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Abstract
A monopolistic information provider sells an informative experiment to a large number of perfectly competitive firms. Within each firm, a principal contracts with an exclusive agent who is privately informed about his production cost. Principals decide whether to acquire the experiment, that is informative about the agent's production cost. While more accurate information reduces agency costs and allows firms to increase production, it also results in a lower market price, which reduces principals' willingness to pay for information. We show that, even if information is costless for the provider, the optimal experiment is not fully informative when demand is price-inelastic and agents are likely to be inefficient. This result hinges on the assumption that firms are competitive and exacerbates when principals can coordinate vis-à-vis the information provider. In an imperfectly competitive information market, providers may restrict information by not selling the experiment to some of the principals.

Keywords: Adverse Selection, Information Acquisition, Experiments, Competitive Markets.

JEL Classification: D40, D82, D83, L11.

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1 Introduction

Information asymmetries have important effects in many industries (see, e.g., Lafontaine and Slade, 1997, and Lafontaine and Shaw, 1999). A large theoretical literature analyzes the impact of agency costs on firms' decisions,[1] and shows that information asymmetries between uninformed principals (firms' owners or shareholders) and privately informed agents (managers) create distortions in production that impact firms' performance, industry structure and ultimately social welfare. The severity of these distortions, however, depends on the degree of asymmetric information, which is exogenous in most models.

When firms that delegate decisions to self-interested agents design incentive schemes, principals often acquire information from intermediaries, such as auditors and certification companies, that are able to discover agents' private information and credibly reveal it. We show that, although information acquisition enhances efficiency by reducing agency costs and improving production, the aggregate amount of information acquired in a market also affects firms' profits and welfare indirectly, through its impact on equilibrium market prices and quantities.

How much are competitive firms willing to pay for information? How much information do intermediaries collect and reveal to competitive firms? What is the difference between firms' individual and collective incentives to acquire information? Do firms in competitive markets acquire too much or too little information?

Information acquisition and information disclosure are two aspects of the information management problem that, in recent years, has become central to the mechanism design literature (see the survey by Bergemann and Välimäki, 2002). In fact, the emergence of endogenous information structures provides both theoretical insights for mechanism design, and policy implications for market design and regulation.

We contribute to this literature by analyzing an environment in which a monopolistic information provider (e.g., a certification intermediary such as an auditing company or a debt rating agency) sells an informative experiment to a large number of perfectly competitive firms,[2] each composed by a principal and an exclusive agent who is privately informed about his binary cost of production.[3] Principals take the market clearing price as given, simultaneously choose whether to acquire information and offer incentive compatible mechanisms to agents. The information provider designs the accuracy of the experiment (which is the same for all firms) that produces an informative signal (which is specific to each firm) about the agent's cost. This signal allows the principal to better screen the agent.

Our main result is that, even if information is costless for the provider (and even if the provider

[1] See, e.g., Bassi *et al.* (2015), Boyer and Laffont (2003), Caillaud *et al.* (1999), Gal-Or, (1991, 1999), Hart (1983), Hermalin (1992), Martimort (1996), Martin (1993), and Raith (2003), among many others.

[2] Considering a monopolistic information provider provides a useful benchmark. A concentrated market structure in the certification industry often arises due to economies of scale or specialization — see, e.g., Lizzeri (1999) and Bergmann *et al.* (2015) who also considers a monopolistic market for information.

[3] The production cost may be interpreted as a measure of the manager's efficiency or of the extent to which his preferences are aligned to those of the firm's owner.

has the same information as the principal ex ante), the optimal experiment is not fully informative when demand is inelastic — i.e., in industries that face low competition from other markets where substitute products are sold — and agents are likely to have high costs — i.e., in industries with low R&D intensity or far from the technological frontier.

A key role in the analysis is played by a firm's *incremental value* of acquiring information. This represents the price that a principal is willing to pay for the experiment, and is equal to the difference between the profit of a firm that acquires information, and his outside option — i.e., the profit of a firm that does not acquire information, when all other firms do. Increasing the experiment's accuracy has two effects on the incremental value of information. First, a more informative experiment increases principals' willingness to pay because, holding the market price constant, it reduces agents' information rent and increases production and profits: a *quantity effect* of information. Second, since a more informative experiment increases the aggregate quantity produced, it also reduces the market clearing price, which (ceteris paribus) reduces both principals' equilibrium profit and their outside option: a *price effect* of information.

If the price effect is negative and dominates the quantity effect of information, the provider prefers to offer an experiment that does not fully reveal agents' cost. This happens when demand is relatively price inelastic because, in this case, increasing the experiment's accuracy greatly reduces the market price and, hence, principals' willingness to pay for information. Moreover, the price effect is stronger when the probability of the agent having a low cost is low because, in this case, the informativeness of the experiment has a large impact on aggregate supply and, hence, on the market price.

Our analysis suggests the existence of a positive relationship between competition, transparency and efficiency. In very competitive markets (where demand is very responsive to prices or with high R&D intensity), firms obtain accurate information on agents' costs and produce on the first-best frontier. By contrast, in more mature and established industries that face relatively low competition from other markets (where demand is less responsive to prices), less accurate information is produced, which results in higher information rents that distort production and increase prices, thus harming final consumers.

Although our main model analyzes a monopolist selling information to competitive firms, we also consider alternative market structures both in the product market and in the information market. When firms coordinate production decisions and act as a monopoly in the product market, the optimal experiment is fully informative. Similarly, perfect competition between information providers (with each firm independently choosing its provider) induces them to offer the fully informative experiment.[4] In imperfectly competitive information markets, however, information providers may still restrict the total amount of information disclosed, by exploiting their market power to exclude some firms from the market, in order to increase profits. Finally, if firms can jointly commit to acquire information from a single provider (i.e., they form a monopsony in the information market) but lack market power in the product market, the equilibrium experiment

[4] See Lizzeri (1999) for a similar result.

is less informative than with a monopolistic provider. In this case, the willingness to pay for information only depends on firms' equilibrium profit (and not on the outside option that affects the incremental value of information), thus resulting in a stronger price effect of information. Hence, a monopsony in the information market may be worse than a monopoly for final consumers.

The most natural interpretation of our theoretical framework is auditing. Like our information provider(s), auditing companies sell to their clients information that can take different forms — e.g., information about firms' production technologies and how efficiently they are employed, or information about firms' financial conditions. The auditing market feature four large international service networks (the Big 4) that are highly specialized in offering their services to specific industries. Craswell *et al.* (1995), among many others, argue that auditees voluntarily contract with expensive industry specialists that offer quality-differentiated audits, even though any licensed auditor can legally perform audits (see also Eichenseher and Danos, 1981). In fact, an important component of audit pricing is an industry-specific premium that provides positive returns to investment in industry specialization. This is consistent with our model's implication that information providers have an incentive to monopolize an industry and suggest that antitrust authorities should worry about industry-specific auditors that may reduce welfare.

Our paper contributes to the literature on selling information. The closest paper is Bergemann *et al.* (2015), that analyzes a monopolist selling informative experiments to buyers facing a decision problem, who have different prior information and, hence, willingness to pay for the experiment. When the monopolist offers a menu of experiments to screen buyers' types, a rent-extraction/efficiency trade off may lead to a distortion in the experiment's accuracy and require flat or discriminatory pricing. Our analysis complements Bergemann *et al.* (2015) because it shows that a monopolist may undersupply information even when buyers have no private information.

In the auction literature, Milgrom and Weber (1982) consider the incentives of an auctioneer to disclose public information about the characteristics of the object on sale and show that transparency increases the seller's revenue when signals are affiliated (the *linkage principle*).[5] In a price discrimination environment, Ottaviani and Prat (2001) show that a monopolist wants to acquire and commit to reveal information affiliated with the buyer's information. Similar results are obtained by Johnson and Myatt (2006), Esö and Szentes (2007), Bergemann and Pesendorfer (2007), and Li and Shi (2013) in models where the seller commits (simultaneously or sequentially) to disclosure and pricing policies. We extend this literature by: (i) highlighting the effect of information disclosure on the market clearing price (which is typically neglected in mechanism design); (ii) considering an endogenous information structure, as in Bergemann *et al.* (2015), while in other papers the information provider only chooses whether to disclose his exogenous information.

As in our analysis, the effect of accuracy on market prices also plays an important role in Admati and Pfleiderer (1986, 1990), who analyze the sale of information to traders in financial markets. They show that the seller may prefer to supply noisier versions of the information he posses, in order to reduce the information revealed to traders by prices. In our model, this dilution problem

[5] See also Abraham *et al.* (2014) who study vertical information disclosure in auctions.

is absent since agents' costs are independent, so that principals cannot infer them from prices, yet the seller may still offer an experiment that is not fully informative to soften competition.

Lizzeri (1999) shows that a monopolistic certification intermediary can benefit from manipulating information about the quality of a seller's product and extracts all the information surplus by only revealing whether quality is above a minimal standard. While Lizzeri (1999) considers a single buyer of information, in our model principals compete in the product market so that their production choices create negative externalities through the price mechanism.

More recent papers, among which Balestrieri and Izmalkov (2014), Celik (2014), Koessler and Skreta (2014), Mylovanov and Tröger (2014), and Piccolo *et al.* (2015) take an informed-principal perspective: privately informed sellers choose the amount of information on the product's quality to disclose to buyers. By contrast, in our model principals and the information provider are different players. A similar approach is developed in the growing literature on Bayesian persuasion — e.g., Rayo and Segal (2010) and Kamenica and Gentzkow (2011) — where, however, there are no monetary transfers.

The rest of the paper is organized as follows. Section 2 discusses the model. We characterize the equilibrium and present the main results in Section 3. Section 4 analyzes extensions and discusses how our results depend on the market structure. Section 5 concludes. All proofs are in the Appendix.

2 The Model

Market and Players. A perfectly competitive market has a continuum of unit mass of risk-neutral firms that produce a homogeneous good.[6] Following Legros and Newman (2013), we assume that there is a representative consumer with smooth quasi-linear utility function

$$u\left(x\right) - px,$$

where $x \geq 0$ represents the quantity consumed and p the market price, with $u'\left(\cdot\right) > 0$ and $u''\left(\cdot\right) \leq 0$. Since consumers take the price p as given, the first order condition for utility maximization, $u'\left(x\right) = p$, yields a standard differentiable downward-sloping demand function $D\left(p\right) = u'^{-1}\left(p\right)$.

Firms also take the (correctly anticipated) market price p as given when taking their production decisions. Each firm owner (principal) relies on a self-interested and risk-neutral manager (agent) to run the firm. A firm's production technology depends on the agent's (private) marginal cost of production $\theta_i \in \Theta \equiv \left\{\underline{\theta}, \overline{\theta}\right\}$, with $\Pr\left[\theta_i = \underline{\theta}\right] = \nu$. Agents are privately informed about their cost of production, and have reservation utility normalized to zero without loss of generality.

For simplicity, we assume that each firm either produces 1 unit of the good, or it does not produce at all — i.e., a firm's supply is $y_i \in \{0, 1\}$. A binary production technology can be interpreted as an approximation of symmetric firms' production decisions in a perfectly competitive market, since firms are price takers and can either produce zero or a fixed share of the total quantity demanded.

[6] In Section 4.1, we consider a monopolistic market.

Information Acquisition. A principals can acquire information on his agent's cost from a monopolistic information provider.[7] Following the literature, we assume that the information provider commits to an anonymous disclosure policy $\{E, \rho_E\}$, which specifies an experiment E and its price ρ_E — see, e.g., Bergemann *et al.* (2014).[8] An experiment $E \equiv \{S_E, f_E\}$ is an information structure consisting of a set of signals $S_E \subseteq \mathbb{R}$, with generic element s_i, and a likelihood function $f_E : \Theta \to \Delta(S_E)$ mapping states into signals. Signals are independent conditional on the agent's cost. Slightly abusing notation, we denote by $F_E(s_i|\theta_i)$ the cumulative distribution function indicating the probability that experiment E yields a signal lower than s_i when the agent's cost is θ_i, with corresponding density $f_E(s_i|\theta_i)$.

