

# Chunky Information and Adverse Selection\*

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## Abstract

A group of appraisers face a prospect in a random order. Not all prospects are good so, upon encountering a prospect, an appraiser may acquire costly information before deciding to accept or reject it. As each prospect can only be accepted by one appraiser, selectivity causes an adverse selection externality. I show that if appraisers may acquire any signal of the prospect's quality, all appraisers, regardless of their number, have positive expected payoffs. By contrast, when information is chunky, equilibrium adverse selection limits the number of appraisers who can profit by participating. Thus, equilibrium adverse selection deters entry if and only if information is chunky.

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# 1 Introduction

Consider a venture capitalist inspecting a start-up soliciting an investment. Ideally, she invests when the return on investment clears some benchmark; however, this is not immediately apparent. The venture capitalist may aid her decision by acquiring costly information about the start-up. The prior distribution of the start-up's profitability, naturally, informs the venture capitalist's decision of what information — if any — to purchase.

However, the venture capitalist must also consider that she may not be the first potential investor solicited. Could the start-up have already been turned down by other venture capitalists? What would those other venture capitalists have learned about the start-up, and how would it have influenced rejections? The answers to these questions affect the venture capitalist's beliefs about the start-up, and therefore her own information acquisition decisions. If other venture capitalists are being circumspect, perhaps this is cause to be circumspect oneself.

One may reason similarly of health insurers learning about applicants, employers inspecting job candidates, faculty taking time to learn about potential advisees, and consumers poking their fingers into that last avocado in the grocery aisle. More generally, information acquisition produces an interdependent adverse selection externality in common values settings. When agents screen in sequence, this manifests as a *solicitation curse*<sup>1</sup> analogous to the *winner's curse* in simultaneous setups. In these kinds of settings, an agent's incentives to acquire information are affected by the strategic information acquisition of other agents. An intriguing possibility arises: could equilibrium beliefs be so pessimistic that some agents give up on learning altogether? In a stylized environment, I will show that this depends on the fine details of information acquisition.

I develop a model with a set of *appraisers* that encounter a *prospect* in a uniform random *visit order*. As the realization of the visit order is unknown to appraisers, and bad prospects will in equilibrium be rejected more often by other appraisers, beliefs conditioned on encountering the prospect exhibit a solicitation curse.

When faced with the prospect, an appraiser can choose what information to learn about the prospect's quality. This is modeled as choosing a Blackwell experiment - a

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<sup>1</sup>I use the term in the sense of [Kim and Pease \(2017\)](#), but the analogy is imperfect. In that paper, the solicitation curse results from worse prospects exerting more search effort, rather than their being rejected more often.

signal whose distribution varies with the prospect’s quality. Experiments vary in cost, so a more informative one is not always preferable. An appraiser may, in fact, opt to spend nothing and receive no information. Following information acquisition, the appraiser must accept or reject the prospect. If the appraiser rejects the prospect she reaps neither loss nor benefit, and the prospect is encountered by the next appraiser.<sup>2</sup> If the appraiser accepts the prospect, she gains or loses utility on the basis of the prospect’s quality, and the game ends.

I argue that this setting is ideal for studying the relationship between information acquisition and adverse selection externality in isolation. An appraiser acquiring information holds full decision rights over the prospect at that time. Thus, information acquisition decisions are not affected by a concurrent competition for the prospect, as in the auction setting of [Persico \(2000\)](#), but instead reflect current beliefs alone. Furthermore, there is no additional source of adverse selection such as mutual consent to transactions, as in [Lauermann and Wolinsky \(2016\)](#).<sup>3</sup> Compared to models such as these, the present model considerably broadens the forms information acquisition may take. This is at the cost of dispensing with any notion of prices or bids, like [Ely and Siegel \(2013\)](#).

The model takes full advantage of recent advances in the literature on information acquisition. *Smooth* information entails the freedom to collect arbitrarily small increments of information and use them to inform further collection of information, at a constant marginal cost. A result from [Bloedel and Zhong \(2020\)](#) (henceforth, BZ) allows me to represent smooth information with a Uniform Posterior-Separable (UPS) cost function over posteriors. Such functions are rapidly becoming ubiquitous since their introduction by [Caplin and Dean \(2013\)](#). When information is *chunky*, on the other hand, there is still a constant marginal cost, but information is not available in arbitrarily small increments. But this is not to say chunky information is necessarily rigid - there may well be a rich menu of chunks.

In both cases, information acquisition strategies should be thought of as reduced-form descriptions of potentially complex dynamic plans. That is, appraisers are not merely “setting the bar” in a test, but also deciding on how long the test goes on for, as a function of the answers given.

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<sup>2</sup>Thus, as an appraiser may always opt to acquire no information and reject the prospect, 0 is a lower bound on the equilibrium expected payoff of each appraiser.

<sup>3</sup>The latter includes a form of (Groucho) Marxist adverse selection - one should be wary of being party to transactions that others would be party to.

Should information costs vary with beliefs? Mensch (2018) and Denti et al. (2019) demonstrate how information costs that depend arbitrarily on beliefs are inapt for strategic settings. On the other hand, BZ show that experiments that represent sequential procedures cannot have belief-invariant costs. Moreover, I want to allow experiments' costs to vary with outcomes. Thus, I model costs as depending on the prospect's type directly, so that expected costs are linear in beliefs. Any further generalization on this front would prohibit formulating the strategic interaction as a standard game. A consequence of assuming primitive information costs over experiments and qualities is that even with chunky information, the set of beliefs at which appraisers would choose to experiment must be convex.

I show two main results. First, when information is smooth, all appraisers acquire information and each receives a positive expected payoff. This is due to the marginality of beliefs about rejected prospects. Appraisers acquire just enough information that their posterior beliefs about rejected prospects lie on a threshold between a region in which rejection is strictly optimal and one in which further experimentation is strictly optimal. An appraiser encountering a prospect might be the first to do so, or might be later in the order. As a consequence, an appraiser assumed for contradiction not to acquire any information in equilibrium would hold beliefs equal to a convex combination of the prior for fresh prospects and the posterior for rejected ones. As the prior is above the threshold and the posterior for rejected prospects equals the threshold, these equilibrium beliefs would be above the threshold.<sup>4</sup> With such beliefs, the appraiser should deviate to acquiring some information, a contradiction. Therefore, no matter how many appraisers are in the game, all acquire information in equilibrium; earning positive expected payoffs. Smooth information attenuates the informational externality due to each appraiser as the number of appraisers increases.

Second, when information is chunky, the informational externality limits the number of appraisers reaping a positive expected payoff. There cannot be equilibria with too many appraisers gainfully acquiring and acting on information. If there were, either they would be spending too much on acquiring information, or the prospect would be accepted too often. In the former case some appraiser could gain by deviating to rejecting without information; in the latter case some appraiser could gain

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<sup>4</sup>The fact the visit order is determined by uniform randomization plays an important role here. If, say, a particular appraiser knew she was always last in the order, she would never acquire information, and would receive a payoff of 0.

by screening more heavily. As information acquisition cannot be finely tuned in a chunky information market, posteriors for the rejected are strictly below the rejection/further experimentation threshold. Unlike in the smooth case, the informational externality due to this excessive information acquisition is powerful enough to limit market participation.

It is important to recognize that the latter result is not due to 'fixed costs', as in a model in which appraisers acquire information before encountering the prospect. In my model, *all costs are marginal*, in the sense that the appraiser only pays for information when she has unilateral power to decide the fate of the prospect, and each quantum of information costs no more than the next one. Unlike in [Bergemann et al. \(2009\)](#), an increase in the number of appraisers does not affect the value of information via a decrease in 'market share'. Instead, beliefs become excessively pessimistic as the adverse selection externality intensifies. Section 4.1 shows how this force is blunted as information becomes smoother. It is important, however, that appraisers can always acquire *more* information; the example in Section 4.2 shows that the result is not valid when appraisers cannot sample repeatedly. Moreover, Section 4.3 illustrates the externality caused by chunkiness by way of a market with an appraiser with commitment power; she can commit to a chunky experiment that keeps entrants out.

