continuous, convex function Ψ on S_{n-1} that is not affine on S_{n-1}.*

[5] Since we only use increasing returns for counter-examples, we model it in the simplest way, as a quasi-fixed cost.

[6] If the signal is continuous, then $H(z, x) = \int^z \sum_j \rho_j^0 f(\omega|\gamma_j; x)d\omega$; if the signal is discrete then $H(z, x) = \sum_{\omega\leq z} \left[\sum_j \rho_j^0 f(\omega|\gamma_j; x)\right]$.

In words: better information makes the expectation of any continuous, convex function of beliefs (that is not affine) rise. (In Blackwell's definition, the inequality is weak and the function Ψ need only be continuous and convex.)[7]

Consider the stage-2 problem for a monopolist. Let

$$\widehat{g}(q,\rho) = g(q,\gamma_1) + \sum_{i=2}^{n} \rho_i \left[g(q,\gamma_i) - g(q,\gamma_1)\right] \tag{2}$$

denote the mean inverse demand, and

$$\pi(q,\rho) = \widehat{g}(q,\rho)q - c_I(q).$$

The interim value function (that is, after updating beliefs) is

$$V_M(\rho) = \max_{q\geq 0} \pi(q,\rho).$$

The *ex ante* value function is $W_M(x) = \int V_M(\rho)dG(\rho;x)$. The monopolist's information choice is an element of

$$X_M^* \equiv \arg\max_{x\geq 0} \left\{W_M(x) - C(x)\right\}. \tag{3}$$

We impose the following assumption on the signals and the cost of information.

Assumption A2 (i) There is an interval $[0,\overline{x}]$ with $\overline{x} > 0$ such that (a) if $\overline{x} \geq x' > x \geq 0$, then x' is strictly more informative than x; (b) $C(x) > W_M(x)$ for all $x > \overline{x}$; (ii) $C(\cdot)$ is continuous and $W_M(0) \geq C(0)$.

Parts (ib) and (ii) together ensure that a monopolist's optimal choice for information exists and lies in $[0,\overline{x}]$. Note that $x = 0$ does not necessarily correspond to null information.

We do not specify how firms acquire information. Since the uncertainty is about demand, two interpretations are natural. One is market research. In this case x might be spending on research, with higher spending yielding more information. Another is learning from market experience. In this case, the incumbent is a monopoly producer at stage 1 and uses the market outcome as a signal of future demand. For example, x might be the stage-1 output and z the resulting price realization. This experimentation interpretation neatly rationalizes our assumption that the entrant cannot directly acquire information, since it is not yet in the market at stage 1; if the market outcome (x,z) is observable, then it also rationalizes our public information assumption. The following example illustrates how market experimentation fits into our framework and recalls a few facts from the literature.[8]

[7] Undoubtedly we could extend many of our results beyond Blackwell's definition to the monotone information orders that Athey and Levin (2000) and Persico (2000) use.

[8] Mirman, Samuelson and Urbano (1993), Treffler (1993), and Creane (1994) consider monopoly models of experimentation.

Example 1 *(Information from Market Experimentation) Here stage 1 is a production stage. The stage-1 inverse demand is $z = \alpha - \beta x + \varepsilon$, where x is output, z is the price and ε the realization of random variable. The firm chooses an output x and then observes the price realization z. The firm knows the distribution of ε, but not its realization, so that the price need not reveal the demand state (α, β) for sure. If the distribution of ε is given by a log-concave density function and $n = 2$, then higher output will give a more informative price signal under A1(i) with $\beta_2 < \beta_1$ (Mirman, Samuelson and Urbano, 1993, Lemma 2). The cost of information is the profit lost from producing an output that does not maximize stage-1 expected profit.*

3 The Effect of Entry on Information Acquisition

We consider only Perfect Bayesian equilibria: loosely, strategies are optimal given beliefs, and beliefs are consistent with Bayes's Rule whenever possible.[9] In stage 1, the incumbent chooses x and the signal z is realized. Both firms observe x and z and update beliefs. Let $(q_I^*(\rho), q_E^*(\rho))$ denote stage-2 equilibrium outputs at the common posterior, ρ. (The stage-2 Cournot game has a unique equilibrium under Assumption A1 and constant returns; otherwise we take a selection from the equilibrium correspondence.) The incumbent's interim value function is (the subscript "D" denotes duopoly)

$$V_D(\rho) \equiv \widehat{g}(q_I^*(\rho) + q_E^*(\rho), \rho) q_I^*(\rho) - c_I(q_I^*(\rho)), \tag{4}$$

and its *ex ante* value function is

$$W_D(x) = \int V_D(\rho) dG(\rho; x).$$

The incumbent's information choice in a PBE (Perfect Bayesian Equilibrium) is an element of

$$X_D^* \equiv \arg\max_{x \geq 0} \{W_D(x) - C(x)\}. \tag{5}$$

The only difference between the objective functions in (3) and (5) is stage-2 expected profit. If $W_M - W_D$ is strictly increasing, then the entry threat reduces information. In general (3) and (5) are not concave problems (Radner and Stiglitz, 1984)[10] so we cannot ensure that X_M^* and X_D^* are singletons even if $C(\cdot)$ is convex. We use the following partial order to compare sets of maximizers.

