Management Science

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

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MANAGEMENT SCIENCE
Vol. 61, No. 6, June 2015, pp. 1292–1305
ISSN 0025-1909 (print) | ISSN 1526-5501 (online)

http://dx.doi.org/10.1287/mnsc.2014.2003

Disclosure Policy and Industry Fluctuations

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This paper examines voluntary disclosures in a repeated oligopoly and their association with price-setting behavior and industry profits along industrial fluctuations. The analysis focuses on the collectively optimal equilibrium among oligopoly firms. We show that, in industries that are highly concentrated or feature low cost of capital, nondisclosure is prevalent and results in stable product prices and high profit margins. Otherwise, firms may selectively disclose to soften competition in the product market. Under partial disclosure, firms withhold information during sharp industry expansions or declines. Consequently, the disclosure policy dampens the dissemination of shocks to the industry.

Keywords: voluntary disclosure; industrial organization; competition; market structure; firm strategy; business cycles; information sharing

History: Received October 4, 2012; accepted March 29, 2014, by Mary Barth, accounting. Published online in *Articles in Advance* December 19, 2014.

The relationship between information disclosure and product-market competition has been studied in prior research in single-period settings. In these models, firms bear no adverse consequences in future periods from competitive actions that decrease the current industry profit. However, this simplifying assumption can be limiting because many product segments feature a small number of large firms engaged in repeated relationships over an unspecified horizon. The single-period model overstates the true level of competition by assuming away forms of tacit cooperation that might emerge along repeated interactions. Furthermore, such cooperation plays a special role in repeated settings: to survive in the long run, the industry as a whole must be capable to adapt to short-term fluctuations.

Several facts suggest that tacit cooperation is a relatively common phenomenon. In industrial organization, it is a leading explanation for the price rigidity observed across a wide range of industries (Carlton 1986, 1989; Borenstein and Shepard 1996). In practice, firms engage in various forms of cooperation with competitors such as, for example, sharing advance production or sales information via trade associations (Chandra et al. 1999, Bertomeu et al. 2013). In most countries, antitrust law prohibits organized price fixing ("collusion") but criminal law generally requires the existence of an overt act demonstrating conspiracy. Aside from the most egregious market manipulation examples,[1] the more widespread (and implicit) forms of cooperation do not meet the legal threshold for conspiracy and, thus, within reason, remain within the boundaries of the law.

This paper examines the optimal disclosure policy in a dynamic oligopoly where the threat of competition in future periods serves to discipline tacit cooperation. Our analytical framework is a variant of Rotemberg and Saloner (1986; hereafter, RS) with industry demand shocks. In this framework, firms in an oligopoly compete over an infinite horizon with time-varying industry shocks. If the industry demand shock is public knowledge, RS show that firms set prices that are countercyclical in order to soften competition during industry booms. As a point of departure from RS, we assume that the demand information is privately known to only one firm. This firm can withhold or publicly disclose the information prior to choosing prices in the product market.[2] A disclosure allows otherwise uninformed firms to adjust their production and prices in advance of the shock. Thus, how much the industry responds to a shock depends on what information is being disclosed.

[1] A case at hand is the market for *lysine*, an additive used in meat production. This case was federally prosecuted and settled in 1996 because executives held private meetings to set price targets (see Hay and Kelley 1974 for other examples).

[2] As in Darrough (1993), the stylized assumption of a single firm being informed is made for parsimony in order to better illustrate information transfers within an industry. The main insights extend to environments in which multiple firms receive information (a proof is available from the authors upon request).

In industries subject to low discount rates and limited number of competitors, we show firms collectively achieve monopoly profit in the equilibrium in which the informed firm never discloses its information. The key intuition here is that incentives to cut prices below the monopoly price are the greatest when demand is high (and potential profits are large). Nondisclosure makes uninformed competitors uncertain about current demand, which lowers the perceived benefits of cutting prices; on the other hand, the informed firm knows about the upcoming demand and captures a greater proportion of the industry profits than its competitors when the demand shock is sufficiently favorable. As a result, the equilibrium market share of the informed firm is positively associated with total industry demand and the profit of uninformed firms may decline during an expansion.