I argue that the contribution of this paper is threefold. First, it develops a model in which interdependent adverse selection can be studied in isolation. The model is applicable to several settings and yields tractable implications despite allowing agents wide discretion in information acquisition. Second, it shows that the minute details of the information acquisition technology affect macroscopic outcomes such as market structure. 'Cheap enough' information is not free, and its character not separable from market entry; moreover, the quanta of information matter. Finally, the paper illustrates the usefulness and limits of the modern information acquisition literature, at once applying its results to a new domain and showing that its stylization is not without loss.

## 2 Model

There is a single prospect, characterized by quality,  $\theta$ , drawn from  $\Theta = \{\underline{\theta}, \bar{\theta}\}$  with the prior putting probability  $p_0 \in (0, 1)$  on  $\bar{\theta}$ . This  $\theta$  is the benefit to an appraiser of accepting the prospect. I assume  $\underline{\theta} < 0 < \bar{\theta}$ ; appraisers want to accept some, but not all, prospects. There also exist  $N$  identical appraisers, who will act as players in this game.

### 2.1 Timing

Nature chooses  $\theta$  according to the prior, and a *visit order*  $\pi$  chosen equiprobably from the set of permutations of the  $N$  appraisers. Then, the game proceeds in up to  $N$  stages, starting with stage 1.

If and when stage  $n$  is reached, appraiser  $\pi(n)$  encounters the prospect. This appraiser may then choose to acquire information about  $\theta$  using the available technology. Once information is acquired, the appraiser may choose to accept or reject the prospect. Following the appraiser's decision, if the prospect is accepted or  $n = N$ , the game ends. On the other hand, if the prospect is rejected and  $n < N$ , stage  $n + 1$  follows.

Each appraiser becomes active at a single information set. That is to say, appraisers are not aware of the prospect's history of encountering other appraisers. As a nonempty history has only rejections, which in equilibrium would convey bad information about the prospect's quality, the prospect would not disclose a nonempty history even if the model were augmented with a cheap-talk stage.

To summarize, the prospect visits appraisers in a (uniform) random order, until either an acceptance occurs, or the prospect has been rejected by every appraiser. When an appraiser encounters the prospect, the appraiser sees only that a prospect has arrived, not the history, the visit order, or the date.

### 2.2 Information Acquisition

When an appraiser encounters the prospect, that appraiser can then acquire information about the prospect's quality. Information acquisition is modeled as choice of a *Blackwell experiment*, a collection of quality-conditional distributions  $\{\sigma(\cdot|\theta)\}_{\theta \in \Theta}$  for a signal on Euclidean space  $S_\sigma$ . The set of all Blackwell experiments is denoted  $\mathcal{B}$ . A

null experiment  $\sigma_{null}$  carries no information, so that  $\sigma_{null}(\cdot|\theta)$  does not depend on  $\theta$ .<sup>5</sup>

Appraisers have access to a collection of experiments  $\mathcal{G} \subseteq \mathcal{B}$ , the *information menu*. This menu represents the procedures available to an appraiser in order to learn about prospects. The information menu is common to all appraisers. Experiments will vary in cost, so a more informative experiment will not always be preferable.

Unlike much of the literature, I do not always assume that  $\mathcal{G}$  is equal to  $\mathcal{B}$ . This is crucial; I am primarily interested in varying the nature of  $\mathcal{G}$  rather than the cost function  $c$ . I assume that  $\mathcal{G}$  contains a null experiment.

## 2.3 Strategies

Each appraiser  $n$  must choose two things: what (if any) information to acquire and how to use it. Thus, each appraiser  $n$  must choose a  $\sigma_n \in \mathcal{G}$ . The use of information reduces to a function  $a_n : S_{\sigma_n} \rightarrow \{0, 1\}$ , which denotes (as a function of the experiment's outcome) whether the appraiser accepts (1) or rejects (0) the prospect. Thus, the strategy space of each appraiser  $n$  is  $\Delta\{(\sigma_n, a_n) | \sigma_n \in \mathcal{G}, a_n : S_{\sigma_n} \rightarrow \{0, 1\}\}$ . A typical (mixed) strategy for appraiser  $i$  is denoted  $\varphi_n$ .

## 2.4 Payoffs

Each experiment is assigned a cost. As experiments may represent ‘reduced form’ descriptions of sequential testing procedures, or costs may depend on experimental outcomes, we allow these costs to depend on  $\theta$ .<sup>6</sup> Formally, let  $c : \mathcal{G} \times \Theta \rightarrow \mathbb{R}_+$  denote the experiment cost function. It is assumed that experiments producing the same distribution over posterior likelihoods are equally costly, and that  $c(\sigma, \theta) = 0$  iff  $\sigma$  is a null experiment.<sup>7</sup>

Thus, if appraiser  $n$  encounters a prospect of quality  $\theta$ , that appraiser's payoff from  $(\sigma_n, a_n)$  is

$$\theta E_{\sigma_n(\cdot|\theta)} [a_n] - c(\sigma, \theta). \tag{1}$$

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<sup>5</sup>Often, with some abuse of notation,  $\sigma_{null}$  will refer to a *generic* null experiment.

<sup>6</sup>Technically, many results carry over to broader classes of information acquisition cost functions. Proposition 1 applies under any uniform posterior-separable cost function. However, such a generalization would involve payoff functions that are non-linear in beliefs. Thus, the game would have to be defined as a Psychological Game á la [Geanakoplos et al. \(1989\)](#).

<sup>7</sup>Experiments produce the same distribution over posterior likelihood functions iff they are Blackwell equivalent, as shown by Stern and Pereira (2012).

To compute the appraiser's expected payoffs we'll first need to find the probability she encounters a prospect of each quality - in other words, we have to account for selection. When a prospect of quality  $\theta$  visits appraiser  $m$ , the chance she *rejects* given her strategy  $\varphi_m$  is  $(1 - E_{\varphi_m} [E_{\sigma_m(\cdot|\theta)}[a_m]])$ . Now, notice that for a given visit order  $\pi$  and strategy profile  $\varphi$ , the chance  $n$  encounters the prospect is the chance that *all* previous (with respect to  $\pi$ ) appraisers reject the prospect; or

$$\prod_{m:\pi(m)<\pi(n)} (1 - E_{\varphi_m} [E_{\sigma_m(\cdot|\theta)}[a_m]]) . \quad (2)$$

To find appraiser  $n$ 's payoff for the strategy profile  $\varphi$ , we multiply the payoff on an encounter (1) by the probability of an encounter (2) for a given visit order and then take an expectation over qualities and visit orders:<sup>8</sup>

$$E_{p_0,\pi} \left[ E_{\varphi_n} [\theta E_{\sigma_n(\cdot|\theta)} [a_n] - c(\sigma, \theta)] \cdot \prod_{m:\pi(m)<\pi(n)} (1 - E_{\varphi_m} [E_{\sigma_m(\cdot|\theta)}[a_m]]) \right] . \quad (3)$$

As we have assumed that the visit order is uniform random, denoting by  $\Pi_N$  the set of permutations of the naturals  $\{1, 2, \dots, N\}$ , we can rewrite this as

$$E_{p_0} \left[ E_{\varphi_n} [\theta E_{\sigma_n(\cdot|\theta)} [a_n] - c(\sigma, \theta)] \frac{1}{N!} \sum_{\pi \in \Pi_N} \prod_{m:\pi(m)<\pi(n)} (1 - E_{\varphi_m} [E_{\sigma_m(\cdot|\theta)}[a_m]]) \right] . \quad (4)$$

Following BZ, given an experiment  $\sigma \in \mathcal{B}$  and a function that maps its outcomes into experiments,  $\sigma' : S_\sigma \rightarrow \mathcal{B}$ , I denote by  $\sigma * \sigma'$  a *compound experiment* that performs  $\sigma$  first, and then for each outcome  $s$  performs the experiment  $\sigma'(s)$ . I say that  $c$  exhibits *constant marginal cost* if  $\sigma, \sigma'(s)$  for each  $s$ , and  $\sigma * \sigma'$  are in  $\mathcal{G}$ , implies that

$$c(\sigma * \sigma', \theta) = c(\sigma, \theta) + E_\sigma [c(\sigma'(s), \theta)] . \quad (5)$$

Constant marginal cost requires that compound experiments cost as much as the sum of the expected costs of their constituent parts.<sup>9</sup> For instance, if our venture

<sup>8</sup>Here,  $E_{p_0}$  is an abuse of notation; by this, I mean an expectation over qualities using the prior distribution  $p_0$ .