Definition 2 *For any two sets A and B of real numbers, A is **completely higher** than B ($A \geq_C B$) if $x \geq y$ for any $x \in A$, and $y \in B$.*

[9] Ours is a Bayesian game in which the types (demands) are perfectly correlated.

[10] Chade and Schlee (2002) consider the source of nonconcavities in the value of information in some detail; their Corollary 1 covers our model.

If A is completely higher than B, then the supremum of B cannot exceed the infimum of A.

Lemma 1 *Let A2 hold. If $W_M - W_D$ is strictly increasing on $[0, \overline{x}]$, then $X_M^* \geq_C X_D^*$.*[11]

Proof: Assume that $W_M - W_D$ is strictly increasing on $[0, \overline{x}]$. Let $x_M \in X_M^*$ and $x_D \in X_D^*$. By Assumption A2, both x_M and x_D lie in $[0, \overline{x}]$. Clearly we have

$$W_M(x_M) - C(x_M) \geq W_M(x_D) - C(x_D)$$

and

$$W_D(x_D) - C(x_D) \geq W_D(x_M) - C(x_M).$$

Rearranging these inequalities yields that $W_M(x_M) - W_D(x_M) \geq W_M(x_D) - W_D(x_D)$. Since $W_M - W_D$ is strictly increasing, $x_M \geq x_D$. ■

The following lemma confirms that entry decreases information acquisition if $V_M - V_D$ is strictly convex. Recall from Definition 1 that convexity of the interim value function is equivalent to a nonnegative value of information; intuitively, Lemma 2 says that an increase in the convexity of the interim value function raises the marginal value of information, and hence how much is acquired.

Lemma 2 *Let A2 hold. If $V_M - V_D$ is continuous and convex, but not affine, on S_{n-1}, then $X_M^* \geq_C X_D^*$.*

Proof: Since

$$W_M(x) - W_D(x) = \int (V_M(\rho) - V_D(\rho))\, dG(\rho; x),$$

the result follows immediately by Definition 1 and Lemma 1. ■

A monopolist of course always values information: its interim value function, V_M, is convex since it is the maximum over a collection of affine functions. But the value of information can be negative in a duopoly: V_D can be strictly concave.[12] If V_D is strictly concave, then the entry threat clearly reduces information acquisition by Lemma 2. One reason that we emphasize linear demands is that the value of information is at least nonnegative for duopolists (if both firms are active in stage 2 and have constant returns).[13]

3.1 Information-Reducing Entry

We say that the state-contingent demands satisfy *increasing dispersion (in q)* if for any $q \geq 0$ and any i and j in $\{1, ..., n\}$ we have "$g(q, \gamma_i) \geq g(q, \gamma_j)$ implies

[11] Although this result is standard (e.g. Milgrom and Shannon 1994, Theorem 4′), we include the simple proof for completeness.

[12] Mirman, Samuelson and Schlee (1994) give several examples.

[13] Mirman, Samuelson, and Schlee (1994: 376), Example 2.

that $\frac{\partial}{q}g(q,\gamma_i) \geq \frac{\partial}{q}g(q,\gamma_j)$." In words, the demands become more spread out as quantity increases. Figure 1(a) illustrates state-contingent demands which satisfy this condition, while Figure 1(b) illustrates demands which violate it.[14] Increasing dispersion implies that the states order the demands in the sense that $g(q,\gamma_i)$ increases with i for all $q \geq 0$; it also implies that a monopolist's one-shot optimal output rises whenever beliefs about demand undergo a first-order stochastic dominance improvement.[15]

To make the proof easier on the eye, define the following notation for the expected values of the demand parameters:

$$\begin{aligned}\widehat{\alpha}(\rho) &= \alpha_1 + \sum_{i=2}^{n} \rho_i(\alpha_i - \alpha_1), \qquad \widehat{\beta}(\rho) = \beta_1 + \sum_{i=2}^{n} \rho_i(\beta_i - \beta_1), \\ \widehat{\alpha}_0 &= \widehat{\alpha}(\rho^0), \qquad \widehat{\beta}_0 = \widehat{\beta}(\rho^0).\end{aligned}$$

Proposition 1 *If A1 and A2 hold, returns to scale are constant ($F_I = F_E = 0$) and the demands satisfy increasing dispersion, then $X_M^* \geq_C X_D^*$: the entry threat reduces information acquisition.*

Proof: Straightforward calculations yield that $V_M = (\widehat{\alpha} - k_I)^2/4\widehat{\beta}$. Since the stage-2 equilibrium is unique under A1 and constant returns, V_D is continuous. We want to show that $V_M - V_D$ is convex, but not affine, on S_{n-1}. It suffices to show that $V_M - V_D$ is convex on every line segment in S_{n-1} and strictly convex on some line segments.