The provider can produce any information structure at no cost. Essentially, the provider does not know the agent's cost, but he can improve upon each principal's original information with arbitrarily precise and costless signals. The outcome of an experiment purchased by a principal is verifiable by his agent, but not by other players.

Contracts. Agents need to be induced by principals to truthfully reveal their information. Following the literature — e.g., Baron and Myerson (1982) and Myerson (1981) — we assume that principals offer a direct revelation mechanism

$$\{q_i(m_i, s_i), t_i(m_i, s_i)\}_{m_i \in \Theta, s_i \in S_E \cup \{\varnothing\}},$$

which specifies a probability of production

$$q_i(\cdot) : \Theta \times S_E \cup \{\varnothing\} \to [0, 1]$$

and a transfer paid to the agent

$$t_i(\cdot) : \Theta \times S_E \cup \{\varnothing\} \to \mathbb{R},$$

both contingent on the agent's report about his cost (m_i) and on the signal produced by the information provider (s_i).[9] As a convention, $s_i = \varnothing$ indicates that principal i has not acquired information. Contracts between principals and agents are secret.

Timing. The timing of the game is the following:

- Agents learn their marginal costs.

[7] In Section 4.2, we consider competitive information providers.

[8] The assumption of anonymous contracts is reasonable since firms are ex ante identical and, hence, price discrimination may be legally impossible due to non-discriminatory requirements. In addition, this assumption simplifies the opportunism problem that arises in an oligopolistic industry, whose solution depends on the choice of off-equilibrium beliefs.

[9] We assume that principals have the bargaining power to offer a mechanism to the agent. This is consistent, for example, with a situation in which there is a continuum of competing identical agents of mass greater than the mass of principals.

- The information provider announces an information disclosure policy.
- Principals decide whether to acquire the experiment from the information provider.
- Principals offer contracts to agents.
- Each firm that has acquired the experiment observes a signal.
- Firms produce, transfers are paid, and goods are traded.

Equilibrium. A (symmetric) equilibrium specifies a disclosure policy $\{E^e, \rho_E^e\}$ that maximizes the information provider's expected profit;[10] an individual supply function $y^e(\theta_i, s_i) \in \{0, 1\}$ that maximizes principals' expected profit and depends on the individual draw $(\theta_i, s_i) \in \Theta \times S_{E^e} \cup \{\varnothing\}$; an aggregate supply function that (because of the continuum of firms and the law of large numbers) is almost surely equal to

$$y(E^e) \equiv \sum_{\theta_i \in \Theta} \Pr[\theta_i] \int_{s_i \in S_{E^e} \cup \{\varnothing\}} y^e(\theta_i, s_i)\, dF_{E^e}(s_i|\theta_i),$$

and an equilibrium price $p^e = u'(y(E^e))$ that equalizes demand and aggregate supply. As in Legros and Newman (2013), the aggregate supply $y(\cdot)$ should be interpreted as a "short run" supply curve, when there is no entry of new firms in the market.

Assumptions. To make the problem interesting we assume that with complete information — i.e., if the experiment fully reveals the agents' costs — it is always profitable for principals to produce.

Assumption 1 $u'(1) > \overline{\theta} > \underline{\theta}$.

We also assume that the information provider's maximization problem is strictly concave.

Assumption 2 *The function* $\Phi(x) = xu''(\nu + (1-\nu)x) + 2u'(\nu + (1-\nu)x)$ *is decreasing in* x.

We denote by $P \equiv [u'(1), u'(\nu)]$ the set of admissible equilibrium prices.[11]

3 Equilibrium Analysis

Consider a symmetric equilibrium in which all principals acquire information. Given an experiment E offered by the information provider, for any expected market price p, let $V_E(p)$ be a principal's equilibrium indirect profit function when he acquires the experiment, and let $V_\varnothing(p)$ be his indirect profit function when he does not acquire the experiment and all other principals do, ceteris paribus.

[10] We assume that all principals can acquire the experiment offered by the provider, if profitable, and briefly discuss policies based on stochastic rationing at the end of Section 3.3.

[11] The lowest possible quantity produced is ν since by Assumption 1 firms always produce in equilibrium when the cost is low.

Given the equilibrium market price $p(E)$ induced by experiment E, (when all principals acquire E) the highest price that the information provider can charge a principal reflects the *incremental value* of acquiring information and is equal to

$$\rho(E) \equiv V_E(p(E)) - V_\varnothing(p(E)).$$

Since this price makes each principal indifferent between acquiring E and not,[12] the information provider offers the experiment that maximizes $\rho(E)$. The functions $V_E(p(E))$ and $V_\varnothing(p(E))$ determine the impact of the experiment's informativeness on the provider's profit. In the next 2 sections, we are going to separately analyze these two functions.

3.1 Uninformed Principal

Consider a principal who does not acquire experiment E, while all other principals do. Agent i's expected utility is

$$u_i(\theta_i, \varnothing) \equiv q_i(\theta_i, \varnothing)(t_i(\theta_i, \varnothing) - \theta_i).$$

Using standard techniques, agent i's (relevant) incentive compatibility constraint is

$$u_i(\underline{\theta}, \varnothing) \geq u_i(\overline{\theta}, \varnothing) + q_i(\overline{\theta}, \varnothing)\Delta\theta,$$

while his (relevant) participation constraint is $u_i(\overline{\theta}, \varnothing) \geq 0$.

Setting $u_i(\overline{\theta}, \varnothing) = 0$, for any expected equilibrium price $p \in P$, a principal who does not acquire information solves

$$\max_{q_i(\cdot,\varnothing)\in[0,1]} \left\{ \sum_{\theta_i \in \Theta} \Pr[\theta_i]\, q_i(\theta_i, \varnothing)(p - \theta_i) - \nu q_i(\overline{\theta}, \varnothing)\Delta\theta \right\}, \tag{1}$$

where $q_i(\overline{\theta}, \varnothing)\Delta\theta$ is the information rent of a low-cost agent. Differentiating equation (1) with respect to $q_i(\overline{\theta}, \varnothing)$ and re-arranging yields the principal's virtual surplus when his agent has a high cost

$$\Gamma_\varnothing(p) \equiv p - \overline{\theta} - \frac{\nu}{1-\nu}\Delta\theta.$$

This is positive if and only if

$$\nu \leq \underline{\nu}(p) \equiv \frac{1}{1 + \frac{\Delta\theta}{p - \overline{\theta}}} < 1.$$

Hence, if a principal expects his agent to have a low cost with a sufficiently low probability, he induces a high-cost agent to produce; otherwise, he shuts down production of a high-cost agent.

The following lemma characterizes the solution to problem (1).

[12] Notice that, with a continuum of principals, the production choice of a single principal does not affect the market price. Hence, if a principal unilaterally deviates from a candidate equilibrium with price $p(E)$, the market price remains $p(E)$.

Proposition 3 *For any expected market price $p \in P$, the optimal contract offered by a principal who does not acquire information features $q_i(\underline{\theta}, \varnothing) = 1$ and*

$$q_i(\overline{\theta}, \varnothing) = \begin{cases} 1 \text{ if } \nu \le \underline{\nu}(p), \\ 0 \text{ if } \nu > \underline{\nu}(p). \end{cases}$$

A principal who does not acquire information always produces when his agent has a low cost; while he induces a high-cost agent not to produce if the expected rent that he has to pay to a low-cost agent in order to induce him to reveal his information (when the high-cost agent produces), $\nu\Delta\theta$, is large relative to the expected price-cost margin when the agent has a high cost, $(1-\nu)\left(p-\overline{\theta}\right)$. In this case, the profit obtained by producing with a high cost is so low that the principal prefers to reduce the information rent of a low-cost agent to zero by shutting down production when the agent has a high cost.

Therefore, the principal's expected profit if he does not acquire experiment E when all other principals do is

$$V_{\varnothing}(p(E)) \equiv \nu(p(E) - \underline{\theta}) + (1-\nu)\max\{0; \Gamma_{\varnothing}(p(E))\}, \tag{2}$$

where $p(E)$ is the equilibrium market price when all principals acquire information.

3.2 Informed Principal

Consider now a situation in which all principals acquire experiment E, so that a principal's equilibrium profit function is $V_E(p)$.

Given an experiment E offered by the information provider and an expected market price p, the problem of a principal who acquires information is

$$\max_{q_i(\cdot,\cdot)\in[0,1]} \left\{ \sum_{\theta_i\in\Theta} \Pr[\theta_i] \int_{s_i\in S_E} q_i(\theta_i, s_i)(p-\theta_i)\, dF_E(s_i|\theta_i) - \nu\Delta\theta \int_{s_i\in S_E} q_i(\overline{\theta}, s_i) dF_E(s_i|\underline{\theta}) \right\}, \tag{3}$$

where $\Delta\theta \int_{s_i\in S_E} q_i(\overline{\theta}, s_i) dF_E(s_i|\underline{\theta})$ is the expected information rent of a low-cost agent. Differentiating equation (3) with respect to $q_i(\overline{\theta}, s_i)$ and rearranging yields the principal's virtual surplus when his agent has a high cost and he observes signal s_i

$$\Gamma_E(s_i, p) \equiv p - \overline{\theta} - \underbrace{\frac{\nu}{1-\nu} \frac{f_E(s_i|\underline{\theta})}{f_E\left(s_i|\overline{\theta}\right)}}_{=\frac{\Pr[\underline{\theta}|s_i]}{\Pr[\overline{\theta}|s_i]}} \Delta\theta.$$

As in the case of an uninformed principal, whether a principal who acquires information chooses to shut down production of a high cost-agent depends on the ratio between his posterior beliefs about the agent's cost. If this ratio is large, the principal assigns a relatively high probability to state $\underline{\theta}$ (rather than $\overline{\theta}$) when he observes signal s_i. In this case, $\Gamma_E(s_i, p) < 0$ and the principal prefers to induce a high-cost agent not to produce in order to eliminate the rent of a low-cost agent, because he expects to pay this rent with a relatively high probability. By contrast, if the ratio is small relative to the price-cost margin when the agent has a high cost, $\Gamma_E(s_i, p) \geq 0$ and the principal prefers to produce and pay the information rent.

The following lemma characterizes the solution to problem (3).

Lemma 1 *Let* $\tilde{S}_E(p) \equiv \{s_i \in S_E : \Gamma_E(s_i, p) \geq 0\}$. *For any expected market price* $p \in P$*, the optimal contract offered by a principal who acquires information features* $q_i(\underline{\theta}, s_i) = 1 \quad \forall s_i$*, and*

$$q_i(\overline{\theta}, s_i) = \begin{cases} 1 \text{ if } s_i \in \tilde{S}_E(p), \\ 0 \text{ if } s_i \notin \tilde{S}_E(p). \end{cases}$$

A principal always produces when his agent has low cost by Assumption 1, and produces if and only if his virtual surplus is positive when his agent has high cost. Moreover, if all principals acquire information, then by the law of large numbers aggregate supply is

$$y(E) = \nu + (1-\nu)\Pr\left[s_i \in \tilde{S}_E(p_E)\right],$$

where the equilibrium market price is $p_E = u'(y(E))$, and the principal's expected profit is

$$\begin{aligned} V_E(p_E) &\equiv \nu(p_E - \underline{\theta}) + (1-\nu)\int_{s_i \in S_E} \max\{0, \Gamma_E(s_i, p_E)\}\, dF_E(s_i|\overline{\theta}) \\ &= \nu(p_E - \underline{\theta}) + (1-\nu)\int_{s_i \in \tilde{S}_E(p_E)} \Gamma_E(s_i, p_E)\, dF_E(s_i|\overline{\theta}). \end{aligned}$$

Notice that the equilibrium price and the principals' expected profit only depend on $\tilde{S}_E(p_E)$, the subset of signals that do not induce shut down of the high-cost agent. This allows to simplify the analysis through the following result, which echoes the findings of Bergemann *et al.* (2014).