<sup>9</sup>BZ term this *indifference to sequential learning*. The concept is slightly altered as costs are

capitalist chooses to conduct interviews first and then proceed with market analysis only if she likes what she hears, the cost of this procedure is equal to the cost of only the interview, plus the probability of ‘liking what she hears’ times the cost of only the market analysis.

## 2.5 Equilibrium

I regard as a solution to the game any Bayes-Nash equilibrium strategy profile  $\varphi^*$ . That is, each  $\varphi_n^*$  maximizes player  $n$ ’s expected payoff (4), given  $\varphi_{-n}^*$ .

## 2.6 Market Size

The main question I’ll be asking is, how does the information available for acquisition affects the number of appraisers who can gainfully participate in the market? Accordingly, I should define the benchmarks for market size results.

I’ll say that *information always limits entry* if there exists a number of appraisers  $\bar{N}$  such that, if the number of appraisers is any  $N > \bar{N}$ , at most  $\bar{N}$  of them can earn a positive expected payoff. Suppose a rough model of appraisers contemplating entry. When information always limits entry, even if entry is free, there are always equilibria with as few as  $\bar{N}$  appraisers. Moreover, the number of entrants (in pure equilibria of the entry game) will be bounded by  $\bar{N}$  if there is an entry cost, no matter how small.

I’ll say that *information never limits entry* if, for any number of appraisers  $N$ , in every equilibrium of the game, every appraiser gets a positive expected payoff. When information never limits entry, every appraiser that can enter the market freely will. This requires that in all equilibria, each appraiser occasionally accepts the prospect.

These two cases, while not exhaustive, will suffice for my results.

## 3 Equilibria of smooth- and chunky-information markets.

First, let’s agree to say the market is *trivial* if a null experiment maximizes (4) when  $p_n$  is set to  $p_0$ . A monopsonist would not acquire information in a trivial market. She might choose to accept or reject, depending on  $p_0$ , but will do so without acquiring information. In such a market, there is always an equilibrium in which all

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defined over  $\mathcal{G} \times \Theta$  in my setting.

players use null experiments. Additionally, any equilibrium with experimentation would be purely coordination failure: appraisers acquiring information only because other appraisers are. Neither chasing equilibrium refinements nor producing policy that alleviates coordination failure is germane to the topic at hand; so we won't dwell on trivial markets.

It will be useful to normalize payoffs by conditioning on an encounter occurring at all (as an appraiser gets 0 when she is not visited). Furthermore, I simplify notation by introducing  $p_n$  as each appraiser  $n$ 's *interim belief*.<sup>10</sup> This is the belief placed by appraiser  $n$  on the prospect being quality  $\bar{\theta}$  once she has updated on an encounter occurring. Naturally, they depend on  $\varphi_{-n}$ .

$$p_n = \frac{p_0 \sum_{\pi \in \Pi_N} \prod_{m: \pi(m) < \pi(n)} (1 - E_{\varphi_m} [E_{\sigma_m(\cdot|\bar{\theta})}[a_m]])}{E_{p_0} \left[ \sum_{\pi \in \Pi_N} \prod_{m: \pi(m) < \pi(n)} (1 - E_{\varphi_m} [E_{\sigma_m(\cdot|\theta)}[a_m]]) \right]}. \quad (6)$$

Given  $\varphi_{-n}$ , for any strategy  $(\sigma_n, a_n)$ , appraiser  $n$ 's interim payoffs - her payoffs conditional on an encounter - can now be written as

$$E_{p_n} [E_{\sigma_n(\cdot|\theta)} [a_n] \theta - c(\sigma, \theta)]. \quad (7)$$

Before we proceed to examine smooth and chunky information separately, we can immediately state a rather trivial general finding.

**Lemma 1** *In any equilibrium of the game  $\varphi$ , for each  $n$ ,  $p_n \leq p_0$ .*

**Proof.** From (6), the contrary would imply

$$\sum_{\pi \in \Pi_N} \prod_{m: \pi(m) < \pi(n)} (1 - E_{\varphi_m} [E_{\sigma_m(\cdot|\bar{\theta})}[a_m]]) > \sum_{\pi \in \Pi_N} \prod_{m: \pi(m) < \pi(n)} (1 - E_{\varphi_m} [E_{\sigma_m(\cdot|\theta)}[a_m]]). \quad (8)$$

This would in turn require that for some appraiser  $m$ ,  $E_{\sigma_m(\cdot|\theta)}[a_m] > E_{\sigma_m(\cdot|\bar{\theta})}[a_m]$ , or, in other words, that bad prospects are accepted by  $m$  more frequently than good ones. Clearly, this is incompatible with optimization. ■

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<sup>10</sup>This is not necessary to define equilibrium, as in the extensive form, the information set at which each appraiser becomes active is always on-path.

With this in hand, we commence our search for equilibria, beginning with the case of smooth information.

### 3.1 Markets with smooth information

Smooth information, which allows appraisers the freedom to acquire any experiment in  $\mathcal{B}$ , most closely matches the models of information acquisition used in the literature. My canonical formulation is narrower in one way — I use a primitive quality-based cost, so that optimizing appraisers take expectations of it using their interim beliefs to determine their expected cost. This is so that the interaction being modeled can be defined as a standard game, and allows comparison with the chunky information case.

In this section, however, I have chosen to generalize the proofs to the broader class of Uniform Posterior-Separable (UPS) cost functions (including, say, Mutual Information) used in the literature. Although I could leverage [Morris and Strack \(2017\)](#) and my assumption that information costs are additively separable in quality (or, equivalently, linear in beliefs) in order to give  $c$  a generalized “Total Information” structure, I avoid doing this so that the proofs remain portable. Thus, the cost function  $c$  used in this section is allowed to vary over experiments and beliefs, rather than just experiments and types. This requires defining the setting as a Psychological Game (in the manner of [Geanakoplos et al. \(1989\)](#)), and admits my standard-game application as a special case.

A cost function  $c : \mathcal{B} \times [0, 1]$  is UPS if there exists a strictly convex potential function  $V$  such that

$$c(\sigma, p_n) = E_{\sigma, p_n} V(q) - V(p_n) \tag{9}$$

where  $q(s)$  is the posterior on  $\Theta$  induced by the experimental outcome  $s$ .

The first step is to invoke BZ to establish that in the smooth information setting, under a mild continuity condition,  $c$  is UPS.<sup>11</sup>

**Theorem 1 (Bloedel and Zhong 2020)** *Suppose  $\mathcal{G} = \mathcal{B}$ , and that  $c$  is continuous and exhibits constant marginal cost. Then,  $c$  is Uniform Posterior-Separable.*

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<sup>11</sup>The exact type of continuity required is that when a sequence of experiments’ induced posteriors weak\*-converge, their cost converges to the cost of an experiment that produces the limiting posteriors.

From here, we can identify the solution to the information acquisition problem for a single appraiser, for a given  $p_n$ . Lemmata 2, 3, and 4 retread some ground from the rational inattention literature, adapted to the present setting. First, Lemma 2 shows that with a UPS cost function, optimally acquired information results in at most as many posteriors as there are actions - here, this is just two.