Since A1(ii) ensures that at least one firm is active in stage 2, we have three cases to consider:

(i) $\alpha_1 + k_E - 2k_I \geq 0$ and $\alpha_1 + k_I - 2k_E \geq 0$ (neither firm shuts down during stage 2 except possibly at $\rho_1 = 1$);

(ii) $\alpha_1 + k_E - 2k_I < 0$ (the incumbent shuts down for ρ_1 close enough to 1); and

(iii) $\alpha_1 + k_I - 2k_E < 0$ (the entrant shuts down for ρ_1 close enough to 1).

For case (i), we have $V_D = (\widehat{\alpha} + k_E - 2k_I)^2/9\widehat{\beta}$. Hence

$$V_M - V_D = \frac{(\widehat{\alpha} - k_I)^2}{4\widehat{\beta}} - \frac{(\widehat{\alpha} + k_E - 2k_I)^2}{9\widehat{\beta}} \equiv (\widehat{\beta}^{-1})\phi(\widehat{\alpha}) > 0.$$

[14] Note that A1 says that demands are linear *for all* $q \geq 0$, so that price becomes negative for large enough output. This can happen, for example, if the firm must pay to dispose of any excess output. To illustrate what happens if we relax linearity to constrain prices to be nonnegative, consider Figure 1(a): if the lowest inverse demand equals zero to the right of its intersection with the horizontal axis, q_0, then the demands will get closer together for $q > q_0$ (and hence fail increasing dispersion). Rather than allow negative prices, we could require the unit costs to be high enough to insure that the stage-2 equilibrium price is positive with probability one.

[15] Assuming that $g(q,\gamma_i)$ increases with i for all q, belief ρ' first-order stochastically dominates ρ if $\sum_{i=1}^{k}\rho_i' \leq \sum_{i=1}^{k}\rho_i$ for all $k = 1,...,n$ with a strict inequality for some k. The comparative statics conclusion follows since, under increasing dispersion, the monopolist's objective function is supermodular in (i,q), where i indexes the demand state (e.g. Milgrom and Shannon [1994]).

Let ρ^* and ρ^{**} be distinct points in S_{n-1} and let Γ be the following real-valued function on $[0,1]:$

$$\Gamma(t)=\frac{\phi(\widehat{\alpha}(t\rho^{**}+(1-t)\rho^*))}{\widehat{\beta}(t\rho^{**}+(1-t)\rho^*)}.$$

We have

$$\Gamma'(t)=-(\beta^{**}-\beta^*)\widehat{\beta}^{-2}\phi(\widehat{\alpha})+(\alpha^{**}-\alpha^*)\phi'(\widehat{\alpha})\widehat{\beta}^{-1}, \tag{6}$$

and

$$\begin{aligned}\Gamma''(t)&=2\widehat{\beta}^{-3}\phi(\widehat{\alpha})(\beta^{**}-\beta^*)^2\\ &-2\widehat{\beta}^{-2}\phi'(\widehat{\alpha})(\alpha^{**}-\alpha^*)(\beta^{**}-\beta^*)+\widehat{\beta}^{-1}\phi''(\widehat{\alpha})(\alpha^{**}-\alpha^*)^2\end{aligned} \tag{7}$$

where $\alpha^{**}=\widehat{\alpha}(\rho^{**})$, $\alpha^*=\widehat{\alpha}(\rho^*)$, $\beta^{**}=\widehat{\beta}(\rho^{**})$, and $\beta^*=\widehat{\beta}(\rho^*)$.

Clearly, $\phi(\widehat{\alpha})>0$, which implies that $(\widehat{\alpha}-k_I)/4>(\widehat{\alpha}+k_E-2k_I)/9$. But then

$$\phi'(\widehat{\alpha})=2\left(\frac{(\widehat{\alpha}-k_I)}{4}-\frac{(\widehat{\alpha}+k_E-2k_I)}{9}\right)>0.$$

Also, $\phi''(\widehat{\alpha})=\frac{5}{18}>0$. Assumption A1 and increasing dispersion together imply that $(\alpha^{**}-\alpha^*)(\beta^{**}-\beta^*)\le 0$. Hence (7) is nonnegative and Γ is convex. Since ρ^* and ρ^{**} were arbitrary, V_M-V_D is convex. Moreover if ρ^{**} and ρ^* satisfy $\rho_i^{**}>\rho_i^*$ for $i=2,...,n$, then the corresponding Γ will be strictly convex, so that V_M-V_D is not affine on S_{n-1}. Thus $X_M^*\ge_C X_D^*$ by Lemma 2.