In industries in which either discount rates are high or the number of firms is large, firms are unable to collectively earn monopoly profits by implementing a nondisclosure equilibrium because the uninformed firms have incentive to cut prices below the monopoly price. Disclosure helps coordinate all firms on a price schedule declining in demand shocks. When the forces in full disclosure and nondisclosure are combined, partial disclosure may emerge in equilibrium. Firms disclose voluntarily intermediate demand shocks but withhold extreme variations in demand. This, in turn, leads to our prediction that more disclosure occurs in industries with prices that are more strongly associated to industry demand and disclosure is more likely to occur in industries that are less concentrated. This prediction is consistent with evidence that less industry competition is associated with lower disclosure quality (Harris 1998, Cohen 2008, Balakrishnan and Cohen 2009, Ali et al. 2014).

Our paper is part of the literature on disclosure within a competitive environment (Wagenhofer 1990, Evans and Sridhar 2002, Corona and Nan 2013). These studies focus on competition in a single-period interaction, whereas we analyze equilibria in which cooperation is a result of repeated interactions. Further, existing research in this area typically focuses on duopolies, with comparative statics on the degree of product substitution or whether competition is in price or quantity (Darrough 1993, Suijs and Wielhouwer 2014). In comparison, our comparative statics are in terms of the number of firms in an industry (industry concentration), which, in these single-period models, may not affect the optimal disclosure policy (Raith 1996).[3] A separate strand of this literature focuses on cooperation over repeated interactions between members of a team, e.g., Baldenius et al. (2010) and Glover and Xue (2012). Unlike in an oligopoly, the principal chooses agents' payoffs and, thus, as a mechanism design problem, partly controls the set of cooperative equilibria.

Lastly, recent literature examines voluntary disclosure in repeated capital market settings. Marinovic (2010), Beyer and Dye (2012), and Beyer et al. (2013) develop models where communication occurs over time and firms endogenously form a reputation as a function of a sequence of past reports. Fischer et al. (2012) further consider a model in which current investors expect future investors to overweight earnings in their valuation model. These studies emphasize financial reporting concerns, whereas we focus here on interactions between disclosure and the product market.

1. The Model

1.1. Basic Setup

We borrow from Rotemberg and Saloner (1986) the basic elements to model stochastic industry fluctuations. There are N firms ($N \geq 2$) selling homogeneous goods over an infinite time horizon indexed by $t = 0, \ldots, +\infty$. Firms are risk neutral and face a constant marginal cost normalized to zero and discount payoffs in each period with a common factor $\delta \in (0, 1)$. We interpret this discount as the expected return, or cost of capital, demanded by outside investors. In each period, firms face a demand $s_t D(p)$, where s_t represents a time-varying mass of consumers (market size) and $D(p)$ is the demand at price p. The profit per consumer $pD(p)$ is continuous and concave, with a maximum at $p^* > 0$. The price p^* represents the optimal monopoly price and we denote $\Pi^* = p^* D(p^*)$. We summarize the notation that is used throughout the following analysis in Table 1.

In this model, shocks affect the mass of consumers willing to purchase the product. For example, consumers may have time-varying disposable income or, alternatively, an industry-wide innovation may make the product sold in the industry attractive to a set of customers. Shocks do not directly change the average consumer's price elasticity; i.e., the demand $D(\cdot)$ is not a function of s_t. Therefore, the optimal monopoly price is not a function of the current demand shock. As in Bagwell and Staiger (1997), this restriction is imposed to abstract away from other competing forces causing time-varying price schedules.

The game is decomposed in time periods, with each period t representing a stage game and $t.i$ denoting the ith event in period t (see Figure 1).