**Lemma 2** *Suppose  $\mathcal{G} = \mathcal{B}$  and  $c$  is UPS. For a given interim belief  $p_n$ , an optimal experiment leads to at most two posteriors.*

**Proof.** Denoting by  $\alpha : [0, 1] \rightarrow \{0, 1\}$  the acceptance policy as a function of induced posteriors, and by  $F \in \Delta[0, 1]$  the appraiser's distribution over posteriors  $q$  induced by information acquisition, the appraiser's problem can be rewritten as

$$\max_{F \in \Delta[0,1], \alpha: [0,1] \rightarrow \{0,1\}} E_F[\alpha(q)(q\bar{\theta} + (1-q)\underline{\theta}) - (V(q) - V(p_n))] \quad (10)$$

$$\text{subject to } E_F[q] = p_n. \quad (11)$$

Optimally, we have  $\alpha(q) = 0$  if  $q \leq -\frac{\underline{\theta}}{\bar{\theta} - \underline{\theta}}$  and  $\alpha(q) = 1$  if  $q \geq -\frac{\underline{\theta}}{\bar{\theta} - \underline{\theta}}$ . Thus we can rewrite the problem of choosing  $F$  as

$$\max_{F \in \Delta[0,1]} E_F[\max\{q\bar{\theta} + (1-q)\underline{\theta}, 0\} - V(q)] \quad (12)$$

$$\text{subject to } E_F[q] = p_n. \quad (13)$$

Suppose  $F$ 's support contains more than a single  $q \leq -\frac{\underline{\theta}}{\bar{\theta} - \underline{\theta}}$ . In this region, the maximand is strictly concave in  $q$ , and thus reallocating all this mass to  $E_F[q|q \leq -\frac{\underline{\theta}}{\bar{\theta} - \underline{\theta}}]$  is strictly preferable. The same applies for those  $q \geq -\frac{\underline{\theta}}{\bar{\theta} - \underline{\theta}}$ . Thus an optimal experiment either induces two posteriors, one leading to acceptance  $q_a$  and one to rejection  $q_r$ , satisfying  $q_a > p_n > q_r$ , or the experiment is null and produces only one posterior,  $p_n$ . ■

Lemma 2 follows from the fact that a UPS cost function is strictly convex. If two experimental outcomes inducing different posteriors led to the same action (acceptance or rejection), the appraiser could merge them. This would coarsen the experiment, and therefore cheapen it, without changing the distribution of actions conditional on the quality  $\theta$ .

Now, Lemma 3 can use this fact to show that the optimal experiment is essentially unique.

**Lemma 3** *Suppose  $\mathcal{G} = \mathcal{B}$  and  $c$  is UPS. For a given interim belief  $p_n$ , the optimal experiment is unique (up to Blackwell-equivalence).*

**Proof.** Suppose  $F^*$ ,  $F^{*'}$  are optimal and not identical. Let  $\hat{F}$  be any mixture of  $F^*$  and  $F^{*'}$ . By the fact the maximand (10) and constraint (11) are linear in  $F$ , the distribution  $\hat{F}$  is feasible and also achieves the maximum. But such a mixture will feature at least three points in its support, a contradiction to Lemma 2. Thus the maximizer  $F$  must be unique. Any two experiments generating the same distribution of posteriors are Blackwell-equivalent, so the optimal experiment is unique up to Blackwell-equivalence. ■

So far, we have not invoked non-triviality. We will use it to induce uniform behavior - in terms of the posteriors of optimal experiments - as  $p_n$  is allowed to vary. Intuitively, non-triviality eliminates not only the case when the market is pointless as all appraisers always reject, but also cases where there is multiplicity, with information acquired in only some equilibria. Formally, non-triviality allows us to show that there is an interval of interim beliefs for which appraisers will acquire information, and that the purpose of optimally acquired information is to push posteriors to the endpoints of that same interval. When the agent's interim beliefs do not lie in the interval, the agent will acquire no information.

**Lemma 4** *Suppose  $\mathcal{G} = \mathcal{B}$ ,  $c$  is UPS, and the market is non-trivial. There exist beliefs  $q_a^*$ ,  $q_r^*$  such that  $n$ 's optimal experiment is non-null iff  $p_n \in (q_a^*, q_r^*)$ ; if so, it produces only the posteriors  $q_a^*$ ,  $q_r^*$ . An optimal acceptance policy is pure.*

**Proof.** Suppose the optimal experiment is non-null. From Lemma 2 an optimal non-null experiment splits  $p_n$  into an acceptance posterior  $q_a^*$  and a rejection posterior  $q_r^*$ . Let's manipulate the constraint,  $E_F[q] = p_n$ . For an experiment producing only two posteriors  $q_a$  and  $q_r$  with probabilities  $z$  and  $1 - z$  respectively, the constraint reduces to  $zq_a + (1 - z)q_r = p_n$ . Solving for  $z$ , we get that the probability of a signal corresponding to posterior  $q_a$  is  $z = \frac{p_n - q_r}{q_a - q_r}$ . Thus, we can rewrite the objective as

$$\max_{q_a, q_r} \left[ \frac{p_n - q_r}{q_a - q_r} [q_a \bar{\theta} + (1 - q_a) \underline{\theta}] - \frac{p_n - q_r}{q_a - q_r} V(q_a) - \frac{q_a - p_n}{q_a - q_r} V(q_r) \right]. \quad (14)$$

Differentiating, we arrive at the first-order conditions

$$-q_r^* \bar{\theta} - (1 - q_r^*) \underline{\theta} + V(q_a^*) - V(q_r^*) - (q_a^* - q_r^*) V'(q_a^*) = 0 \quad (15)$$

$$-q_a^* \bar{\theta} - (1 - q_a^*) \underline{\theta} + V(q_a^*) - V(q_r^*) - (q_a^* - q_r^*) V'(q_r^*) = 0 \quad (16)$$

which are independent of  $p_n$ . Furthermore, the SOSOC confirms that if a solution exists and is feasible (requiring  $p_n \in (q_r^*, q_a^*)$ ), it is a maximum. A corner solution (with  $q_r^* = 0$ ,  $q_a^* = 1$ , or both) may instead obtain; but from Lemma 3 the solution is unique. If neither an interior or a corner optimum exists, a null experiment is optimal. Notice that if a solution  $(q_r^*, q_a^*)$  does not exist, then a null experiment is optimal for *any*  $p_n \in [0, 1]$ . Thus even a monopsonist with  $p_n = p_0$  would decline to acquire information. This contradicts non-triviality, so there exists a solution  $q_a^*, q_r^*$ , proving the first part of the lemma.

For the second part of the lemma, it suffices to see that since from non-triviality  $0 \leq q_r^* < p_0 < q_a^* \leq 1$ , (i) if  $p_n \leq q_r^*$  then a null experiment is chosen and the acceptance policy rejects; (ii) if  $p_n \geq q_a^*$  a null experiment is chosen and the prospect accepted; and (iii) if  $q_r^* < p_n < q_a^*$  then a non-null experiment which only induces the posteriors  $q_r^*, q_a^*$  is chosen with rejection at the former posterior and acceptance at the latter. ■

Figure 1 displays acceptance rates under optimally-acquired information, as well as beliefs about the rejected. From Lemma 4, any information acquired by an appraiser produces a posterior  $q_r^*$  on a rejection. Thus, all rejections are marginal: an appraiser that rejects a prospect is just indifferent between acquiring more information about them or not. Furthermore, an appraiser that had as their interim beliefs exactly the rejection belief,  $p_n = q_r^*$ , would be *just on the fence* between acquiring some information or not. The fact that these thresholds coincide is crucial. It is a consequence of the fact UPS cost functions all satisfy constant marginal cost: an appraiser who just encountered a prospect and holds some interim belief  $q$  is in the same position as an appraiser who got to that belief by way of an experiment's realization.