Now consider case (ii). Let $\alpha^c=k_E-2k_I>\alpha_1$, the critical value of the intercept at which the threatened incumbent just shuts down. Here

$$V_M(\rho)-V_D(\rho)=\begin{cases}V_M(\rho) & \text{on } \{\rho|\widehat{\alpha}(\rho)\le\alpha^c\}\\ \phi(\widehat{\alpha}(\rho))/\widehat{\beta}(\rho) & \text{on } \{\rho|\widehat{\alpha}(\rho)\ge\alpha^c\}.\end{cases}$$

Clearly, $V_M(\rho)-V_D(\rho)$ is convex on any line segment wholly contained within $\{\rho|\widehat{\alpha}(\rho)\le\alpha^c\}$ or within $\{\rho|\widehat{\alpha}(\rho)\ge\alpha^c\}$. Moreover, it is strictly convex on some line segments in $\{\rho|\widehat{\alpha}(\rho)\le\alpha^c\}$. Thus we are done if we show that it is convex on line segments which intersect both regions. Let ρ^{**} and ρ^* satisfy $\widehat{\alpha}(\rho^{**})<\alpha^c$ and $\widehat{\alpha}(\rho^*)>\alpha^c$ and let $\Lambda(t)=V_M(t\rho^{**}+(1-t)\rho^*)-V_D(t\rho^{**}+(1-t)\rho^*)$ for $0\le t\le 1$. We have

$$\Lambda'(t)=\frac{(\widehat{\alpha}-k_I)}{2\widehat{\beta}}(\alpha^{**}-\alpha^*)-\frac{(\widehat{\alpha}-k_I)^2}{4\widehat{\beta}^2}(\beta^{**}-\beta^*)$$

for all t satisfying $\widehat{\alpha}(t\rho^{**}+(1-t)\rho^*)<\alpha^c$ and $\Lambda'(t)=\Gamma'(t)$ (from equation (6)) for all t satisfying $\widehat{\alpha}(t\rho^{**}+(1-t)\rho^*)\ge\alpha^c$. Since $\phi(\widehat{\alpha})=(\widehat{\alpha}-k_I)^2/4$ and $\phi'(\widehat{\alpha})=(\widehat{\alpha}-k_I)/2$, we have that Γ is differentiable on $[0,1]$ and Γ' is increasing on $[0,1]$. Hence V_M-V_D is convex (but not affine) on S_{n-1} and the result follows from Lemma 2.

Finally consider case (iii) and let $\alpha^e = k_I - 2k_E > \alpha_1$, the critical value of the intercept at which the entrant just shuts down. We have

$$V_M - V_D = \begin{cases} 0 & \text{for } \widehat{\alpha}(\rho) \leq \alpha^e \\ (\widehat{\beta}^{-1})\phi(\widehat{\alpha}) & \text{for } \widehat{\alpha}(\rho) \geq \alpha^e \end{cases},$$

with $\phi(\alpha^e) = 0$. In this case, $V_M - V_D$ is convex on S_{n-1} (but not affine by the case-(i) argument), so that Lemma 2 again applies. ■

As an easy illustration of part (a), suppose that the firms have the same unit costs ($k_I = k_E$). In this case, $V_D(\rho) = \frac{4}{9}V_M(\rho)$ for all ρ and hence

$$W_D(x) = \frac{4}{9}W_M(x) \tag{8}$$

for all x: the threatened monopolist's profits are always a given fraction of the isolated monopolist's, so the entry threat always lowers the marginal value of information.

Remark 1 To clarify why entry makes the incumbent's interim value function less convex as a function of beliefs (and hence why entry lowers the marginal value of information) let $q_M^*(\rho)$ denote the isolated monopolist's output at belief ρ. Let $n = 2$. We have

$$V_M'' = \pi_{\rho\rho} + \pi_{q\rho}\frac{\partial q_M^*}{\partial \rho}.$$

This expression is of course nonnegative since the objective function is affine in beliefs, and the maximum over a collection of affine functions is convex. Since $\pi_{\rho\rho} = 0$, its magnitude is determined by the product of $\pi_{q\rho}$ and $\partial q_M^*/\partial\rho$ (which must be of the same sign). Since $\partial q_M^*/\partial\rho = -\pi_{q\rho}/\pi_{qq} = \pi_{q\rho}/2\widehat{\beta}(\rho)$, we have that $V_M'' = (\pi_{q\rho})^2/2\widehat{\beta}(\rho) = 2\widehat{\beta}(\rho)\partial q_M^*/\partial\rho$. Any change in the parameters $(\alpha_2, \alpha_1, k_I)$ that raises the value of $\pi_{q\rho}$ for all (q, ρ) will increase the sensitivity of output to beliefs and make information more valuable to the monopolist. If the monopolist is threatened with entry, then the stage-2 problem is a game, rather than a decision problem. If the entrant is active for all beliefs then $q_E^*(\rho) = (\widehat{\alpha}(\rho) + k_I - 2k_E)/3\widehat{\beta}(\rho)$ and hence

$$\begin{aligned} V_D(\rho) &= \max_{q_I \geq 0}\left\{\left(\widehat{\alpha}(\rho) - \widehat{\beta}(\rho)q_E^*(\rho) - \widehat{\beta}(\rho)q_I - k_I\right)q_I\right\} \\ &= \max_{q_I \geq 0}\left\{\left(\widehat{\alpha}(\rho) - \left(\frac{\widehat{\alpha}(\rho) + k_I - 2k_E}{3}\right) - \widehat{\beta}(\rho)q_I - k_I\right)q_I\right\}. \end{aligned} \tag{9}$$