Lemma 2 ***Binary Experiments****: Every experiment offered by the information provider in equilibrium consists of only two signals.*

The see why this result holds, consider a generic experiment E with $S_E \subseteq \mathbb{R}$. The market price when all principals acquire information, p_E, only depends on the probability of production in the high-cost state

$$\Pr\left[s_i \in \tilde{S}_E(p_E)\right] = \int_{s_i \in \tilde{S}_E(p_E)} dF_E(s_i|\overline{\theta}).$$

Hence, the information provider can offer a simpler experiment E', with $S_{E'} \subset S_E$, that assigns positive probability

$$\int_{s_i \in \tilde{S}_E(p_E)} dF_E(s_i|\overline{\theta})$$

only to the signal

$$s_i^* \in \arg\min_{s_i \in \tilde{S}_E(p)} \frac{f_E(s_i|\underline{\theta})}{f_E(s_i|\overline{\theta})}$$

that minimizes the probability of shut down in the high-cost state. Principals strictly prefer experiment E' to experiment E, since E' increases principals' profits by reducing agents' information rents and results in the same production decision and market price p_E.

Lemma 2 allows us to focus on binary experiments that consist of two signals only, $\overline{s}$ and $\underline{s}$, and that we can represent as

	$\overline{s}$	$\underline{s}$
$\overline{\theta}$	α	$1-\alpha$
$\underline{\theta}$	$1-\beta$	β

where, slightly abusing notation, the precision parameters $\alpha = \Pr\left[\overline{s}|\overline{\theta}\right]$ and $\beta = \Pr\left[\underline{s}|\underline{\theta}\right]$ measure the informativeness, or accuracy, of the experiment. As a convention (and without loss of generality), we assume that $\alpha + \beta \geq 1$. An experiment with $\alpha = \beta = 1$ is fully informative.

With binary experiments, the principal's problem (3) is

$$\max_{q_i(\cdot)\in[0,1]} \left\{ \sum_{\theta_i \in \Theta} \Pr\left[\theta_i\right] \sum_{s_i \in \{\underline{s},\overline{s}\}} q_i\left(\theta_i, s_i\right)\left(p - \theta_i\right) \Pr\left[s_i|\theta_i\right] - \nu \Delta\theta \sum_{s_i \in \{\underline{s},\overline{s}\}} q_i(\overline{\theta}, s_i) \Pr\left[s_i|\underline{\theta}\right] \right\},$$

and the principal's virtual surplus when his agent has a high cost is

$$\Gamma_{\alpha,\beta}\left(s_i, p\right) = \begin{cases} p - \overline{\theta} - \frac{\nu}{1-\nu}\frac{\beta}{1-\alpha}\Delta\theta & \text{if } s_i = \underline{s}, \\ p - \overline{\theta} - \frac{\nu}{1-\nu}\frac{1-\beta}{\alpha}\Delta\theta & \text{if } s_i = \overline{s}. \end{cases}$$

This surplus is decreasing in α and β when $s_i = \underline{s}$: with a more informative experiment, a principal who observes signal $\underline{s}$ assigns a higher probability to the agent having a low cost and, hence, increases production distortion in the high-cost state to reduce the information rent. By contrast, the virtual surplus is increasing in α and β when $s_i = \overline{s}$, because in this case a more informative experiment induces a principal who observes signal $\overline{s}$ to reduce production distortion in the high-cost state. Clearly, when the experiment is fully informative, in the high cost-state a principal observes $\overline{s}$ and always produces (by Assumption A1). Moreover, by the definition of α and β, $\Gamma_{\alpha,\beta}\left(\overline{s}, p\right) \geq \Gamma_{\alpha,\beta}\left(\underline{s}, p\right)$.

Proposition 4 *For any expected market price $p \in P$, the optimal contract offered by a principal who acquires a binary experiment features $q_i\left(\underline{\theta}, \underline{s}\right) = q_i\left(\underline{\theta}, \overline{s}\right) = 1$ and*

$$q_i\left(\overline{\theta}, \underline{s}\right) = \begin{cases} 1 & \textit{if } \frac{\beta}{1-\alpha} \leq \frac{1-\nu}{\nu}\frac{p-\overline{\theta}}{\Delta\theta} \\ 0 & \textit{otherwise} \end{cases}$$

$$q_i\left(\overline{\theta}, \overline{s}\right) = \begin{cases} 1 & \textit{if } \frac{1-\beta}{\alpha} \leq \frac{1-\nu}{\nu}\frac{p-\overline{\theta}}{\Delta\theta} \\ 0 & \textit{otherwise.} \end{cases}$$

Hence, distorting production of an inefficient agent when the principal observes signal $\underline{s}$ is optimal if α is high so that the experiment is informative, holding β constant. In this case, the principal prefers to eliminate the information rent of an efficient agent, since he expects the agent to have a low cost with a high probability. By contrast, distorting production of an inefficient agent when the principal observes signal $\overline{s}$ is optimal if α is low, holding β constant, because in this case the signal is not informative enough about the agent's cost.

If all principals acquire a binary experiment with precision α and β, by Proposition 4 aggregate supply is

$$y(\alpha) \equiv \begin{cases} 1 & \text{if } \Gamma_{\alpha,\beta}(\underline{s}, p(\alpha)) \geq 0, \\ \nu + (1-\nu)\alpha & \text{if } \Gamma_{\alpha,\beta}(\overline{s}, p(\alpha)) \geq 0 > \Gamma_{\alpha,\beta}(\underline{s}, p(\alpha)), \\ \nu & \text{if } \Gamma_{\alpha,\beta}(\overline{s}, p(\alpha)) < 0, \end{cases}$$

where $p(\alpha) \equiv u'(y(\alpha))$ is the market clearing price. Hence, a principal's expected profit is

$$V_{\alpha,\beta}(p(\alpha)) \equiv \nu\left(p(\alpha) - \underline{\theta}\right) + (1-\nu) \sum_{s \in \{\underline{s}, \overline{s}\}} \Pr\left[s|\overline{\theta}\right] \max\left\{0, \Gamma_{\alpha,\beta}(s, p(\alpha))\right\}. \tag{4}$$

Notice that aggregate supply and the market clearing price only depend on α and not on β because principals always produce in the low-cost state. In particular, when α increases — i.e., the experiments becomes more accurate — expected production increases and, as a consequence, the equilibrium price decreases.

3.3 Optimal Experiment

If the information provider offers a binary experiment with precision α and β, the price that each principal is willing to pay for the experiment is $V_{\alpha,\beta}(p(\alpha)) - V_{\varnothing}(p(\alpha))$ — i.e., the difference between a principal's expected profits with and without information acquisition, if all other principals acquire information. Hence, using (2) and (4), the information provider chooses α and β to maximize[13]

$$\rho(\alpha, \beta) \equiv (1-\nu)\left[\sum_{s \in \{\underline{s}, \overline{s}\}} \Pr\left[s|\overline{\theta}\right] \max\left\{0, \Gamma_{\alpha,\beta}(s, p(\alpha))\right\} - \max\left\{0, \Gamma_{\varnothing}(p(\alpha))\right\}\right].$$

Through its effect on the market price, the experiment's precision affects both the equilibrium profit with information acquisition and the deviation profit of a principal who does not acquire information. Moreover, the experiment's precision also directly affects the principal's virtual surplus when his agent has a high cost and, hence, his production choice.

In order to characterize the solution to the provider's problem, it is useful to establish the following facts. First, it is never optimal for the information provider to always induce shut down of the high-cost agent because, in this case, $\rho(\alpha, \beta) \leq 0$. Second, if the information provider offers an experiment that induces shut down with only one signal, then this signal must be $\underline{s}$.[14] Third, the best experiment that never induces shut down is the fully informative one. The reason is that an experiment that never induces shut down with $\max\{\alpha, \beta\} < 1$ yields $\rho(\alpha, \beta) = 0$,[15] while an

[13] Of course, the objective function does not depend on the principal's surplus in the low-cost state, because the principal always produces when the agent has a low cost (the "no distortion at the top" property).

[14] This immediately follows from the fact that $\Gamma_{\alpha,\beta}(\overline{s}, p(\alpha)) \geq \Gamma_{\alpha,\beta}(\underline{s}, p(\alpha))$.

[15] Notice that it is straightforward to show that $\Gamma_{\alpha,\beta}(\underline{s}, p(\alpha)) > 0$ implies $\Gamma_{\varnothing}(p(\alpha)) > 0$.

experiment with $\alpha = \beta = 1$ yields

$$\rho(1,1) = \min\left\{\nu\Delta\theta, (1-\nu)\left(u'(1) - \overline{\theta}\right)\right\} > 0.$$

Therefore, the optimal experiment for the information provider is either the fully informative one, or the best experiment that induces shut down only with signal $\underline{s}$.

Let $\tilde{\alpha}$ be such that

$$\Gamma_{\varnothing}(p(\tilde{\alpha})) = 0 \quad \Leftrightarrow \quad \underbrace{u'(\nu + (1-\nu)\tilde{\alpha})}_{p(\tilde{\alpha})} = \overline{\theta} + \frac{\nu}{1-\nu}\Delta\theta. \tag{5}$$

Since the price function is decreasing in α, when $\alpha \geq \tilde{\alpha}$ the profit of a principal who does not acquire information (given that his competitors do) is equal to zero.

Lemma 3 *An experiment that is not fully informative and induces shut down with only one signal yields*

$$\rho(\alpha,\beta) = \begin{cases} (1-\nu)\alpha\left[u'(\nu + (1-\nu)\alpha) - \overline{\theta}\right] - \nu(1-\beta)\Delta\theta & \text{if } \alpha \geq \tilde{\alpha}, \\ \nu\Delta\theta - (1-\alpha)(1-\nu)\left[u'(\nu + (1-\nu)\alpha) - \overline{\theta}\right] & \text{if } \alpha < \tilde{\alpha}. \end{cases} \tag{6}$$

When a principal who does not acquire information shuts down production in the high-cost state (i.e., when $\alpha > \tilde{\alpha}$), the incremental value of information in Lemma 3 is equal to the expected profit when the agent has high cost and the signal is $\overline{s}$,

$$(1-\nu)\alpha\left[u'(\nu + (1-\nu)\alpha) - \overline{\theta}\right],$$

minus the rent of a low-cost agent, $\nu(1-\beta)\Delta\theta$. By contrast, when a principal who does not acquire information produces in the high-cost state (i.e., when $\alpha < \tilde{\alpha}$), the incremental value of information is equal to the rent saved by the experiment, $\nu\Delta\theta$, minus the revenue loss when the signal is $\underline{s}$ (since in this case information induces shuts down),

$$(1-\alpha)(1-\nu)\left[u'(\nu + (1-\nu)\alpha) - \overline{\theta}\right].$$

The next result characterizes the experiment that maximizes the information provider's profit, by comparing the experiment that maximizes (6) with the fully informative one. We let $\varepsilon(1) \equiv \frac{u'(1)}{|u''(1)|}$ denote the elasticity of demand with respect to price at $q = 1$, which is the inverse of the elasticity of price with respect to quantity.

Theorem 5 *For any pair $(\nu, \overline{\theta})$ and any utility function $u(\cdot)$, there exists a threshold $\overline{\varepsilon}(\nu, \overline{\theta})$ such that the optimal experiment features $\alpha^* < 1$ if and only if $\varepsilon(1) \leq \overline{\varepsilon}(\nu, \overline{\theta})$, and $\beta^* = 1$. The threshold $\overline{\varepsilon}(\nu, \overline{\theta})$ is decreasing in ν and increasing in $\overline{\theta}$.*

The optimal experiment features $\beta^* = 1$ because, holding α constant, a higher β increases the informativeness of signal $\underline{s}$ and allows principals to reduce information rents (see (6)). By contrast, the optimal experiment may feature $\alpha^* < 1$ because an increase in the informativeness of signal $\overline{s}$ has two contrasting effects on the value of information. First, a higher α increases principals' willingness to pay for information because, holding the market price constant, it increases expected production (since it increases the probability of signal $\overline{s}$ when the cost is high): a quantity effect of information. Second, however, by increasing production a higher α also reduces the market price which, ceteris paribus, reduces both the principals' equilibrium profits and their deviation profit: a price effect of information. This has an ambiguous effect on principals' willingness to pay for information.