Thus, if the interim belief of an appraiser were *any higher* than the beliefs held by appraisers who acquired a 'bad' experiment realization, that appraiser would acquire information. The work done by the next proposition is to show that the possibility of a fresh prospect - one no other appraiser has screened yet - is always sufficient, in equilibrium, to produce interim beliefs for all appraisers above the  $q_r^*$  threshold. The

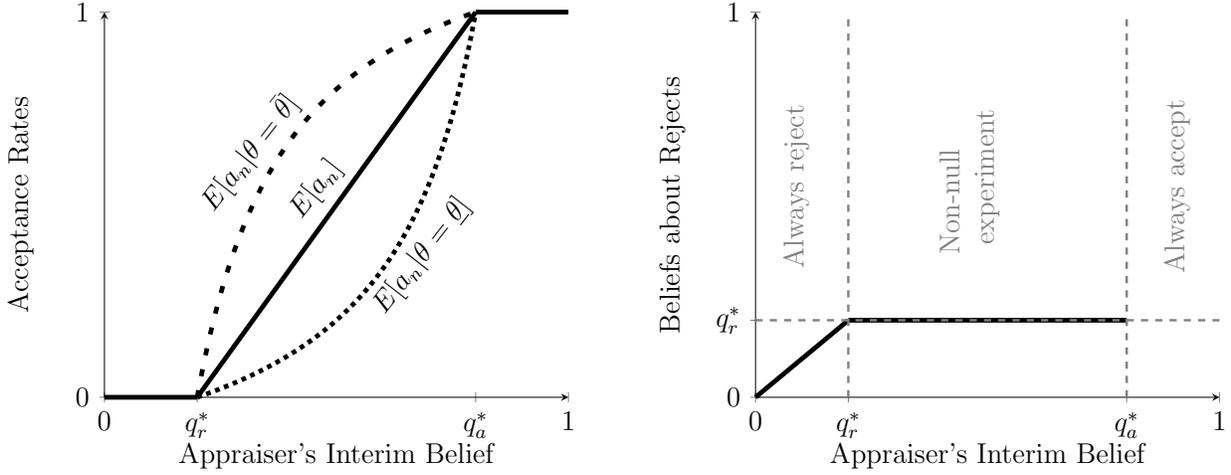


Figure 1: Optimal ‘smooth information’ acquisition. Left panel: acceptance rates for good and bad prospects, as well as the average rate, as a function of interim beliefs. Right panel: beliefs about rejected prospects, as a function of interim beliefs.

reader is reminded that information never limits entry if, for any number of appraisers  $N$ , in every equilibrium of the game, every appraiser gets a positive expected payoff.

**Proposition 1** *Suppose that  $\mathcal{G} = \mathcal{B}$ , that  $c$  is UPS, and that the market is not trivial. Then, information never limits entry. Moreover, in every equilibrium, every appraiser uses a non-null experiment.*

**Proof.** We will proceed by contradiction. To begin, notice that using a null experiment and rejecting following any outcome of the experiment yields a payoff of 0. From Lemma 3 the optimal experiment is essentially unique. Therefore if in equilibrium an appraiser receives an expected payoff of 0, that appraiser must be acquiring a null experiment and always rejecting. So, the task at hand consists of finding that there are no such ‘inactive’ appraisers in equilibrium. First, suppose that there is an equilibrium  $\varphi$  of the game with some  $N$  appraisers featuring an inactive appraiser (wlog)  $N$ . An inactive appraiser never accepts, or in other words sets  $E_{\varphi}[a_N|\theta] = 0$ . Notice that the inactive appraiser drops out of (6). Thus,  $(\varphi_n)_{n \leq N-1}$  is an equilibrium of the game with  $N - 1$  appraisers as for each appraiser  $n < N$  the interim belief  $p_n$  computed from (6) is the same as when appraiser  $N$  is present, and thus the best responses of  $n$  coincide in the two scenarios. So, if the game with  $N$  appraisers features an equilibrium in which  $k \geq 1$  are inactive, then the game with  $N - (k - 1)$  appraisers

features an equilibrium in which just one is inactive. Therefore, for our purposes it will suffice to show that there is no equilibrium of the game for any  $N$  in which *one* appraiser is inactive.

Now, suppose there is an equilibrium  $\varphi$  of the game with some  $N$  appraisers such that appraiser (wlog)  $N$  is the sole inactive one. From non-triviality,  $N > 1$ . From the above,  $\varphi_{-N}$  is an equilibrium of the game with  $N - 1$  appraisers. Fix an appraiser  $n \neq N$  and consider an auxiliary game with  $N$  appraisers in which we alter the visit order by forcing  $N$  to always come exactly after  $n$ . The conditioned distribution is, of course, a uniform distribution over  $\{1, \dots, n - 1, (n, N), n + 1, \dots, N - 1\}$ .

I claim  $\varphi$  is an equilibrium of the auxiliary game. Optimality for  $m \neq N$  comes from the fact that  $N$  drops out of the calculation of  $p_n$  and therefore incentives are as in the  $N - 1$  appraiser game. Optimality for  $N$  being inactive flows from the fact that  $N$ 's interim belief is computable as  $p_n$  updated for a rejection by  $n$ , which coincide with  $n$ 's beliefs when rejecting. From Lemma 1,  $p_n < p_0$ ; from non-triviality  $p_0 < q_a^*$ ; thus,  $n$  acquires a non-null experiment. Using Lemma 4, the beliefs of  $n$  on rejection are  $q_r^*$ . At these beliefs, indeed  $N$  finds it optimal to reject.

Now, notice the relation between  $N$ 's beliefs in the auxiliary games and the original  $N$ -appraiser game while holding fixed the strategy profile  $\varphi$ . We can rewrite  $N$ 's interim beliefs in the original game as a probability-weighted combination of her beliefs when she knows she comes right after  $n$ , for each  $n$ , and her beliefs when she knows she comes first. In the former cases her beliefs are  $q_r^*$ ; if she knew she were first in the order, her beliefs would be  $p_0$ . As non-triviality implies that  $q_r^* < p_0$ , and coming first has probability at least  $1/N$ , we have that  $p_N > q_r^*$ ; but this contradicts Lemma 2. ■

Proposition 1 relies crucially on the fact that the visit order is uniform. Thus, an inactive appraiser can be ignored in calculations by other appraisers. The fact that an inactive appraiser's interim beliefs updated on the event of acting after some other appraiser are exactly equal to that other appraiser's beliefs on rejection is contingent on uniformity.

This underlies the key argument in the proof: an inactive appraiser who knew she was acting after another appraiser would have interim beliefs equal to the rejection beliefs  $q_r^*$ . An appraiser who knew she's first in the order would have beliefs equal to the prior. An inactive appraiser who is uncertain about which is the case, should have beliefs equal to a convex combination of the two, and hence better than the

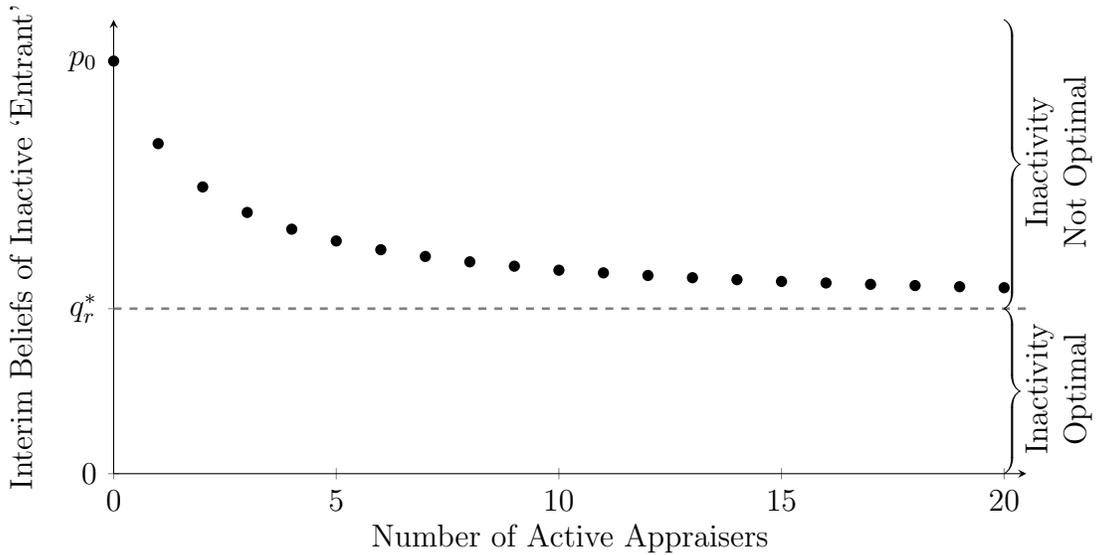


Figure 2: An inactive  $(N + 1)$ st appraiser computing interim beliefs when others play a symmetric equilibrium of the  $N$ -appraiser game. For any  $N$ , the inactive appraiser's beliefs indicate inactivity is not, in fact, a best-response.

rejection beliefs. Figure 2 illustrates this - for any number of other appraisers who are best-responding, the inactive appraiser has interim beliefs that make it profitable for her to acquire a non-null signal. Thus, our inactive appraiser should be acting after all!