Note that the linearity of demand implies that the incumbent's objective function is still affine in beliefs after the entrant's equilibrium choice $q_E^*(\rho)$ is substituted into it. Indeed from the incumbent's viewpoint, entry amounts to changing its demand intercept from $\widehat{\alpha}(\rho)$ to $2\widehat{\alpha}(\rho)/3 + (k_I - 2k_E)/3$, so that its *residual* demand is less variable after entry. Letting $\pi^D(q_I, \rho)$ denote the objective in (9), we can write

$$V_D'' = \pi_{\rho\rho}^D + \pi_{q\rho}^D \frac{\partial q_I^*}{\partial \rho}.$$

Since π^D is affine in ρ, the first term, $\pi_{\rho\rho}^D$, is again zero. But since entry makes the intercept of the incumbent's residual inverse demand less variable (while leaving the slope unchanged), the threatened incumbent's output vary less with ρ than the isolated monopolist's; hence information is less valuable with entry.

3.2 Information-Increasing Entry

We now show how relaxing the assumptions of Proposition 1 lead to information-increasing entry. As we noted in the introduction, the compression of the incumbent's profit from entry tends to reduce information acquisition (and of course must do so if entry drives the incumbent's profit to zero in all demand states). As a result a general theorem on information-increasing entry is hard to come by. We instead illustrate the role of the assumptions of Proposition 1 with examples. In each of the examples, we assume that there are two demand states ($n = 2$), so that $\rho = \rho_2$. We will use the following family of signal distributions, which we call *all-or-nothing information*. Under it, the marginal value of information is proportional to the expected value of perfect information; thus, if entry ever increases the expected value of perfect information for the incumbent, then it increases information acquisition.

Example 2 *(All-or-nothing information) Let $n = 2$. For $x > 1$, the demand parameter is learned for sure; for $x \in [0, 1]$, the firms learn the value of γ with probability x; with probability $1 - x$ they learn nothing. Thus for $x \in [0, 1]$, the firms learn that $\gamma = \gamma_1$ with probability $x(1 - \rho^0)$ and learn that $\gamma = \gamma_2$ with probability $x\rho^0$, so that*

$$\begin{aligned} W_\theta(x) &= x\rho^0 V_\theta(1) + x(1-\rho^0)V_\theta(0) + (1-x)V_\theta(\rho^0) \\ &= x\text{EVPI}_\theta + V_\theta(\rho^0), \end{aligned}$$

for $\theta \in \{M, D\}$, where $\text{EVPI}_\theta = V_\theta(1)\rho^0 + V_\theta(0)(1-\rho^0) - V_\theta(\rho^0)$, the expected value of perfect information. In this case the marginal value of information, $W_\theta'(x)$, equals EVPI_θ for $\theta \in \{M, D\}$.

We will also assume that the cost function for information, $C(\cdot)$, is differentiable and strictly convex, with $C'(0) = 0$. In this case, the objective functions in (3) and (5) are strictly concave in x under all-or-nothing information. It follows that entry increases information acquisition if $W_M - W_D$ is strictly decreasing on $[0, \overline{x}]$.

3.2.1 Incumbent increasing returns

Here we let $F_I > F_E = 0$. Using the calculations from Example 2, we have that

$$W_M(x) - W_D(x) = x\left[EVPI_M - EVPI_D\right] + V_M(\rho^0) - V_D(\rho^0). \qquad (10)$$

Set $k_I = k_E = 0$ and $\beta_2 = \beta_1 = 1$. If the isolated monopolist is always active but the threatened one is indifferent between shutting down and staying active at $(\alpha_2, \alpha_1, \rho^0, F_I)$, then

$$EVPI_M - EVPI_D = (V_M(1) - V_D(1))\,\rho^0 + V_M(0)(1-\rho^0) - V_M(\rho^0)$$
$$= \quad (\alpha_2)^2\left(\frac{1}{4} - \frac{1}{9}\right)\rho^0 + \frac{(\alpha_1)^2}{4}(1-\rho^0) - \frac{(\widehat{\alpha}_0)^2}{4} + \rho^0 F_I. \tag{11}$$

This expression is negative (and the threatened firm just shuts down at the prior) for the parameter values $\alpha_2 = 2$, $\alpha_1 = 1, \rho^0 = 1/10$ and $F_I = (11/10)^2/9$. In this case $EVPI_M -\ EVPI_D = -17/2000 < 0$ so that entry increases information acquisition.

Figure 2 illustrates this possibility. Suppose first that there is no quasi-fixed cost. The isolated monopolist's interim value function is convex and increasing in ρ. Its *EVPI,* which equals $V_M(1)\rho^0 + V_M(0)(1-\rho^0) - V_M(\rho^0)$, is the vertical distance *ab*. The threatened monopolist's interim value function is $o'de$ and by Proposition 1 its *EVPI* is less than *ab*.