[3] A growing body of literature considers information sharing in supply chains (vertical relationships), e.g., Cachon and Fisher (2000), Lee et al. (2000), and Li (2002). As compared to our study, these models introduce additional benefits to share information, by making the entire supply chain more efficient. Baiman et al. (2010) examine the design of a supply chain operating over an infinite horizon. However, their focus is on the design of an incentive mechanism rather than information dissemination.

Table 1 Main Notations

Notation	Definition	Notes
N	Industry concentration	
δ	Discount factor	
s	Current demand shock (market size)	Independent and identically distributed in each period t
$sD(p)$	Demand function given s	
p^*	Monopoly price	Maximizes $spD(p)$
$s\Pi^*$	Industry monopoly profit	
m	Disclosure choice	$m \in \{\varnothing, s\}$
z	Choice whether to slightly cut prices (undercut)	$z \in \{share, undercut\}$
θ	Prices in the stage game	$\theta = (p_i, z_i)_{i=1}^N$
σ_k	Generic strategy of firm k in the repeated game	$\sigma \equiv (\sigma_1, \ldots, \sigma_N)$
p_{nd} (respectively, p_{pd})	Uninformed price under nondisclosure (respectively, partial disclosure)	$z \in \{share, undercut\}$
Ω_z	Market sizes with withholding and z	$m = \varnothing$ and all firms set same price
Ω_{over}	Market sizes with informed choosing $p > p_{nd}$	or $p > p_{pd}$ under partial disclosure
δ_{nd}	Smallest discount factor to sustain monopoly prices	
s^{over}	Maximum incentive-compatible s with overpricing	Under full-disclosure equilibrium
s^{share}	Maximum incentive-compatible s with sharing	Under full-disclosure equilibrium
s_{pd}^{share}	Maximum incentive-compatible s with sharing	Under partial-disclosure equilibrium
S	Maximum disclosed s with monopoly price p^*	Under full-disclosure equilibrium
V_{fd} (respectively, V_{pd})	Expected per-period payoff under full (respectively, partial) disclosure	

At $t.1$, an informed firm privately learns market size s_t (or state of the industry) at the beginning of each period; we refer to this firm as *informed* and the others as *uninformed*. The demand shocks s_t are independent and identically distributed, drawn from a continuous distribution with full support over $\mathbb{R}^+$ and a density $h(s)$ bounded away from zero. Without loss of generality, we normalize the distribution of s_t such that $\mathbb{E}(s_t\Pi^*) = 1$.[4] The demand shock s_t is not publicly known at the beginning of each period t. Each period, every firm is equally likely to become informed.[5]

At $t.2$, the informed firm makes a voluntary disclosure m_t, which is either a choice to publicly announce s_t or to stay silent. We use the terminology of "voluntary" to refer to disclosures that are under the control of the firm making the disclosure and examine the consequences of further disclosure requirements in §4. Firms cannot precommit to a disclosure policy and a disclosure must be truthful; i.e., $m_t \in \{ND, s_t\}$, where $m_t = ND$ indicates nondisclosure.

At $t.3$, firms engage in perfect price competition, simultaneously choosing a price p_k. As in Bagwell and Staiger (1997) and Athey et al. (2004), price competition removes other known drivers of information sharing under imperfect competition (e.g., Darrough 1993 shows that in a static model, firms engaging in Bertrand competition would prefer to share demand information). Because cooperation will occasionally exhibit small price cuts on the equilibrium path, we define an additional variable z_k, which represents a decision to cut prices slightly below p_k. Formally, let $z_k \in \{under, share\}$ be a binary label to represent the action of undercutting or not. The joint choice of a price and an undercutting action (p_k, z_k) is then what fully describes a pricing strategy.[6]