### 3.2 Markets with chunky information

To talk sensibly about information being “chunky” but retaining the experimental nature of the exercise, I want to ensure that appraisers are free to run experiments repeatedly or in whatever sequence they choose. To that end, we'll say that  $\mathcal{G}$  is *sequentially closed* if whenever non-null  $\sigma$  and each  $\sigma'(s)$  are in  $\mathcal{G}$ , we have that  $\sigma * \sigma'$  is also in  $\mathcal{G}$ . Intuitively, this captures the notion that appraisers may always perform more tests, and the set of available experiments does not depend on the outcomes of prior experiments.

Information is said to be *chunky* when  $\inf\{c(\sigma, \theta) | \text{non-null } \sigma \in \mathcal{G}, \theta \in \Theta\} > 0$ , that is, when the cost of non-null experiments is bounded away from zero. This infimal non-null experimentation cost is denoted  $\underline{c}$ .

As an example, a sequentially closed, chunky  $\mathcal{G}$  can be obtained by starting with

finitely many ‘primitive’ experiments and then applying the definition of sequential closure to generate the rest of the information menu. Any non-null experiment, in this case, can be interpreted as the reduced form of a procedure that at each stage, depending on the history of experimental output, either orders another primitive experiment or terminates. This can model acquiring information via a lab which prices each medical test independently.

Alternatively, one can start with a  $c(\cdot, \cdot)$  over  $\mathcal{B} \times \Theta$  and produce a restricted menu  $\mathcal{B}_{\underline{c}}$  by choosing only those non-null experiments that always cost at least  $\underline{c}$ . In this case as well, arbitrarily cheap non-null experiments are not available; but, above the cutoff, experiments can be designed very flexibly. An example is a consultant who can be hired to do all sorts of market research and charges by the minute, but won’t accept tasks worth less than  $\underline{c}$ .

Lemma 5 establishes that the interim beliefs at which information acquisition would occur form an interval.

**Lemma 5** *If information is chunky and the market is not trivial, there exist  $1 < \underline{p} < \bar{p} < 0$  such that*

- *acquiring a null experiment and rejecting is optimal iff  $p_n \in [0, \underline{p}]$ ;*
- *acquiring a null experiment and accepting is optimal iff  $p_n \in [\bar{p}, 1]$ ; and*
- *acquiring a non-null experiment is optimal if  $p_n \in [\underline{p}, \bar{p}]$ .*

**Proof.** A strategy of acquiring a null experiment and accepting is optimal when the interim belief puts probability 1 on good quality. This yields a payoff of  $\bar{\theta}$ . Conversely, at this belief any other pure strategy can give at most 0 if it acquires a null experiment and rejects, and  $\bar{\theta} - \underline{c}$  if it involves a non-null experiment. From this and the fact that for any strategy  $\varphi_n$ , player  $n$ ’s payoff (7) is linear in  $p_n$ , the set of beliefs where acquiring a null experiment and accepting is optimal is some interval  $[\bar{p}, 1]$ . Similarly, acquiring no information but rejecting is optimal on some interval  $[0, \underline{p}]$ . We must still rule out that  $\underline{p} \geq \bar{p}$ . Non-triviality asserts that  $p_0$  is a belief in which acquiring a null experiment is not optimal; as a consequence,  $\underline{p} < p_0 < \bar{p}$ . Thus, it is optimal to acquire a non-null experiment for beliefs in  $[\underline{p}, \bar{p}]$  ■

Lemma 6 establishes that any profiting appraiser is acquiring a non-null experiment, and therefore imposes an externality on other appraisers.

**Lemma 6** *In every equilibrium of a non-trivial market with chunky information, any appraiser making a profit acquires a non-null experiment.*

**Proof.** From Lemma 1 we have that  $p_n \leq p_0$  in every equilibrium. From non-triviality and Lemma 5, that  $p_0 < \bar{p}$ . Together, they give us  $p_n < \bar{p}$  in every equilibrium. Thus, in equilibrium either  $p_n \leq \underline{p}$  and  $n$  gets a payoff of zero (as immediate rejection is optimal), or  $\underline{p} < p_n \leq p_0 < \bar{p}$  and acquiring a null experiment and rejecting is *not* optimal. Thus, the appraiser's payoff in this second case must be greater than 0. Thus, whenever the appraiser's expected payoff is positive in equilibrium, a null experiment is not optimal. ■

Together, Lemmata 5 and 6 will allow us to show that, as the number of appraisers grows, along any sequence of equilibria in which the acceptance probability of the market as a whole goes to 1, eventually some appraiser must be accepting when her beliefs on acceptance are below  $\bar{p}$ . This would imply that she has a profitable deviation due to sequential closure of the information menu. On the flip side, if the acceptance probability of the market as a whole limits to something other than 1 along a sequence of equilibria in which all appraisers profit, Lemma 6 implies they must be acquiring information. Then, the chunkiness of information implies the expected market-wide total expenditure on experiments is going to infinity, so that some appraiser is getting a negative payoff and should deviate to being inactive. Finally, a sequential compactness argument shows one kind of subsequence or another exists if there are equilibria in which arbitrarily large numbers of appraisers profit. Thus, such a sequence of equilibria cannot exist, and there must be a maximal number of profitable appraisers; in other words, *information always limits entry*. Proposition 2 formalizes this argument.

**Proposition 2** *Suppose that  $\mathcal{G}$  is sequentially closed, that information is chunky with some  $\underline{c} > 0$ , and that the market is not trivial. Then, information always limits entry.*

**Proof.** To prove the proposition, I proceed by contradiction. Suppose that there is a strictly increasing sequence of natural numbers  $(N_i)_{i \in \mathbb{N}}$  such that for each  $i$ , there is an equilibrium  $\varphi^i$  of the game with some  $N'_i \geq N_i$  appraisers where  $N_i$  appraisers profit. For each such equilibrium, we consider the *total rejection rate* for each quality  $\theta$ . The probability that every appraiser rejects a prospect of the given quality is

$$R_i(\theta) = \prod_{n=1}^{N'_i} (1 - E_{\varphi_n^i} [E_{\sigma_n^i(\cdot|\theta)}[a_n^i]]). \quad (17)$$

For all  $i$ , the profile of total rejection rates  $R_i = (R_i(\bar{\theta}), R_i(\underline{\theta}))$  is in  $[0, 1]^2$ , which is a sequentially compact space. Hence, there is some accumulation point  $R^\infty$  which is the limit point of some subsequence  $(R_{i_k})_{k \in \mathbb{N}}$ . I will show that whatever this limit is, we can find some  $\varphi^{i_k}$  that is not an equilibrium.

First, suppose  $R^\infty \neq (0, 0)$ . Then, there is some  $\varepsilon > 0$ , some  $\theta \in \Theta$ , and some  $k^* \in \mathbb{N}$  such that for all  $k \geq k^*$ ,  $R_{i_k}(\theta) > \varepsilon$ . Thus, with enough appraisers, there is some type that is rejected by all appraisers with probability at least  $\varepsilon$ . Type  $\theta$  is assigned probability at least  $\min\{p_0, 1 - p_0\}$  by the prior. Choose some  $k > k^*$  that satisfies

$$N_{i_k} > \frac{\bar{\theta}}{\varepsilon \min\{p_0, 1 - p_0\} \cdot \underline{c}}. \quad (18)$$

Thus, there is at least a  $\varepsilon \min\{p_0, 1 - p_0\}$  chance that the prospect is quality  $\theta$  and visits every appraiser in the equilibrium  $\varphi^{i_k}$ . Given that every appraiser with a positive utility must conduct a non-null experiment, the expected cost of all experiments in the market is at least  $N_{i_k} \cdot \varepsilon \min\{p_0, 1 - p_0\} \cdot \underline{c}$ . On the other hand, the highest expected gains from acceptances can be across the market is  $\bar{\theta}$ . Using (18),  $N_{i_k} \cdot \varepsilon \min\{p_0, 1 - p_0\} \cdot \underline{c} > \bar{\theta}$ , and therefore the total expected payoffs in the equilibrium are negative. Thus, at least one appraiser has negative expected utility under  $\varphi^{i_k}$ ; deviating to no experimentation and immediate rejection, she could get 0. Therefore  $\varphi^{i_k}$  could not be an equilibrium, and hence we reject the hypothesis that  $R^\infty \neq (0, 0)$ .