The price effect is negative and dominates the quantity effect of information when price is elastic with respect to quantity (or, equivalently, when demand is inelastic with respect to price), which is typically the case for markets that face weak competition from other industries where substitute products are sold. In this case, a higher α induces a large reduction in the market price which reduces principals' willingness to pay for information. Moreover, the price effect is stronger when the probability of the agent having a low cost is low because, in this case, the informativeness of the experiment has a large impact on aggregate supply and, hence, on the market price. By contrast, an increase in the agent's highest possible cost $\overline{\theta}$ reduces principals' profit and induces the information provider to offer a less informative experiment, so that a higher market price is required (other things being equal) in order not to shut down production.

Let $\hat{\alpha}$ be the accuracy of the experiment that maximizes principals' (expected) profit in the high-cost state — i.e., the solution of the first-order condition

$$u'\left(\nu + \left(1-\nu\right)\hat{\alpha}\right) - \overline{\theta} + \hat{\alpha}\left(1-\nu\right)u''\left(\nu + \left(1-\nu\right)\hat{\alpha}\right) = 0, \tag{7}$$

which is unique by Assumption 2. The next proposition analyzes the factors that affect the informativeness of the optimal experiment when it is not fully informative.

Proposition 6 *If $\varepsilon\left(1\right) \leq \overline{\varepsilon}(\nu, \overline{\theta})$, the optimal experiment features $\alpha^* = \max\left\{\tilde{\alpha}, \hat{\alpha}\right\}$. Moreover, there exists a threshold $\underline{\Delta\theta}$ such that $\alpha^* = \hat{\alpha}$ if and only if $\Delta\theta \geq \underline{\Delta\theta}$.*

To maximize principals' willingness to pay for information $\rho\left(\alpha, 1\right)$, the information provider would like to offer an experiment that: (i) induces an uninformed principal to shut down production by a high-cost agent, because this reduces the principal's deviation profit, and (ii) maximizes the profit of a principal who acquires information in the high-cost state — i.e., that solves condition (7). When $\hat{\alpha}$ is higher than $\tilde{\alpha}$, the experiment that solves (7) also induces an uninformed principal to shut down production by a high-cost agent, because a high $\hat{\alpha}$ results in a low market price $p(\hat{\alpha}) \equiv u'(\nu + (1-\nu)\hat{\alpha})$. By contrast, when $\hat{\alpha}$ is lower than $\tilde{\alpha}$, the experiment that solves (7) does not induce an uninformed principal to shut down production by a high-cost agent. In this case, the information provider prefers to offer an experiment with accuracy $\tilde{\alpha}$ to minimize the difference between production with and without information acquisition (as explained in the discussion following Lemma 3). Finally, ceteris paribus, $\tilde{\alpha}$ is low and the information provider chooses $\hat{\alpha}$ when the adverse selection problem is particularly severe — i.e., when $\Delta\theta$ is relatively large (see (5)) and it is thus expensive to screen agents.

Notice that we focus on policies that do not discriminate principals. An alternative way to implement the optimal policy for the information provider consists in offering the fully informative experiment to some, but not all, principals. However, since in our model total demand for information is fixed (because the number of firms is fixed and they are ex ante identical), this can only be achieved through stochastic rationing, which would require random devices that are hardly verifiable in practice.

3.4 Example

To gain further insights on the optimal policy, consider a linear example that allows to obtain closed form solutions. Let $\underline{\theta} = 0$, $\overline{\theta} = 1$, and let the utility function be

$$u(x) = 2x - b\frac{x^2}{2},$$

so that $\varepsilon(1) = \frac{2}{b} - 1$ is decreasing in b.[16] By equation (5),

$$\tilde{\alpha} \equiv \frac{1 - \nu(2 + b(1-\nu))}{b(1-\nu)^2},$$

which is decreasing in ν and in b (when it is positive).

First, if $\tilde{\alpha} > 1$ — i.e., $b \leq \underline{b}(\nu) \equiv \frac{1-2\nu}{1-\nu}$ — then

$$\rho(\alpha, 1) = \nu - (1-\alpha)(1-\nu)[1 - b(\nu + (1-\nu)\alpha)] \quad \forall \alpha \in [0,1],$$

which is increasing in α. In this case, the optimal experiment is fully informative.

Second, if $\tilde{\alpha} \leq 0$ — i.e., $b > \overline{b}(\nu) \equiv \frac{1-2\nu}{\nu(1-\nu)}$ — then

$$\rho(\alpha, 1) = (1-\nu)\alpha[1 - b(\nu + (1-\nu)\alpha)] \quad \forall \alpha \in [0,1].$$

This function is maximized at

$$\hat{\alpha} \equiv \min\left\{1, \frac{1-b\nu}{2b(1-\nu)}\right\},$$

which is (weakly) increasing in ν and decreasing in b. Hence, $\hat{\alpha} < 1$ when

$$b > b^*(\nu) \equiv \frac{1}{2-\nu}.$$

[16] Assumption 1 requires $b < 1$ while Assumption 2 is always satisfied.

Third, if $\tilde{\alpha} \in (0,1)$ — i.e., $\underline{b}(\nu) < b < \overline{b}(\nu)$ — then the optimal experiment features

$$\alpha^* = \begin{cases} \max\{\hat{\alpha}, \tilde{\alpha}\} & \text{if } \hat{\alpha} < 1, \\ 1 & \text{if } \hat{\alpha} = 1. \end{cases}$$

Moreover,

$$\hat{\alpha} - \tilde{\alpha} = \frac{b\nu(1-\nu) + 3\nu - 1}{2b(1-\nu)^2} \geq 0 \quad \Leftrightarrow \quad b \geq \frac{1-3\nu}{\nu(1-\nu)}$$

(which holds if ν is sufficiently low).

Summing up, the optimal experiment features

$$\alpha^* = \begin{cases} 1 & \text{if } b \leq \max\{\underline{b}(\nu), b^*(\nu)\}, \\ \tilde{\alpha} & \text{if } \max\{\underline{b}(\nu), b^*(\nu)\} < b \leq \frac{1-3\nu}{\nu(1-\nu)}, \\ \hat{\alpha} & \text{if } b \geq \max\left\{b^*(\nu), \frac{1-3\nu}{\nu(1-\nu)}\right\}. \end{cases}$$

Hence, when demand is relatively unresponsive to price, the information provider offers an experiment that does not fully reveal the agent's cost in order to increase the market price. The optimal informativeness of the experiment α^* is decreasing in b, while it is decreasing (resp. increasing) in ν for intermediate (resp. large) values of b.

4 Extensions

In this section we show how the results of Section 3 change under alternative assumptions on the degree of competition in the product market and in the information market.

4.1 Downstream Monopoly

Suppose there is a single information buyer that produces in a monopolistic downstream market. The result of Theorem 5 on underprovision of information hinges on the assumption that there is competition in the product market. The intuition is that, like a monopolist operating in multiple locations that compete with each other, a monopolistic information buyer internalizes the business-stealing externalities of its decisions.

Proposition 7 *The information provider offers a fully informative experiment to a monopolist.*

The information provider has no incentive to distort the informativeness of the experiment offered to a monopolist, or to principals that act as a cartel in the product market, because a less informative experiment reduces the monopolist willingness to pay for two reasons. First, an imperfectly informative experiment reduces production efficiency due to the standard trade-off between rents and efficiency. Second, when the monopolist is uncertain about the agent's cost, he must provide a rent to induce truthful information revelation. Both of these effects reduce the surplus that can be extracted from the monopolist.

Note, however, that the main trade-off described in Theorem 5 does not necessarily require the product market to be perfectly competitive, since it would still arise with imperfect competition. Essentially, as long as more accurate information allows principals to reduce information rents but also increases the market price, there is a tension between the price and the quantity effects described in Section 3.[17]

4.2 Competing Information Providers

Consider now the case in which both the product and the information markets are competitive. An example that the reader may want to keep in mind is that of multiple competing credit rating agencies or auditing companies. For simplicity, assume that there are two identical information providers who announce simultaneously their (anonymous) policy — i.e., each information provider offers an experiment and fixes its price. Principals cannot coordinate their information acquisition decisions — i.e., they cannot commit to buy from the same information provider.

In order to capture the effect of competition in the information market on the amount of information supplied, consider the 'linear city' model of Hotelling (1929). Principals are uniformly distributed with density 1 over the interval $[0,1]$. Information providers, hereafter A and B, are located at the extremes of interval, with A located at 0 and B at 1. Principals pay a quadratic transportation cost to reach the information providers. Specifically, a principal located at $x \in [0,1]$ pays tx^2 to buy from A and $t(1-x)^2$ to buy from B.

Each information provider $j \in \{A, B\}$ announces a policy $\left\{E_j, \rho_j\right\}$ that consists in an experiment E_j with precision α_j and β_j and a (uniform) price ρ_j.[18] Principals observe the offers and decide whether to buy information or not and from whom to buy. For simplicity, we assume that

$$u'(\nu) < \frac{\nu}{1-\nu}\Delta\theta. \qquad \text{(Assumption 3)}$$

Hence, when no information is provided only low-cost agents produce.

We first consider symmetric equilibria with full coverage, in which all principals acquire information and information providers offers the same policy $\{(\alpha^*, \beta^*), \rho^*\}$. The principal that is indifferent between buying from A or B is such that

$$\begin{aligned} & V_A(\boldsymbol{\alpha}, \boldsymbol{\beta}) - \rho_A - tx^2 = V_B(\boldsymbol{\alpha}, \boldsymbol{\beta}) - \rho_B - t(1-x)^2 \\ \Leftrightarrow \quad & x^*(\boldsymbol{\rho}, \boldsymbol{\alpha}, \boldsymbol{\beta}) \equiv \frac{1}{2} + \frac{\rho_B - \rho_A}{2t} + \frac{V_A(\boldsymbol{\alpha}, \boldsymbol{\beta}) - V_B(\boldsymbol{\alpha}, \boldsymbol{\beta})}{2t}, \end{aligned}$$

[17] An important caveat is that Lemma 2 may not hold when firms' production choice is a continuous variable — e.g., when firms choose quantities or prices (Cournot or Bertrand or differentiated products) — because the optimal experiment may require more than two signals.

[18] It can be shown using the arguments developed above that we can restrict attention (without loss of generality) to binary experiments. In fact, holding constant the policy offered by his competitor, each information provider weakly prefers to offer a binary experiment rather than a more complex one.

where $\boldsymbol{\rho} = (\rho_A, \rho_B)$, $\boldsymbol{\alpha} = (\alpha_A, \alpha_B)$, $\boldsymbol{\beta} = (\beta_A, \beta_B)$ and

$$V_j(\boldsymbol{\alpha}, \boldsymbol{\beta}) \equiv \nu(p(\boldsymbol{\alpha}, \boldsymbol{\beta}) - \underline{\theta}) + (1-\nu) \sum_{s_j \in \{\underline{s}, \overline{s}\}} \Pr\left[s_j | \overline{\theta}\right] \max\left\{0, \Gamma^j_{\alpha_j, \beta_j}(s_j, p(\boldsymbol{\alpha}, \boldsymbol{\beta}))\right\}.$$

When $\alpha_B = \alpha^*$ and $\beta_B = \beta^*$,

$$p(\alpha_A, \beta_A, \alpha^*, \beta^*) = u'(\nu + (1-\nu)(x^*(\cdot)\alpha_A + (1 - x^*(\cdot))\alpha^*)),$$

where, if it exists, the cut-off $x^*(\cdot)$ is implicitly defined by

$$x^*(\alpha_A, \beta_A, \rho_A, \rho^*, \alpha^*, \beta^*) \equiv \frac{1}{2} + \frac{\rho^* - \rho_A}{2t} + \underbrace{\frac{V_A(\alpha_A, \beta_A, \alpha^*, \beta^*) - V_B(\alpha^*, \beta^*, \alpha_A, \beta_A)}{2t}}_{\text{Vertical differentiation}}.$$

Hence, when B behaves according to equilibrium, A's expected profit is

$$\pi_A(\rho_A, \alpha_A, \beta_A, \rho^*, \alpha^*, \beta^*) = x^*(\cdot)\rho_A.$$

Notice that, compared to a standard Hotelling game, our model also involves a form of (endogenous) vertical differentiation between information providers, which derives from the accuracy of the experiments offered. Clearly, other things being equal, principals are willingness to pay a higher price to acquire a more informative experiment. Hence, apart from competing in prices, information providers also compete through the accuracy of their experiments. However, competing along this dimension might not be in their individual and joint interest because the equilibrium market price is decreasing in the amount of information provided, and so does the surplus that providers can extract from inframarginal principals.