Now suppose that the quasi-fixed cost F_I is positive and is such that the isolated monopolist is always active but the threatened monopolist is indifferent between shutting down and remaining active at ρ^0. We depict this change in Figure 2 by shifting the origin on the profit axis to o''. Since the isolated monopolist is always active, this change lowers $V_M(0), V_M(1)$, and $V_M(\rho^0)$ by the same amount, F_I, so $EVPI_M$ remains *ab*. But although $V_D(1)$ and $V_D(\rho^0)$ each fall by F_I, $V_D(0)$ falls by *less than* F_I, so that $EVPI_D$ rises with the addition of this quasi-fixed cost. In the figure, the $EVPI_D$ is *cd*, which exceeds *ab*, as in the numerical example.

As an alternative explanation in the spirit of Remark 1, note that the threatened incumbent's optimal output is discontinuous at the prior in the example: even a small amount of information (starting from null information) is very valuable, since the optimal action changes by a lot.[16]

3.2.2 Entrant increasing returns

Here we set $F_I = k_I = k_E = 0$ and set F_E so that the entrant is just indifferent between entering and shutting down at ρ^0. Assuming that the entrant enters at ρ^0, we have $EVPI_M -\ EVPI_D = (V_M(1) - V_D(1))\,\rho^0 + V_D(\rho^0) - V_M(\rho^0)$. Since $\lim_{\rho^0 \to 0} EVPI_M - EVPI_D < 0$, we have that $W_M - W_D$ is strictly decreasing on $[0, \overline{x}]$ for ρ^0 small enough.

Figure 3 illustrates the case of entrant increasing returns. It is drawn on the assumption that F_E is positive and set so that the entrant is just indifferent between entering or shutting down at ρ^0 : for $\rho < \rho^0$, the entrant stays out, for $\rho > \rho^0$, the entrant's output is bounded below by $\widehat{\alpha}(\rho^0)/3 > 0$. Since the incumbent is not indifferent about the entrant's choice at $\rho = \rho^0$, V_D is discontinuous there. If we suppose that the entrant always enters at ρ^0, then the probability

[16] The logic here is similar to that in Example 7 (Failure of Single-Valued Choice) in Chade and Schlee (2002: 440).

of entry is $1 - x(1-\rho^0)$, which decreases with the index of information, x. Thus a threatened incumbent might acquire more information than an isolated one to deter entry. In Figure 3 $EVPI_M$ is ab and $EVPI_D$ is cd.

3.2.3 Linear demands which violate increasing dispersion

Here we impose constant returns ($F_I = F_E = 0$) and relax the condition that $\beta_2 \leq \beta_1$ (while retaining A1). If the firms have the same unit costs, then equation (8) holds and entry lowers information acquisition whether the demands satisfy increasing dispersion or not. So the firms must have asymmetric costs if entry is to raise information acquisition. Let $\alpha_1\beta_2 = \alpha_2\beta_1$, with $\alpha_2 > \alpha_1$, and $k_E > k_I = 0$, with $\alpha_1 - 2k_E > 0$ (so that the entrant is active). The demands are depicted in Figure 1(b). Since the linear demands intersect the horizontal axis at the same output, q_1, the corresponding marginal revenue functions intersect the horizontal axis at the same point, $q_1/2$. Since $k_I = 0$, the isolated monopolist's output is the same under either demand state, so that information is useless and therefore valueless to it (i.e. V_M is affine in beliefs and the incumbent acquires no information). Since, however, the entrant's unit cost is positive, the entrant's output varies with the demand state, so that information is useful to the threatened monopolist ($q_I^* = (\widehat{\alpha} + k_E)/3\widehat{\beta}$ varies with beliefs and V_D is strictly convex).

3.2.4 Non-linear demands which satisfy increasing dispersion

We now identify a pair of state-contingent demands which satisfy increasing dispersion for which an entry threat under constant returns increases information acquisition. Let one of the demands be $g^2(q) = 2 - q$ for all $q \geq 0$ and let the other be $g^1(q) = 2 - q$ for $0 \leq q \leq 1$ and $g^1(q) = 3 - 2q$ for $q \geq 1$.[17] Set $k_I = k_E = F_I = F_E = 0$. Clearly, a monopolist optimally produces one unit of output in each state and so information is valueless to an isolated monopolist. A duopoly, however, must produce more than one unit of aggregate output, since each firm's expected marginal revenue is positive at the output profile $(1/2, 1/2)$. The interim duopoly value function is $V_D(\rho) = (3-\rho)^2/9(2-\rho)$, where ρ is the probability that the demand is g^2. It is easy to confirm that V_D is strictly convex, so that information is valuable for the threatened monopolist.

4 Welfare

We now show that entry can hurt consumers. Since expected profit is always higher under a monopoly, overall welfare will be higher with a monopoly.