Hence, suppose now that  $R^\infty = (0, 0)$  - along this sequence of equilibria, eventually nearly every prospect is accepted by some appraiser. In the market with  $N'_{i_k}$  appraisers, in equilibrium  $\varphi^{i_k}$ , the proportion of prospects accepted by the market as a whole that are of type  $\bar{\theta}$  is

$$p_a^{i_k}(\theta) = \frac{p_0(1 - R_{i_k}(\bar{\theta}))}{p_0(1 - R_{i_k}(\bar{\theta})) + (1 - p_0)(1 - R_{i_k}(\underline{\theta}))}. \quad (19)$$

Consider the beliefs at which acceptance occurs given  $\varphi^{i_k}$ ;  $p_a^{i_k}$  is their average. As  $k \rightarrow \infty$ ,  $(R_{i_k}(\underline{\theta}), R_{i_k}(\bar{\theta})) \rightarrow (0, 0)$ ; thus  $p_a^{i_k} \rightarrow p_0$ . From non-triviality and Lemma 5

we have  $p_0 < \bar{p}$ ; so that from  $p_a^{i_k} \rightarrow p_0$  there is a  $k \in \mathbb{N}$  such that in the game with  $N'_{i_k}$  appraisers, there is an equilibrium in which some appraiser  $n$  accepts with positive probability and, on average, at a belief below  $\bar{p}$ ; call this belief  $p^*$ . From Lemma 6, an appraiser with beliefs  $p^*$  would not find a null experiment optimal; instead, call  $(\sigma^*, a^*)$  an experiment that is. Now, consider a deviation for  $n$  that compounds experiment  $\sigma^*$  on any outcome of  $n$ 's original experiment that leads to acceptance, and instead uses acceptance rule  $a^*$  at the conclusion of the compound experiment. From the sequential closure of  $\mathcal{B}$ , this experiment is available. From the constant marginal cost assumption, this deviation is profitable. Thus we are again led to a contradiction. ■

The proposition implies that regardless of the available information, so long the information menu  $\mathcal{G}$  does not have arbitrarily cheap experiments on offer, the solicitation bias eventually prevents the entry of additional appraisers. We may, in some sense, regard  $\bar{N}$  as the natural size of the market - the largest number of profitable appraisers.

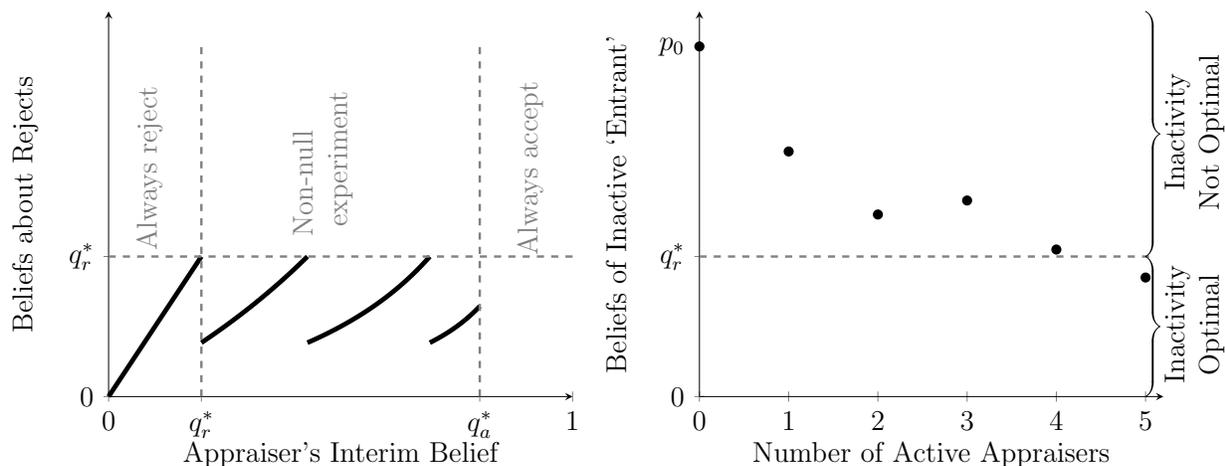


Figure 3: Chunky information example. Left panel: beliefs about rejected prospects, as a function of interim beliefs. Right panel: An inactive  $(N + 1)$ st appraiser computing interim beliefs when others play a symmetric equilibrium of the  $N$ -appraiser game. Five appraisers are enough to keep the sixth inactive.

Figure 3 illustrates the ‘excessively negative’ posteriors in a chunky information market. When appraisers reject, their beliefs at that stage is below  $q_r^*$ . As the number of appraisers increases, this eventually leads to equilibria with inactive appraisers.

It is important to note that this is not a ‘fixed costs’ result in any way. An appraiser that is not visited never pays for information; all costs are effectively marginal, as an appraiser has exclusive transaction rights at the time of information acquisition. Therefore, the number of competitors only matters via adverse selection and not congestion. Moreover, this result hinges crucially on the sequential closure of  $\mathcal{G}$ ; see Section 4.2 for a counterexample to the result when sequential closure fails.

## 4 Discussions and extensions

### 4.1 Reconciling the two Propositions

How are Proposition 1 and Proposition 2 to be reconciled? The former states that smooth information never limits entry: all appraisers, no matter their number, profit. The latter states that if information is the least bit chunky, information always limits entry: all but a small number of appraisers are excluded by the informational externality. We will see how these results are related by starting with a chunky menu, and progressively making it smoother. For a given number of appraisers  $N$ , eventually equilibria in which all appraisers profit appear, and equilibria in which appraisers are excluded disappear.

Start with a market  $(c, \mathcal{B})$  satisfying the assumptions of Proposition 1. Now, take a strictly positive monotonically decreasing sequence  $(k_i)_{i \in \mathbb{N}}$  with  $\lim_{i \rightarrow \infty} k_i = 0$ . Let

$$\mathcal{G}_i = \{\sigma \in \mathcal{B} \mid \sigma \text{ is null or } \min_{\theta} c(\sigma, \theta) \geq k_i\}. \quad (20)$$

Each  $\mathcal{G}_i$  is by construction sequentially closed and therefore satisfies the assumptions of Proposition 2. Also, whenever  $j > i$ ,  $\mathcal{G}_i \subset \mathcal{G}_j$  from monotonicity. Therefore, for any  $\sigma \in \mathcal{B}$ , there is an  $i$  such that  $\sigma \in \mathcal{G}_j$  for all  $j > i$ . We’ll be fixing a number of appraisers  $N$  and inspecting equilibria in the game with  $(c, \mathcal{G}_i)$  as  $i$  increases.

Returning to  $(c, \mathcal{B})$ , from Proposition 1 any equilibrium of the game with  $N \in \mathbb{N}$  appraisers  $\varphi^*$  has each appraiser using a strategy in which she undertakes non-null, and hence costly, experimentation. Therefore, there is an  $i$  after which  $\varphi^*$  is an equilibrium strategy profile in  $(c, \mathcal{G}_i)$ . Therefore, for any *fixed* number of appraisers  $N$ , if the information is *smooth enough* (even if not perfectly smooth) there is an equilibrium in which all  $N$  appraisers profit.