Does the equilibrium features underprovision of information? Will providers exploit both dimensions of differentiation to attract principals?

Proposition 8 *There cannot exist a symmetric equilibrium with full market coverage and imperfect information provision. An equilibrium with full market coverage and full information provision exists if and only if t is sufficiently low. In this equilibrium, the price charged by the information providers is $\rho^* = t$.*

If the market is fully covered in a symmetric equilibrium, it is always profitable for a provider to offer a slightly more informative experiment in order to attract marginal principals from the rival, without changing the price of the experiment. This is because, holding the experiment offered by the rival constant, a provider gains by selling to an additional principal, whose production choice does not affect the market price.[19] Hence, to avoid this free-riding problem, in a symmetric equilibrium with full market coverage providers never offer an experiment that is not fully informative.

[19] Of course, the change in the informativeness of the experiment must be arbitrarily small to have a negligible effect on the market price — i.e., a second order effect on provider's profit compared to the effect of an increase in the number of principals served.

When transportation costs are sufficiently small, there is an equilibrium in which both providers offer the fully informative experiment at price $\rho^* = t$, following the standard 'Hotelling' rule. In this case, competition between providers bites both horizontally and vertically. To understand why, consider the case of perfect competition in the information market — i.e., $t = 0$. A straightforward undercutting logic implies that information providers charge a price equal to zero, $\rho^* = 0$, and make no profit in equilibrium, regardless of the experiment they offer. Moreover, if a provider offers the fully informative experiment at price zero, it is clear that his competitor cannot gain by offering a different experiment and/or a different price (because, when there is no transportation cost, by doing so he cannot attract any principal). A similar logic applies to the case of small t.

Hence, when competition in the information market is relatively strong, full information is provided in equilibrium to all principals. When t is large, however, are there equilibria in which providers limit the amount of information?

By Proposition 8, if full information is not provided to all principals in a symmetric equilibrium, this must be because the market is not fully covered — i.e., each provider sells to a mass of principals smaller than $\frac{1}{2}$. In this case, some principals acquire no information and shut down production in state $\underline{s}$. In the next proposition we show that, indeed, when t is relatively large there exists an equilibrium in which providers offer the fully informative experiment, but price some principals out of the market in order to increase the equilibrium market price and extract a higher surplus.

Proposition 9 *If t is is sufficiently high, there exists a symmetric equilibrium in which each provider offers the fully informative experiment and sells to a mass of principals $\frac{1}{2} - k^*$, with $k^* \in \left(0, \frac{1}{2}\right)$ such that*

$$\frac{t}{4}\left[1 - 2k^*\right]^2 = (1 - \nu)\left[u'\left(1 - 2\left(1 - \nu\right)k^*\right) - \overline{\theta}\right] + \frac{1 - 2k^*}{2}\left(1 - \nu\right)^2 u''\left(1 - 2\left(1 - \nu\right)k^*\right). \qquad (8)$$

In this equilibrium, the price charged by the information providers is $\rho^* > t$. Moreover, k^* is increasing in t.

When competition in the information market is not too strong — i.e., when products are sufficiently differentiated — competition between providers along the 'horizontal dimension' becomes less intense: providers still offer the fully informative experiment (to undercut each other along the 'vertical dimension'), but they charge a price higher than t in order to exclude some principals from the information market, thereby increasing market price and profits.[20] In this case, there will also be underprovision of information, but it will stem from excessive product differentiation that results in the exclusion of some principals, rather than from the accuracy of the experiment itself. One can think of this situation as one where some firms cannot find a rating agency that would understand their business well enough to provide a reasonably reliable rating.

[20] Of course, in addition to the symmetric equilibrium characterized in Proposition 9, with competing providers there may also be asymmetric equilibria in which only one provider offers an experiment that is not fully informative (which also benefits the competitor). Characterizing the full set equilibria is outside the scope of the paper, however, since our purpose is simply to show the robustness of the results obtained in the monopoly case.

Therefore, our qualitative result that the maximal degree of information may not provided, even if information is costless, holds both in a monopolistic and in an imperfectly competitive information market.

Notice that, with competing providers, information may be limited for two reasons. First, as in the case of a monopolistic provider of information, providing less information increases the market price because it reduces the total quantity produced (see the right-hand side of condition (8)). Second, each provider exploits its monopoly power with respect to firms which are close to its location by increasing the price of the experiment and reducing the number of firms to which it sells information (see the left-hand side of condition (8)).[21] As intuition would suggest, this effect becomes stronger as transportation costs increase, implying that information underprovision becomes more severe as competition in the information market weakens.

Of course, in addition to the symmetric equilibria characterized in Propositions 8 and 9, with imperfect competition there may also be asymmetric equilibria in which only one provider offers an experiment that is not fully informative and/or exclude some principals (which also benefits the competitor).[22] This potential multiplicity of equilibria echoes Lizzeri (1994), who in a different context shows that competition between information intermediaries may generate different types of equilibria, with and without full information disclosure. Characterizing the full set equilibria is outside the scope of our analysis, however, since our purpose is simply to show the robustness of the results obtained in the monopoly case.

4.3 Monopsony in the Information Market

In the previous sections, we have assumed that principals do not coordinate their information acquisition decisions — i.e., each principal buys the experiment that maximizes his own profit. Suppose now that principals behave as a single buyer and can commit to purchase information from the same provider, although they are still price takers in the product market. What is the experiment that principals jointly offer to the information provider(s)? Will they acquire more or less information than in the baseline model?

By the same logic of Lemma 2, we can consider binary experiments without loss of generality. If principals commit to deal exclusively with one information provider, they choose the experiment that maximizes their expected profits — i.e., $V_{\alpha,\beta}(p(\alpha))$ in equation (4) — rather than the incremental value of information. As before, it is easy to show that: (*i*) it is never optimal to offer an experiment that always induces shut down of the high-cost agent; (*ii*) if the experiment distorts production with only one signal, then this must be $\underline{s}$; (*iii*) it is optimal to set β equal to 1; (*iv*) for

[21] As discussed at the end of Section 3.3, a monopolistic provider may also want to sell to fewer firms and increase the price of the experiment but, in our model with fixed demand for information, he can only do this by stochastic rationing.

[22] For example, asymmetric equilibria may arise for intermediate values of t, when there is no symmetric equilibrium with full coverage (because a relatively high transportation cost induces providers to ration principals to exploit their monopoly power), and no symmetric equilibrium without full market coverage (because a relatively low transportation cost induces providers to compete aggressively by either reducing the price of the experiment or increasing its accuracy).

any $\alpha < 1$ such that $\Gamma_{\alpha,1}(\underline{s}, p) > 0$,

$$V_{\alpha,1}(p(\alpha)) = p(1) - \mathbb{E}[\theta] - \nu\Delta\theta < p(1) - \mathbb{E}[\theta] = V_{1,1}(p(1)).$$

Hence, as in our main model, if it is optimal to offer an experiment that is not fully informative, then it must be

$$\Gamma_{\alpha,1}(\overline{s}, p) \geq 0 > \Gamma_{\alpha,1}(\underline{s}, p).$$

In this case, principals' objective function is

$$V_{\alpha,1}(p(\alpha)) \equiv \nu\left[u'(\nu + (1-\nu)\alpha) - \underline{\theta}\right] + (1-\nu)\alpha\left[u'(\nu + (1-\nu)\alpha) - \overline{\theta}\right],$$

whose derivative with respect to α is

$$\underbrace{u'(\nu + (1-\nu)\alpha) - \overline{\theta}}_{>0} + \underbrace{(\nu + (1-\nu)\alpha)\,u''(\nu + (1-\nu)\alpha)}_{<0}. \tag{9}$$

The first term represents the quantity effect, which is identical to the one in our main model, while the second represents a modified (stronger) price effect, which also takes into account the effect of information when the agent has a low cost (since this affects principals' expected profit but not the incremental value of information).

Proposition 10 *Suppose that principals act as a single buyer in the information market. There exists a threshold $\overline{\varepsilon}(\overline{\theta}) : \mathbb{R}^+ \to \mathbb{R}^+$ such that the optimal experiment features $\alpha^{**} < 1$ if and only if $\varepsilon(1) \leq \overline{\varepsilon}(\overline{\theta})$, and $\beta^* = 1$. Moreover, $\alpha^{**} \leq \alpha^*$ and $\overline{\varepsilon}(\overline{\theta}) \geq \overline{\varepsilon}(\nu, \overline{\theta})$, with equality at $\nu = 0$.*

Hence, a coalition of principals acquires less accurate information than each principal does because the experiment that maximizes their expected profit does not depend on the outside option, which strengthens the price effect. As a result, contrary to what may be expected, a monopsony in the information market reduces the equilibrium level of information provided.

5 Conclusions

Building on the recent literature on selling information, we have examined the decision problem of a monopolist who sells an informative experiment to a large number of perfectly competitive firms in which principals contract with privately informed agents. We have shown that, even if information is costless for the provider, the optimal experiment is not fully informative when demand is inelastic to price and agents are likely to have a high cost. This result hinges on the assumption that firms are competitive and exacerbates when principals can coordinate vis-à-vis the information provider. In an imperfectly competitive information market, underprovision of information may still occur through the exclusion of some principals from the information market.

The analysis suggests a positive relationship between competition, transparency and efficiency. In very competitive markets — i.e., markets in which demand is very responsive to prices or in industries with a relatively high R&D intensity — firms purchase accurate information in order to solve agency problems and produce on the first-best frontier: the equilibrium experiment is fully informative about the agents' cost. By contrast, firms in mature industries in which demand is not very responsive to prices do not obtain full information. This lack of transparency generates information rents that further reduce production and increase prices, at the expense of final consumers.