We assume that the change in expected consumers' surplus represents consumer welfare in the sense that it equals the aggregate willingness-to-pay for a policy change. The change in expected consumer's surplus exactly equals a consumer's willingness to pay for a change if its indirect utility function is both

[17] The example can be modified so that both inverse demands are smooth.

affine in income and additively separable in income and any other variable that is random.[18] Whether the change in expected consumers' surplus exactly equals the willingness to pay therefore depends on the source of demand uncertainty. One possibility is preference uncertainty: each consumer's preferences depend upon the state of the world; the state is not known when firms choose outputs, but is resolved before consumers buy. We adopt this interpretation. Alternatively, each consumer could know its own preferences, but the price realization is unknown to each consumer (and to the firms) because preferences are private information. Finally, the demand could be initially unknown because the price of some other good is unknown when firms choose output. In each case, consumer welfare from different market structures must be evaluated *ex ante*, before demand is realized.

Ex post consumers' surplus is $\beta q^2/2$, where β is the true inverse demand slope and q is the industry output. The interim expected consumers' surplus for a monopoly (CS_M) and duopoly (CS_D) are

$$CS_M(\rho) = \frac{1}{8}\frac{(\widehat{\alpha}(\rho) - k_I)^2}{\widehat{\beta}(\rho)}$$

and

$$CS_D(\rho) = \frac{1}{18}\frac{(2\widehat{\alpha}(\rho) - k_I - k_E)^2}{\widehat{\beta}(\rho)},$$

where, as before, $\widehat{\alpha}$ and $\widehat{\beta}$ are the interim expected values.

The *ex ante* expected consumers' surplus under a monopoly and a duopoly are

$$E[CS_M(\rho)|x] = \int CS_M(\rho)dG(\rho;x)$$

and

$$E[CS_D(\rho)|x] = \int CS_D(\rho)dG(\rho;x).$$

Entry has two effects on *ex ante* expected consumers'surplus (under the conditions of Proposition 1). First, it raises output. This raises interim expected consumers' surplus for every posterior belief. Second, it reduces information acquisition. Better information makes output more variable, raising it when the high demand appears more likely–i.e. when high consumer valuations appear likely–but lowering it when low demand appears more likely. Under linear demands, *ex ante* expected consumers' surplus increases with better information. We now show that the second effect dominates the first if demand is uncertain enough.

Consider all-or-nothing information from Example 2 and set $k_I = k_E = 0$ and $\beta_2 = \beta_1 = 1$. *Ex ante* expected consumers' surplus is

[18] Schlee (2002) shows that expected consumers' surplus is generally a poor approximation to the willingness to pay for a change when these conditions fail. Here, however, we are merely arguing that consumers sometimes prefer a monopoly to a duopoly, not that they generally do.

$$E[CS_i(\rho)|x] = \\ x\left[CS_i(1)\rho^0 + CS_i(0)(1-\rho^0) - CS_i(\rho^0)\right] + CS_i(\rho^0) \tag{12}$$

for $i \in \{M, D\}$. Defining

$$\sigma_\alpha^2 = \rho^0\alpha_2^2 + (1-\rho^0)\alpha_1^2 - [\widehat{\alpha}_0]^2, \tag{13}$$

equation (12) becomes

$$E[CS_M(\rho)|x] = \frac{\sigma_\alpha^2}{8}x + \frac{[\widehat{\alpha}_0]^2}{8} \tag{14}$$

for a monopoly, and

$$E[CS_D(\rho)|x] = \frac{2\sigma_\alpha^2}{9}x + \frac{2[\widehat{\alpha}_0]^2}{9} \tag{15}$$

for a duopoly. Note that both of these expressions are increasing in x.

Let the information cost function be $C(x) = \frac{1}{2}x^2$. Using the calculations from Example 2, the incumbent's information choice is

$$x_M = EVPI_M = \frac{\sigma_\alpha^2}{4} \tag{16}$$

without entry, and

$$x_D = EVPI_D = \frac{\sigma_\alpha^2}{9} \tag{17}$$

with entry (assuming that $\sigma_\alpha^2 \leq 4$). Substituting (16) into (14) and (17) into (15) yields

$$E[CS_M(\rho)|x_M] - E[CS_D(\rho)|x_D] = \\ \left(\sigma_\alpha^2\right)^2\left(\frac{1}{32} - \frac{2}{81}\right) + [\widehat{\alpha}_0]^2\left(\frac{1}{8} - \frac{2}{9}\right). \tag{18}$$

If we raise α_2 and lower α_1 while preserving the mean of α under the prior, then σ_α^2 in (13) increases. Indeed, if the (prior) variance of α is high enough relative to the mean, then (18) is positive. Intuitively, the loss of expected consumers' surplus from the output effect just depends on the mean intercept; but the information effect depends on the variance of the intercept. Although we constructed this example using all-or-nothing information, it is clear that the principle is far more general: if $k_I = k_E = 0$ and $\beta_1 = \beta_2$, then increasing the prior variance of α, while preserving the mean of α, will increase information acquisition more for the isolated than for the threatened monopolist (since $W_M - W_D = 5\int \widehat{\alpha}(\rho)^2 dG(\rho;x)/36$ in this case), and hence increase $E[CS_M(\rho)|x_M] - E[CS_D(\rho)|x_D]$.[19]

[19] The quasilinear utility assumption that justifies expected consumers' surplus implies that consumers are risk neutral for income gambles. If consumers are sufficiently risk averse (with the same demands), then they may prefer a duopoly to a monopoly in the example just worked out, since better information increases output uncertainty. It turns out that risk averse consumers may prefer a monopoly for cases in which it acquires *less* information about demand: if all consumers are risk averse enough, then each prefers the lower output uncertainty with a less-informed monopolist.