Moreover, fix an  $i \in \mathbb{N}$  and suppose the game with  $(c, \mathcal{G}_i)$  and  $N$  appraisers has

an equilibrium  $\varphi'$  in which some appraiser receives a payoff of 0. From Proposition 1,  $\varphi'$  is not an equilibrium in the game given by  $(c, \mathcal{B})$ . As a consequence, there is some player  $m \leq N$ , a  $\sigma_m \in \mathcal{B} \setminus \mathcal{G}_i$  and some acceptance rule  $a_m$ , such that  $(\sigma_m, a_m)$  would be a profitable deviation for  $m$  if  $\sigma_m$  were available to  $m$ . But as only null experiments cost 0,  $c(\sigma_m, \Theta) > 0$ . Thus, there is a  $j$  so that  $l \geq j \implies \sigma_m \in \mathcal{G}_l$ . Hence, such an equilibrium disappears when information becomes smooth enough.

## 4.2 Chunkiness without sequential closure

This section illustrates how sequential closure is key to Proposition 2. Sequential closure requires that if an experiment is available to an appraiser, so is running that experiment, then conducting another experiment, or not, depending on the outcome. To show that it's essential, we'll study a market in which there is only one non-null experiment available.

Take a market in which  $\mathcal{B} = \{\sigma_{null}, \sigma\}$  where  $\sigma$  has two outcomes  $\{0, 1\}$ , with  $\sigma(s = 1 | \theta = 1) = \sigma(s = 0 | \theta = 0) = k > .5$ . Then the interim beliefs at which it is optimal to acquire  $\sigma$  and condition acceptance or rejection on it satisfy

$$\max\{p_n \bar{\theta} + (1 - p_n) \underline{\theta}, 0\} \leq p_n k \bar{\theta} + (1 - p_n)(1 - k) \underline{\theta} - c. \quad (21)$$

so that an appraiser with interim beliefs  $p_n \in [\frac{-(1-k)\underline{\theta}+c}{k\bar{\theta}-(1-k)\underline{\theta}}, \frac{-k\bar{\theta}-c}{(1-k)\bar{\theta}-k\underline{\theta}}]$  will acquire information, with strict incentives in the interior. The interval being non-empty follows from non-triviality.

Now, suppose there are  $N$  appraisers and each acquires  $\sigma$  and conditions acceptance on the outcome. By (6), the interim beliefs of each appraiser  $n$  are given by

$$p_n^{(N)} = \frac{p_0 \sum_{m=0}^{N-1} (1-k)^m}{p_0 \sum_{m=0}^{N-1} (1-k)^m + (1-p_0) \sum_{m=0}^{N-1} k^m}. \quad (22)$$

Information never limits entry if and only if  $p_n^{(N)} \geq \frac{-(1-k)\underline{\theta}+c}{k\bar{\theta}-(1-k)\underline{\theta}}$  for all  $N$ . As

$$p_n^{(N)} - p_{n+1}^{(N)} = \frac{\frac{p_0(1-p_0)}{k(1-k)} [(1-k)k(k^{n-1} - (1-k)^{n-1}) + k^n(1-k)^n(2k-1)]}{\left(p_0 \frac{1-(1-k)^n}{k} + (1-p_0) \frac{1-k^n}{1-k}\right) \left(p_0 \frac{1-(1-k)^{n+1}}{k} + (1-p_0) \frac{1-k^{n+1}}{1-k}\right)}$$

is always positive (as  $k > .5$ ),  $p_n^{(\cdot)}$  is monotonically decreasing. Thus, to check if

information never limits entry, it suffices to inspect  $\lim_{N \rightarrow \infty} p_n^{(N)}$ . Using (22) we have that  $\lim_{N \rightarrow \infty} p_n^{(N)} = \frac{\frac{p_0}{k}}{\frac{p_0}{k} + \frac{(1-p_0)}{1-k}}$ . Thus, the relevant comparison is

$$\frac{\frac{p_0}{k}}{\frac{p_0}{k} + \frac{(1-p_0)}{1-k}} \leq \frac{-(1-k)\underline{\theta} + c}{k\bar{\theta} - (1-k)\underline{\theta}}. \quad (23)$$

Depending on the parameters, this inequality can go either way. Thus, absent sequential closure, the information acquisition technology alone does not determine the market structure.

### 4.3 Chunky commitments

Consider an appraiser with the ability to commit to acquiring particular information; a ‘first-moving’ appraiser. This may be the result of a permanent information acquisition unit, or a contract with a third party. Such an appraiser may well benefit from committing to acquiring excessive information. The reason is simple: in a symmetric equilibrium with  $N$  appraisers, the most each appraiser can get is  $1/N$  times the monopsonist profit. But committing to over-acquire information can keep other appraisers out. This example illustrates the point.

Suppose  $\Theta = \{-1, 1\}$  with a prior  $p_0 > .5$ . Take a binary experiment with precision  $k$ :  $\sigma(s = 1|\theta = 1) = \sigma(s = -1|\theta = -1) = k$ , and set its cost to be type-independent  $c(\sigma)$ . Take  $\mathcal{B}$  to contain a null experiment,  $\sigma$ , and its sequential closure.

Breaking with the ‘non-triviality’ condition, here let’s assume that immediate acceptance is preferable to acquiring  $\sigma$  before making a decision:  $\hat{p}\bar{\theta} + (1 - \hat{p})\underline{\theta} > \hat{p}k\bar{\theta} + (1 - \hat{p})(1 - k)\underline{\theta} - c(\sigma)$  for each  $\hat{p} \geq .5$ . As both sides are linear, this reduces to

$$.5 > k - c(\sigma). \quad (24)$$

This makes it so that acquiring  $\sigma$  is, in fact, never a best-response in the simultaneous game, as it is preferable to accept with a null signal above a belief of .5 and preferable to reject with a null signal below .5. Assuming that  $c(\sigma) = 1/8$  will make it so that it is never optimal to acquire a compound experiment, either. In equilibrium without an appraiser who can commit, it is immediate that every appraiser acquires a null experiment and accepts. Equilibrium beliefs are equal to the prior for each appraiser.

Each appraiser thus reaps a payoff of  $\frac{1}{N} \cdot (p_0 \cdot \bar{\theta} + (1 - p_0)\underline{\theta}) = \frac{2p_0 - 1}{N}$  in equilibrium.

By committing to acquiring  $\sigma$ , and then accepting following a good outcome and rejecting otherwise, could appraiser 1 benefit? For this to be preferable to no commitment, it has to be that

$$p_0 k - (1 - p_0)(1 - k) - c(\sigma) > \frac{2p_0 - 1}{N}. \quad (25)$$

To see if there is an equilibrium in which appraisers  $\{2, \dots, N\}$  reject all prospects, we first compute the induced interim belief  $p_n$  of appraiser  $n \neq 1$ ,

$$p_n = \frac{p_0(1 + (1 - k))}{p_0(1 + (1 - k)) + (1 - p_0)(1 + k)}. \quad (26)$$

For  $n$ 's immediate rejection to be a best-response, we need that  $p_n \bar{\theta} + (1 - p_n)\underline{\theta} \leq 0$ , or

$$p_0(2 - k) - (1 - p_0)(1 + k) \leq 0 \quad (27)$$

which reduces to simply

$$p_0 \leq \frac{1 + k}{3}. \quad (28)$$

Thus, to summarize, by committing to acquiring experiment  $\sigma$ , an appraiser can keep other appraisers inactive if equation (28) holds. When (25) holds, it is profitable for an appraiser with commitment power to do this.

Therefore, it is possible for an appraiser with commitment power to become a monopsonist by acquiring *too much* information, enough that the informational externality keeps other appraisers out. This is a novel form of entry deterrence, and should give policymakers pause. In this example the market without commitments was more efficient, but this is not necessarily the case in general, complicating the matter.

## 5 Conclusion

I hope I have illustrated that the fine details of information acquisition matter. Even though information bears only marginal and not fixed costs, the viscosity of information determines the emergent market structure. I show that agents constrained to chunky information produce 'excessive' informational externalities, and that in

my setting this leads to informational oligopolies. This should make us think more broadly about informational mechanisms that stymie market entry, and the sensitivity of our models to the details of related assumptions.

Additionally, I bring recent work on information acquisition to bear on an applied setting and achieve some qualitative results without large compromises on abstraction. Admittedly, the setting studied is quite stylized, lacking such ordinary things as prices. Although this is a shortcoming, it allows for a clearer focus on interdependent information acquisition by shutting down strategic responses in other domains.

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