A Appendix

Proof of Proposition 3. Using standard techniques, it can be shown that if a principal does not acquire information and expects a market price $p \in P$, his maximization problem is

$$\max_{q_i(\cdot,\varnothing)\in[0,1]} \left\{ \sum_{\theta_i\in\Theta} \Pr(\theta)\, q_i(\theta_i,\varnothing)(p-\theta_i) - \nu q_i\left(\overline{\theta},\varnothing\right)\Delta\theta \right\}.$$

Differentiating with respect to $q_i(\underline{\theta},\varnothing)$ it follows that $\nu(p-\underline{\theta})>0$ for any $p\in P$. Hence, $q_i(\underline{\theta},\varnothing)=1$. Differentiating with respect to $q_i\left(\overline{\theta},\varnothing\right)$, it follows that $q_i\left(\overline{\theta},\varnothing\right)=1$ if and only if $p-\overline{\theta}-\frac{\nu}{1-\nu}\Delta\theta\geq 0$ — i.e., $\nu\leq\underline{\nu}(p)$. ■

Proof of Lemma 1. A principal expected profit is

$$\sum_{\theta_i\in\Theta}\Pr(\theta_i)\int_{s_i\in S} q_i(\theta_i,s_i)\left[p-t_i(\theta_i,s_i)\right]dF(s_i|\theta_i)$$
$$=\sum_{\theta_i\in\Theta}\Pr(\theta_i)\int_{s_i\in S}\left[q_i(\theta_i,s_i)(p-\theta_i)-u_i(\theta_i,s_i)\right]dF(s_i|\theta_i).$$

For any signal s_i, the agent's incentive compatibility implies

$$u_i(\theta_i,s_i)\equiv T_i(\theta_i,s_i)-q_i(\theta_i,s_i)\,\theta_i\geq T_i(\theta_i',s_i)-q_i\left(\theta_i',s_i\right)\theta_i\quad\forall\theta_i'\neq\theta_i,$$

where $T_i(\theta_i,s_i)\equiv q_i(\theta_i,s_i)\,t_i(\theta_i,s_i)$. Hence, the agent's relevant incentive compatibility constraint is

$$u_i(\underline{\theta},s_i)\geq u_i\left(\overline{\theta},s_i\right)+q_i(\overline{\theta},s_i)\Delta\theta,$$

where $u_i\left(\overline{\theta},s_i\right)=0$ for every s_i due to limited liability. The agent's information rent is

$$u_i(\underline{\theta},s_i)=q_i(\overline{\theta},s_i)\Delta\theta.$$

Substituting this expression into principal i's objective function yields

$$\max_{q(\cdot,\cdot)\in[0,1]}\left\{\sum_{\theta_i\in\Theta}\Pr(\theta_i)\int_{s_i\in S} q_i(\theta_i,s_i)\left[p-\theta_i\right]dF_E(s_i|\theta_i)-\nu\Delta\theta\int_{s_i\in S} q_i(\overline{\theta},s_i)dF_E(s_i|\underline{\theta})\right\}.$$

Optimizing this function with respect to $q_i(\underline{\theta},s_i)$ and $q_i\left(\overline{\theta},s_i\right)$ yields: (*i*) $q_i(\underline{\theta},s_i)=1$ since $p>\underline{\theta}$ for any $p\in P$ by assumption A1; and (*ii*) $q_i(\underline{\theta},s_i)=1$ if and only if

$$\Gamma_E(s_i,p)\equiv p-\overline{\theta}-\frac{\nu}{1-\nu}\frac{f_E(s_i|\underline{\theta})}{f_E\left(s_i|\overline{\theta}\right)}\Delta\theta\geq 0.$$

■

Proof of Lemma 2. We show that it is optimal for the information provider to offer an experiment with two signals only. Let E be a generic experiment with $S_E \subseteq \mathbb{R}$. Denote by p_E the equilibrium price induced by that experiment and let

$$\tilde{S}_E(p) \equiv \{s_i \in S_E : \Gamma_E(s_i, p) \geq 0\}$$

be the subset of signals that induce a principal to produce when the agent's cost is high. Recall that Assumption A1 guarantees that production occurs in the low cost state for any price $p \in P$.

Suppose first that $\tilde{S}_E(p_E) \neq \varnothing$ and that $S_E \backslash \tilde{S}_E(p_E) \neq \varnothing$. Then

$$\rho(E) = (1-\nu)\left[\int_{s \in \tilde{S}_E(p_E)} \left[p_E - \overline{\theta} - \frac{\nu}{1-\nu}\frac{f_E(s_i|\underline{\theta})}{f_E(s_i|\overline{\theta})}\Delta\theta\right] dF\left(s_i|\overline{\theta}\right) - \max\{0, \Gamma_{\varnothing}(p_E)\}\right].$$

Notice that

$$\rho(E) < (1-\nu)\left[\int_{s \in \tilde{S}_E(p_E)} \left[p_E - \overline{\theta} - \frac{\nu}{1-\nu}\min_{s \in \tilde{S}_E(p_E)} \frac{f_E(s|\underline{\theta})}{f_E(s|\overline{\theta})}\Delta\theta\right] dF\left(s_i|\overline{\theta}\right) - \max\{0, \Gamma_{\varnothing}(p_E)\}\right].$$

Next, consider a new experiment E', with $S_{E'} \subset S_E$, such that

$$S_{E'} = S_E \backslash \tilde{S}_E(p_E) \cup \underset{s_i \in \tilde{S}_E(p_E)}{\arg\min} \frac{f_E(s|\underline{\theta})}{f_E(s|\overline{\theta})},$$

and

$$f_{E'}(s|\theta) = \begin{cases} f_E(s|\theta) & \Leftrightarrow s \in S_E \backslash \tilde{S}_E(p_E) \\ \int_{s \in \tilde{S}_E(p_E)} f_E(s|\theta)\, ds & \Leftrightarrow s \in \underset{s \in \tilde{S}_E(p_E)}{\arg\min} \frac{f_E(s|\underline{\theta})}{f_E(s|\overline{\theta})} \\ 0 & \text{otherwise} \end{cases}.$$

Note that $p_E = p_{E'}$ because $y(E) = y(E')$ by the law of large numbers. Hence, $\rho(E) < \rho(E')$. Using the same logic we can show that for any E such that $\tilde{S}_E(p_E) = S_E$ or $\tilde{S}_E(p_E) = \varnothing$ the information provider cannot be worse off by offering a simpler experiment that implements the same price. The result then follows immediately. ■

Proof of Proposition 4. The proof of this result follows immediately from Lemma 1. ■

Proof of Lemma 3. Consider an experiment such that

$$\Gamma_{\alpha,\beta}(\overline{s}, p(\alpha)) \geq 0 > \Gamma_{\alpha,\beta}(\underline{s}, p(\alpha)).$$

Then, by definition,

$$\rho(\alpha, \beta) = (1-\nu)\alpha\left[p(\alpha) - \overline{\theta}\right] - \nu(1-\beta)\Delta\theta - (1-\nu)\max\{0, \Gamma_{\varnothing}(p(\alpha))\},$$

where $p(\alpha)$ is the market clearing price when all principals acquire information. By concavity of

$u(\cdot)$, there exists a unique $\tilde{\alpha}$ that solves

$$u'(\nu + (1-\nu)\alpha) = \overline{\theta} + \frac{\nu}{1-\nu}\Delta\theta,$$

such that

$$\max\left\{0, u'(\nu + (1-\nu)\alpha) - \overline{\theta} - \frac{\nu}{1-\nu}\Delta\theta\right\} > 0 \quad \Leftrightarrow \quad \alpha \leq \tilde{\alpha}.$$

This yields equation (6). ■

Proof of Theorem 5. By Lemma 3**,** it immediately follows that for any experiment such that

$$\Gamma_{\alpha,\beta}(\underline{s}, p(\alpha)) < 0 \leq \Gamma_{\alpha,\beta}(\overline{s}, p(\alpha)),$$

it is optimal for the information provider to set $\beta = 1$. Hence,

$$\rho(\alpha, 1) = \begin{cases} (1-\nu)\alpha\left[u'(\nu + (1-\nu)\alpha) - \overline{\theta}\right] & \text{if } \alpha \geq \tilde{\alpha}, \\ \nu\Delta\theta - (1-\nu)(1-\alpha)\left[u'(\nu + (1-\nu)\alpha) - \overline{\theta}\right] & \text{if } \alpha < \tilde{\alpha}. \end{cases}$$

In order to characterize the precision α that maximizes $\rho(\alpha, 1)$ three cases must be considered.

First, if $\frac{\nu}{1-\nu}\Delta\theta < u'(1) - \overline{\theta}$, then $\tilde{\alpha} > 1$ and

$$\rho(\alpha, 1) = \nu\Delta\theta - (1-\alpha)(1-\nu)\left[u'(\nu + (1-\nu)\alpha) - \overline{\theta}\right] < \rho(1, 1) = \nu\Delta\theta.$$

Hence, in this case the information provider chooses $\alpha^* = \beta^* = 1$.

Second, if $\frac{\nu}{1-\nu}\Delta\theta \geq u'(\nu) - \overline{\theta}$, then concavity of $u(\cdot)$ implies $\frac{\nu}{1-\nu}\Delta\theta > u'(1) - \overline{\theta}$. Hence,

$$\rho(\alpha, 1) = (1-\nu)\alpha\left[u'(\nu + (1-\nu)\alpha) - \overline{\theta}\right].$$

This function is single peaked by Assumption A2 and is maximized at $\alpha \in (0, 1)$ such that

$$u'(\nu + (1-\nu)\alpha) - \overline{\theta} + \alpha u''(\nu + (1-\nu)\alpha)(1-\nu) = 0,$$

if and only if

$$u'(1) - \overline{\theta} + u''(1)(1-\nu) < 0 \quad \Leftrightarrow \quad \varepsilon(1) \equiv \frac{u'(1)}{|u''(1)|} < \overline{\varepsilon}\left(\overline{\theta}, \nu\right) \equiv \frac{\overline{\theta}}{|u''(1)|} + 1 - \nu.$$

Otherwise, $\rho(\alpha, 1)$ is maximized at $\alpha = 1$. Since $\rho(1, 1) = (1-\nu)\left(u'(1) - \overline{\theta}\right)$, the result follows immediately.

Third, if $u'(1) - \overline{\theta} < \frac{\nu}{1-\nu}\Delta\theta < u'(\nu) - \overline{\theta}$, then $\tilde{\alpha} \in (0, 1)$ and

$$\rho(\alpha, 1) = \begin{cases} (1-\nu)\alpha\left[u'(\nu + (1-\nu)\alpha) - \overline{\theta}\right] & \text{if } \alpha \geq \tilde{\alpha}, \\ \nu\Delta\theta - (1-\nu)(1-\alpha)\left[u'(\nu + (1-\nu)\alpha) - \overline{\theta}\right] & \text{if } \alpha < \tilde{\alpha}. \end{cases}$$

Note that

$$\frac{\partial \rho(\alpha,1)}{\partial \alpha} = (1-\nu)\left[u'(\nu+(1-\nu)\alpha)-\overline{\theta}\right] + (1-\nu)^2(1-\alpha)u''(\nu+(1-\nu)\alpha) > 0 \quad \forall \alpha \le \tilde{\alpha},$$

which means that $\max_{\alpha \le \tilde{\alpha}} \rho(\alpha,1) = \tilde{\alpha}\nu\Delta\theta$. Suppose that

$$\frac{\partial}{\partial \alpha}\alpha\left(u'(\nu+(1-\nu)\alpha)-\overline{\theta}\right)\Big|_{\alpha=\tilde{\alpha}} \ge 0.$$

Assumption 2 implies that $\rho(\alpha,1)$ is maximized at α^*. Hence, as before, $\rho(\alpha^*,1) > \rho(1,1)$ as long as $\varepsilon(1) < \overline{\varepsilon}\left(\overline{\theta},\nu\right)$. By contrast, if

$$\frac{\partial}{\partial \alpha}\alpha\left(u'(\nu+(1-\nu)\alpha)-\overline{\theta}\right)\Big|_{\alpha=\tilde{\alpha}} < 0,$$

then Assumption 2 implies that $\rho(\alpha,1)$ is maximized at $\tilde{\alpha}$. But, by definition,

$$\tilde{\alpha}\left(u'(\nu+(1-\nu)\tilde{\alpha})-\overline{\theta}\right) = \frac{\nu}{1-\nu}\Delta\theta - (1-\tilde{\alpha})\left(u'(\nu+(1-\nu)\tilde{\alpha})-\overline{\theta}\right).$$

Hence, $\rho(\tilde{\alpha},1) > \rho(1,1)$ as long as $\varepsilon(1) < \overline{\varepsilon}\left(\overline{\theta},\nu\right)$. In this case, Assumption 2 implies that the optimal experiment features $\beta^* = 1$ and $\alpha^* < 1$. ■