5 Concluding Remarks

Since entry into a monopoly market reduces the incumbent's future profit and sometimes makes the value of information negative, entry sometimes reduces an incumbent's information acquisition. More surprisingly, entry can increase information acquisition if the incumbent or the entrant has increasing returns or if the state-contingent demands are nonlinear or violate increasing dispersion; and entry can hurt consumers.

We assumed that firms choose quantities rather than prices; that market demand, not cost, is uncertain; and that information is public. We now briefly explain how these assumptions affect our results.

Suppose that firms choose price and that they have the same marginal costs. If the entrant has constant returns then entry clearly reduces information acquisition (assuming that the stage-2 equilibrium is in pure strategies): the incumbent's stage-2 profits are zero in the resulting Bertrand game. If only the entrant has increasing returns ($F_E > 0 = F_I$), then an entry threat has no effect. One can also show that our qualitative conclusions hold in the more interesting case in which the firms produce imperfect, rather than perfect, substitutes.

Now suppose that the demand parameter γ is known, but that the incumbent's marginal cost (k_I) is unknown. The incumbent can observe a signal of its own cost (with the signals modelled as before). The entrant's marginal cost may be either known or unknown, but if unknown let it be independent of the incumbent's cost (so that it is pure private-value uncertainty). Since the marginal cost enters the incumbent's interim value function exactly the same way as the demand intercept, little changes. Indeed, the conclusions of Proposition 1 and Sections 3.2.1 (incumbent increasing returns) and 3.2.2 (entrant increasing returns) carry over to this case.

Finally consider private information: the entrant still observes the incumbent's information choice, but does *not* observe the signal realization. As is well-known, under linear demand with intercept uncertainty, private information and interior solutions, a firm's strategy in a Cournot oligopoly just depends on the *expected* output of its rivals (Novshek and Sonnenschein, 1982). It is straightforward to show that this conclusion holds if the slope and intercept are both uncertain. Thus, we can apply standard arguments to show that entry has *no* affect on information acquisition when information is private under the conditions of Proposition 1 (if both firms are always active in stage 2).[20] Although this conclusion differs from our public information case, the main qualitative conclusions of sections 3.2.1 (incumbent increasing returns) and 3.2.3 (violations of increasing dispersion) continue to hold. If the incumbent has increasing returns and shuts down for some beliefs and is active for other beliefs, then an entry threat can increase information acquisition. And if the linear demands violate increasing dispersion, then entry can increase information. (Modify the example from Section 3.2.3 so that $k_E = 0$, $k_I > 0$, and $(\alpha_2 - k_I)/2\beta_2 = (\alpha_1 - k_I)/2\beta_1$ with $\alpha_2 > \alpha_1$–so that information is useless for the isolated monopolist–but

[20]This conclusion also holds if information acquisition is *covert*: the entrant observes nothing about the incumbent's information choice.

suppose that the incumbent is always active when the entrant enters; in that case information is valuable for the threatened incumbent.)

Our assumption that there is only one incumbent is a great simplifier: the benchmark no-entry case is a single-agent problem, rather than a game, so that information is always valuable without entry and comparative statics are easy to derive. As we argued in the Introduction, the extension to oligopolist incumbents is potentially interesting. Several complications arise if there is more than one incumbent in the information-acquisition stage: the value of information can be negative in the benchmark no-entry case; a PBE of the two-stage game might not exist in pure strategies; and comparative statics results are harder to come by. Our results are one step toward understanding how competition affects information acquisition; these complications suggest that the next step will be steeper.

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Figure Legends

Figure 1 (a) Linear demands which satisfy increasing dispersion (the state-2 and state-3 inverse demands have the same slope); (b) linear demands which violate it.

Figure 2 If the incumbent has increasing returns, then entry can increase the expected value of perfect information (EVPI). If the (quasi-)fixed cost is zero, the threatened incumbent's interim value function is o'de. If there is a fixed cost of $F_I > 0$, then the origin shifts up by F_I to *o"*, and the threatened incumbent shuts down at the prior belief and $V_D =$ *o"de*. The EVPI is *ab* for the isolated monopolist and *cd* for the threatened one.

Figure 3 If the entrant has increasing returns, then entry can increase the EVPI. In the figure the entrant shuts down at the prior belief; the discontinuous jump down in the entrant's output to the left of the prior results in a jump up in the incumbent's interim value function.