Proof of Proposition 6. Suppose that $\varepsilon(1) < \overline{\varepsilon}\left(\overline{\theta},\nu\right)$. The fact that $\alpha^* = \max\{\hat{\alpha},\tilde{\alpha}\}$ follows immediately from the proof of Theorem 5**.** Moreover, by concavity of $u(\cdot)$, $\tilde{\alpha}$ is decreasing in $\Delta\theta$ and $\tilde{\alpha} \to 0$ as $\Delta\theta$ becomes large enough; while (other things being constant) $\tilde{\alpha}$ does not vary with $\Delta\theta$ (see condition 7). Hence, by continuity of $u(\cdot)$ there exists a threshold $\underline{\Delta\theta}$ such that $\hat{\alpha} \ge \tilde{\alpha}$ if and only if $\Delta\theta \ge \underline{\Delta\theta}$. ■

Proof of Proposition 7. Consider a fully informative experiment. The agent obtains no rent and, in every state θ, the monopolist produces the output $q^M(\theta)$ that solves

$$u'\left(q^M(\theta)\right) + q^M(\theta)\,u''\left(q^M(\theta)\right) = \theta.$$

Denote the full information profit

$$V^* \equiv \sum_{\theta\in\Theta} \Pr(\theta)\,q^M(\theta)\left[u'\left(q^M(\theta)\right)-\theta\right].$$

Consider now an experiment E that is not fully informative. Let $q(\theta,s)$ be the monopolist's production in the state $(\theta,s) \in \Theta \times S_E$. For any information policy, the monopolist's maximization problem is

$$\max_{q(\cdot)\in[0,1]} \left\{ \sum_{\theta\in\Theta} \Pr(\theta) \int_{s\in S} \left[q(\theta,s)\left(u'(q(\theta,s))-\theta\right)\right] dF_E(s|\theta) - \nu\Delta\theta \int_{s\in S} q(\overline{\theta},s)\,dF_E(s|\underline{\theta}) \right\}. \quad (10)$$

The first-order conditions imply $q\left(\underline{\theta}, s\right) = q^M\left(\underline{\theta}\right)$ for every $s \in S_E$ and

$$u'(q^E(\overline{\theta}, s)) + q^E(\overline{\theta}, s)u''(q^E(\overline{\theta}, s)) = \overline{\theta} + \frac{\nu}{1-\nu}\frac{f_E(s|\underline{\theta})}{f_E(s|\overline{\theta})}\Delta\theta,$$

with $q^E\left(\overline{\theta}, s\right) \leq q^M\left(\overline{\theta}\right)$ for every $s \in S_E$. By Assumption 2, the value function associated to the maximization problem (10) is

$$\begin{aligned} V^M(E) &< \sum_{\theta\in\Theta} \Pr(\theta) \int_{s\in S} q^E(\theta, s)\left[u'\left(q^E(\theta, s)\right) - \theta\right] dF_E(s|\theta) \\ &< \sum_{\theta\in\Theta} \Pr(\theta)\, q^M(\theta)\left[u'\left(q^E(\theta)\right) - \theta\right] = V^*. \end{aligned}$$

Hence, the result. ■

Proof of Proposition 8. Consider a symmetric equilibrium in which information providers equally share the market (i.e., each sells to a mass $\frac{1}{2}$ of principals) and offer an experiment (α^*, β^*) that is not fully informative ($\alpha^* + \beta^* < 2$) and induces principals to shut down production only in state $\underline{s}$. (Since $\alpha + \beta > 1$, if there is shut down in state $\overline{s}$, there must be shut down also in state $\underline{s}$.) If provider B behaves according to equilibrium,

$$x^*(\cdot) \equiv \frac{1}{2} + \frac{\rho^* - \rho_A}{2t} + \frac{V_A(\alpha_A, \beta_A, \alpha^*, \beta^*) - V_B(\alpha^*, \beta^*, \alpha_A, \beta_A)}{2t},$$

where

$$\begin{aligned} V_A(\cdot) - V_B(\cdot) \equiv (1-\nu) &\sum_{s_A\in\{\underline{s},\overline{s}\}} \Pr\left[s_A|\overline{\theta}\right] \max\left\{0, \Gamma^A_{\alpha_A,\beta_A}\left(s_A, p\left(\alpha_A, \alpha^*, \beta_A, \beta^*\right)\right)\right\} \\ &- (1-\nu) \sum_{s_B\in\{\underline{s},\overline{s}\}} \Pr\left[s_B|\overline{\theta}\right] \max\left\{0, \Gamma^B_{\alpha^*,\beta^*}\left(s_B, p\left(\alpha_A, \alpha^*, \beta_A, \beta^*\right)\right)\right\}, \end{aligned}$$

and

$$p\left(\alpha_A, \alpha^*, \beta_A, \beta^*\right) = u'\left(\nu + (1-\nu)\left(x^*(\cdot)\,\alpha_A + (1 - x^*(\cdot))\,\alpha^*\right)\right).$$

Since $\pi_A(\cdot) = x^*(\cdot)\,\rho_A$, the equilibrium experiment is

$$(\alpha^*, \beta^*) \in \underset{(\alpha_A,\beta_A)}{\arg\max}\left\{V_A(\alpha_A, \beta_A, \alpha^*, \beta^*) - V_B(\alpha^*, \beta^*, \alpha_A, \beta_A)\right\}.$$

First the equilibrium features $\beta^* = 1$. Indeed, if $\beta^* < 1$, then a provider, say A, can strictly increase his profit by choosing $\beta_A = \beta^* + \varepsilon$ ($\varepsilon > 0$), since

$$V_A(\alpha^*, \beta^* + \varepsilon, \alpha^*, \beta^*) - V_B(\alpha^*, \beta^*, \alpha^*, \beta^* + \varepsilon) = (1-\nu)\,\varepsilon\Delta\theta > 0.$$

Second, following the same logic of the monopoly case, if $\alpha^* < 1$ then principals cannot always produce in equilibrium.

Third, it is not possible that $\alpha^* < 1$ and $\beta^* = 1$. The reason is that, in this case, a deviation

$\alpha_A = \alpha^* + \varepsilon$, with ε arbitrarily small, is profitable if

$$V_A(\alpha^* + \varepsilon, 1, \alpha^*, 1) - V_B(\alpha^*, 1, \alpha^* + \varepsilon, 1) > 0.$$

Differentiating with respect to ε,

$$\left.\frac{\partial [V_A(\cdot) - V_B(\cdot)]}{\partial \varepsilon}\right|_{\varepsilon=0} = (1-\nu)\left\{\max\left\{0, \Gamma^A_{\alpha^*,1}(\overline{s}, p(\cdot))\right\} + \alpha^* \underbrace{\left[\frac{\partial}{\partial \alpha_A} p(\cdot) - \frac{\partial}{\partial \alpha_A} p(\cdot)\right]}_{=0}\right\},$$

which is strictly positive since $\max\left\{0, \Gamma^A_{\alpha^*,1}(\overline{s}, p(\cdot))\right\} > 0$ in equilibrium.

Fourth, a deviation by a provider, say A, with $x^*(\cdot) > \frac{1}{2}$ is not profitable. In fact, since A cannot charge a price higher than ρ^*, this deviation can be profitable only if

$$x^*(\alpha^*, \beta^*, \rho^*) = \tfrac{1}{2} > \tfrac{1}{2} + V_A(\alpha_A, 1, 1, 1) - V_B(1, 1, \alpha_A, 1),$$

where, by definition,

$$V_A(\alpha_A, 1, 1, 1) - V_B(1, 1, \alpha_A, 1) \equiv (1-\nu)\left\{\sum_{s_A \in \{\underline{s}, \overline{s}\}} \Pr\left[s_A | \overline{\theta}\right] \max\left\{0, \Gamma^A_{\alpha_A,1}(s_A, p(\cdot))\right\} - \left[p(\cdot) - \overline{\theta}\right]\right\}.$$

However:

- If α_A induces shut down in both states,

$$\sum_{s_A \in \{\underline{s}, \overline{s}\}} \Pr\left[s_A | \overline{\theta}\right] \max\left\{0, \Gamma^A_{\alpha_A,1}(s_A, p(\cdot))\right\} = 0,$$

  implying that $V_A(\cdot) < V_B(\cdot)$.

- If $\alpha_A < 1$ never induces shut down,

$$\sum_{s_A \in \{\underline{s}, \overline{s}\}} \Pr\left[s_A | \overline{\theta}\right] \max\left\{0, \Gamma^A_{\alpha_A,1}(s_A, p(\cdot))\right\} = p(\cdot) - \overline{\theta} - \frac{\nu}{1-\nu}\Delta\theta < p(\cdot) - \overline{\theta},$$

  implying that $V_A(\cdot) < V_B(\cdot)$.

- If $\alpha_A < 1$ induces shut down only is state $\underline{s}$,

$$V_A(\cdot) - V_B(\cdot) \equiv (1-\nu)\left\{\alpha_A\left[p(\cdot) - \overline{\theta}\right] - p(\cdot) - \overline{\theta}\right\} < 0.$$

Hence, in a symmetric equilibrium with full market coverage, both providers offer the fully informative experiment — i.e., $\alpha^* = \beta^* = 1$ — and $\rho^* = t$: the standard Hotelling's pricing rule (which follows from differentiation of a provider's expected profit and symmetry).

By Assumption 3, such an equilibrium requires that, for every $x \leq 1/2$,

$$\nu\left(u'(1)-\underline{\theta}\right)+(1-\nu)\left(u'(1)-\overline{\theta}\right)-tx^2-\rho^* \geq \nu\left(u'(1)-\underline{\theta}\right).$$

Substituting $\rho^* = t$ yields

$$(1-\nu)\left(u'(1)-\overline{\theta}\right) \geq \max_{x\leq\frac{1}{2}} t\left(1+x^2\right) \quad \Leftrightarrow \quad t \leq \underline{t} \equiv \frac{4(1-\nu)\left(u'(1)-\overline{\theta}\right)}{5}.$$

■

Proof of Proposition 9. In Proposition 8 we have shown that for $t > \underline{t}$ there is no symmetric equilibrium with full market coverage. Hence, if a symmetric equilibrium exists in this case, it must be such that some principals do not buy information. Accordingly, we now characterize sufficient conditions for an equilibrium without full market coverage — i.e., such that, for some $k^* \in \left(0, \frac{1}{2}\right)$: (i) principals in the interval $\left[0, \frac{1}{2}-k^*\right]$ buy from A; (ii) principals in the interval $\left[\frac{1}{2}+k^*, 1\right]$ buy from B; (iii) principals in the interval $\left[\frac{1}{2}-k^*, \frac{1}{2}+k^*\right]$ do not buy information. Following the logic of the proof of Proposition 8, it can be shown that there is no loss of generality in considering equilibria such that $\beta^* = 1$.

We first show, by contradiction, that such equilibrium cannot feature $k^* \in \left(0, \frac{1}{2}\right)$, $\alpha^* < 1$ and informed principals shutting down production only in state $\underline{s}$. To characterize A's best response when B behaves according to equilibrium notice that, if A offers (α_A, ρ_A) and a mass $\frac{1}{2}-k_A < \frac{1}{2}$ of principals acquires the experiment from him, then it must be

$$V_A\left(\alpha_A, \alpha^*, k_A, k^*\right) - t\left(\tfrac{1}{2}-k_A\right)^2 - \rho_A = V_\varnothing\left(p\left(\alpha_A, \alpha^*, k_A, k^*\right)\right),$$

where

$$p\left(\alpha_A, \alpha^*, k_A, k^*\right) \equiv u'\left(\left(\tfrac{1}{2}-k_A\right)\left(\nu+(1-\nu)\alpha_A\right)+\left(\tfrac{1}{2}-k^*\right)\left(\nu+\alpha^*(1-\nu)\right)+\nu\left(\varepsilon_A+\varepsilon^*\right)\right),$$

and $V_A\left(\alpha_A, \alpha^*, k_A, k^*\right)$ is the gross profit of a principal who buys from A (which depends on k_A and k^* through their effect on the market price). For any k_A that provider A wants to implement, he must charge

$$\rho_A\left(\alpha_A, \alpha^*, k^*, k_A\right) \equiv \underbrace{\Delta V_A\left(\alpha_A, \alpha^*, k_A, k^*\right)}_{V_A\left(\alpha_A,\alpha^*,k_A,k^*\right)-V_\varnothing\left(p\left(\alpha_A,\alpha^*,k_A,k^*\right)\right)} - t\left(\tfrac{1}{2}-k_A\right)^2,$$

where, by Assumption 3,

$$\Delta V_A\left(\alpha_A, \alpha^*, k_A, k^*\right) \equiv (1-\nu)\sum_{s_A\in\{\underline{s},\overline{s}\}} \Pr\left[s_A|\overline{\theta}\right]\max\left\{0, \Gamma_{\alpha_A,1}\left(s_A, p\left(\alpha_A, \alpha^*, k_A, k^*\right)\right)\right\}.$$

Note that $\Delta V_A(\cdot)$ is increasing in k_A because $u''(\cdot) < 0$. Hence, for any α_A, $\rho_A(\cdot)$ is a monotone function of k_A. This implies that we can analyze (without loss of generality) an equivalent game in which information providers choose the fraction of principals they wish to serve rather than prices (which are determined to make the marginal principal indifferent between buying information and not). Note that this change of variables does not affect the nature of the strategic interaction among players because in the equilibrium that we consider information providers do not compete directly and hence, as monopolists, they can either choose prices or quantity, if demand is well behaved.

Therefore, provider A's problem can be written as

$$\max_{k_A,\alpha_A} \rho_A\left(\alpha_A,\alpha^*,k_A,k^*\right)\tfrac{1-2k_A}{2}.$$

The first-order conditions are (imposing symmetry)

$$-\alpha^*\left[u'\left(\nu+\left(1-2k^*\right)\left(1-\nu\right)\alpha^*\right)-\overline{\theta}\right]+\tfrac{3t}{4}\left(1-2k^*\right)^2$$
$$=\tfrac{1}{2}\left(1-2k^*\right)\alpha^{*2}\left(1-\nu\right)u''\left(\nu+\left(1-2k^*\right)\left(1-\nu\right)\alpha^*\right).$$

and

$$u'\left(\nu+\left(1-2k^*\right)\left(1-\nu\right)\alpha^*\right)-\overline{\theta}=-\tfrac{1}{2}\left(1-\nu\right)\left(1-2k^*\right)\alpha^*u''\left(\nu+\left(1-2k^*\right)\left(1-\nu\right)\alpha^*\right).$$

Substituting the second condition in the first and rearranging yields

$$\tfrac{3t}{4}\left(1-2k^*\right)^2=0,$$

which cannot be true if $k^*<\frac{1}{2}$: a contradiction.

Moreover, since a symmetric equilibrium cannot feature $k^*=0$, then it must be $\alpha^*=1$. We now characterize sufficient conditions for this outcome to be an equilibrium. When $\alpha_A=1$, A's problem is

$$\max_{k_A\in\left(0,\frac{1}{2}\right)} \rho_A\left(k_A,k^*\right)\tfrac{1-2k_A}{2},$$

where

$$\begin{aligned}\rho_A\left(k_A,k^*\right) &\equiv \left(1-\nu\right)\left[p\left(k_A,k^*\right)-\overline{\theta}\right]-\tfrac{t}{4}\left(1-2k_A\right)^2=\\ &= \left(1-\nu\right)\left[u'\left(1-\left(1-\nu\right)\left(k_A+k^*\right)\right)-\overline{\theta}\right]-\tfrac{t}{4}\left(1-2k_A\right)^2.\end{aligned}$$

Differentiating A's profit with respect to k_A

$$-\left(1-\nu\right)\left[u'\left(1-\left(1-\nu\right)\left(k_A+k^*\right)\right)-\overline{\theta}\right]+\tfrac{t}{4}\left(1-2k_A\right)^2+$$
$$+\tfrac{1-2k_A}{2}\left[t\left(1-2k_A\right)-\left(1-\nu\right)^2u''\left(1-\left(1-\nu\right)\left(k_A+k^*\right)\right)\right]=0.$$

In equilibrium,

$$\tfrac{t}{4}\left(1-2k^*\right)^2=\left(1-\nu\right)\left[u'\left(1-2\left(1-\nu\right)k^*\right)-\overline{\theta}\right]+\tfrac{1-2k_A}{2}\left(1-\nu\right)^2u''\left(1-2\left(1-\nu\right)k^*\right). \qquad (11)$$

If the solution of this equation exists, it pins down the candidate equilibrium. Let

$$\Phi(x) \equiv -(1-\nu)\left[u'(1-2(1-\nu)x)-\overline{\theta}\right]+\tfrac{t}{4}(1-2x)^2-\tfrac{1-2x}{2}(1-\nu)^2 u''(1-2(1-\nu)x).$$

Note that $\Phi(0.5) = -(1-\nu)\left(u'(\nu)-\overline{\theta}\right) < 0$ by Assumption 1 and

$$\Phi(0) = -(1-\nu)\left(u'(1)-\overline{\theta}\right)+\tfrac{t}{4}-\tfrac{1}{2}(1-\nu)^2 u''(1),$$

which is positive if and only if

$$t \geq \overline{t} \equiv 2(1-\nu)\left[2\left(u'(1)-\overline{\theta}\right)+(1-\nu)u''(1)\right].$$

Moreover, at an optimum $k_A = k^*$, A's profit is concave — i.e.,

$$2\left[(1-\nu)^2 u''(1-(1-\nu)(k_A+k^*))-t(1-2k_A)\right]+ \\ +\tfrac{1-2k_A}{2}\left[(1-\nu)^3 u'''(1-(1-\nu)(k_A+k^*))-2t\right]<0,$$

which is always true if $u'''(x) < \eta$ for every $x \in [0,1]$, with $\eta > 0$ and small enough. Hence, if a symmetric equilibrium in which the market is not fully covered exists, then k^* must solve (11).

To complete the proof we show that A cannot profitably deviate from this candidate equilibrium because A's best deviation features $\alpha_A = 1$ and, hence, his profit is maximized by $k_A = k^*$, as shown above. This is done in the following three steps.

Step 1. For any k_A, a conceivable deviation in α_A such that $\alpha_A < 1$ must induce principals who buy from A to shut down production in state $\underline{s}$ only. In fact, as argued before, A has no incentive to offer $\alpha_A < 1$ if principals who buy the experiment produce in both states.

Step 2. Provider A's optimal deviation cannot feature both $\alpha_A < 1$ and $k_A \in \left(-\frac{1}{2}, \frac{1}{2}\right)$. To see this, note that if the optimal deviation is such that $\alpha_A < 1$, then principals buying from A must shut down production in state $\underline{s}$ only. Otherwise A strictly gain by setting $\alpha_A = 1$, a contradiction. Hence, provider A's maximization problem is

$$\max_{k_A \in \left(-\frac{1}{2},\frac{1}{2}\right), \alpha_A<1} \rho_A(\alpha_A, k_A,)\,\tfrac{1-2k_A}{2},$$

where

$$\rho_A(\alpha_A,k_A) \equiv (1-\nu)\alpha_A\left[u'\left(\left(\tfrac{1}{2}-k_A\right)(\nu+(1-\nu)\alpha_A)+\left(\tfrac{1}{2}-k^*\right)+\nu(k_A+k^*)\right)-\overline{\theta}\right]-\tfrac{t}{4}(1-2k_A)^2.$$

The first-order conditions for an interior solution are

$$-(1-\nu)\alpha_A\left[u'\left(\left(\tfrac{1}{2}-k_A\right)(\nu+(1-\nu)\alpha_A)+\left(\tfrac{1}{2}-k^*\right)+\nu(k_A+k^*)\right)-\overline{\theta}\right]+\tfrac{3t}{4}(1-2k_A)^2+ \\ -\tfrac{1-2k_A}{2}(1-\nu)^2\alpha_A^2 u''\left(\left(\tfrac{1}{2}-k_A\right)(\nu+(1-\nu)\alpha_A)+\left(\tfrac{1}{2}-k^*\right)+\nu(k_A+k^*)\right)=0.$$

and

$$u'\left(\left(\tfrac{1}{2}-k_A\right)\left(\nu+(1-\nu)\,\alpha_A\right)+\left(\tfrac{1}{2}-k^*\right)+\nu\left(k_A+k^*\right)\right)-\overline{\theta}+$$
$$+\tfrac{1-2k_A}{2}\,(1-\nu)\,\alpha_A u''\left(\left(\tfrac{1}{2}-k_A\right)\left(\nu+(1-\nu)\,\alpha_A\right)+\left(\tfrac{1}{2}-k^*\right)+\nu\left(k_A+k^*\right)\right)=0.$$

Substituting the second condition in the first and rearranging yields a contradiction:

$$\tfrac{t}{4}\,(1-2k_A)^2=0 \quad \Leftrightarrow \quad k_A=\tfrac{1}{2}.$$

Step 3. A deviation with $k_A=-\frac{1}{2}$ and $\alpha_A<1$ is not optimal if t is large. To see why, recall that A's objective function is concave in α_A if $u'''(\cdot)$ is small. At $k_A=-\frac{1}{2}$, the derivative of this function with respect to α_A is

$$u'\left(\nu+(1-\nu)\,\alpha_A\right)-\overline{\theta}+(1-\nu)\,\alpha_A u''\left(\nu+(1-\nu)\,\alpha_A\right)=0, \tag{12}$$

while the derivative with respect to k_A is

$$-(1-\nu)\,\hat{\alpha}_A\left[u'\left(\nu+(1-\nu)\,\alpha_A\right)-\overline{\theta}\right]+\tfrac{3}{2}t-\tfrac{(1-\nu)^2}{2}\hat{\alpha}_A^2 u''\left(\left(\nu+(1-\nu)\,\alpha_A\right)\right). \tag{13}$$

Substituting (12) in (13),

$$\tfrac{(1-\nu)^2}{2}\hat{\alpha}_A^2 u''\left(\nu+(1-\nu)\,\hat{\alpha}_A\right)+\tfrac{3}{2}t,$$

which is positive if

$$t>\tfrac{2}{3}\sup_{x\in[0,1]}|u''(x)|.$$

Since by steps 1, 2 and 3 A's best deviation features $\alpha_A=1$ and $k_A\in\left(0,\frac{1}{2}\right)$ and yields at the most the equilibrium profit, the result follows.

Finally, it is easy to show that

$$\rho^*=\tfrac{1-2k^*}{2}\,(1-\nu)^2\,|u''\left(1-2\,(1-\nu)\,k^*\right)|.$$

$\rho^*>t$ follows from the fact that in the equilibrium with full market coverage the fully informative experiment has price t. In addition, the first-order condition (11) and concavity of providers' objective function imply that k^* is increasing in t. ■

Proof of Proposition 10. A coalition formed by principals maximizes

$$V_{\alpha,1}\left(p\left(\alpha\right)\right)\equiv\left(\nu+(1-\nu)\,\alpha\right)u'\left(\nu+(1-\nu)\,\alpha\right)-\nu\underline{\theta}-(1-\nu)\,\alpha\overline{\theta}.$$

Differentiating with respect to α yields

$$u'\left(\nu+(1-\nu)\,\alpha\right)-\overline{\theta}+\left(\nu+(1-\nu)\,\alpha\right)u''\left(\nu+(1-\nu)\,\alpha\right).$$

Since

$$\frac{\partial V_{1,1}(p(1))}{\partial \alpha} = u'(1) - \overline{\theta} + u''(1) < 0 \quad \Leftrightarrow \quad \varepsilon(1) < \frac{\overline{\theta}}{|u''(1)|} \equiv \overline{\varepsilon}(\overline{\theta}),$$

the optimal experiment features $\alpha^{**} < 1$ if $\varepsilon(1) < \overline{\varepsilon}(\overline{\theta})$. Finally, since $\overline{\varepsilon}(\nu, \overline{\theta}) \leq \varepsilon(1)$, $\alpha^{*} < 1$ implies that $\alpha^{**} < 1$. ■

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