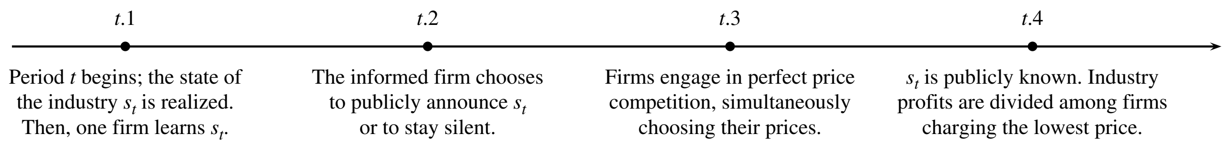
At $t.4$, the total industry profit $s_t \min_k p_k D(\min_k p_k)$ is shared equally among firms charging the lowest price if no such firms choose $z_k = under$. If some among these firms choose to undercut, the total profit is shared among the undercutting firms (i.e., those charging the lowest price and choosing $z_k = under$). Before moving

[4] As in RS (and much of the literature that follows), we make the assumption that demand shocks are independent across time periods. Extensions of our results are possible with some correlation between shocks, but, for reasons of parsimony, it is not usual in these models to introduce correlation unless this is the primary purpose of the analysis (see Bagwell and Staiger 1997 for an extension of this framework to persistent shocks).

[5] As a modelling device, the random information endowment is practical to set no ex ante asymmetry between competitors but the forces are similar if an industry leader is repeatedly informed in advance. We delay until §4.1 a rigorous discussion of situations in which no firm might receive information. It is not critical if the informed firm receives a noisy signal as long as the signal can be truthfully disclosed (with a delay) at the end of a period; in that case, one might reinterpret s_t as the expected demand conditional on the observed signal.

[6] This label is a shortcut to avoid a more technical characterization in terms of limits. Absent the z_k construct, a strategy featuring $z_k = under$ can be represented as the limit of a sequence of strategies with price $\{p_k^j\}$ as p_k^j converges from below to p_k. Note that we need not label multiple degrees of undercutting because this may only occur off-equilibrium and, therefore, we already obtain the supremum of the payoff from such a deviation by considering an infinitesimal decrease in price.

Figure 1 **Model Timeline**



on to the next period, all firms observe the true market size s_t as well as the pricing vector $\theta_t = (p_k^t, z_k^t)_{k=1}^N$.[7]

1.2. Equilibrium in the Repeated Game

As is well known, repeated games have a large number of Nash equilibria and, following RS, we make the assumption that firms coordinate on the equilibrium that yields the highest total industry profit. To motivate this choice of equilibrium, note that we focus on situations with cooperation, so that choosing equilibria that are collectively desirable is partly tautological to the research design. If cooperation is assumed, firms would have no reason to conjecture that their competitors would hurt all, including themselves, by failing to exploit all of its potential benefits.

First, we describe firms' strategies and the equilibrium concept in the repeated game. For any firm k, we refer to σ_k as its strategy at any period in the game; σ_k maps any public history of actions to firm k's disclosure and price choices. That is, in each period t, firms use the history of past play $h_t = (s_{t'}, m_{t'}, \theta_{t'})_{t' \le t}$, which specifies past market shocks, disclosures, and prices, as conditioning variables for current stage-game actions. Under this assumption, the repeated game exhibits *perfect monitoring* because all payoff-relevant information is perfectly known to each firm at the end of a stage game.[8]

We solve for the subgame-perfect Nash equilibrium of the repeated game (see Mailath and Samuelson 2006, p. 23, for a formal presentation). The equilibrium condition required for any proposed equilibrium, described by a strategy profile $\sigma = (\sigma_1, \ldots, \sigma_N)$, is that, for all k, σ_k', t and history h_t, $u_k(\sigma; h_t) \ge u_k^{h_t}((\sigma_1, \ldots, \sigma_k' \ldots, \sigma_N); h_t)$, where $u_k(\cdot; h_t)$ indicates firm k's expected future profits discounted to date t. In shorthand, denote $u_k(\cdot) \equiv u_k(\cdot; \varnothing)$ as this discounted expected payoff as of the first period of the game. We further restrict the attention to symmetric equilibria in which the strategies chosen by all firms are identical and may only depend on their current information. We refer to a symmetric subgame-perfect equilibria as a SPNE and, by symmetry, we can focus on the expected payoff, denoted $u(\sigma)$, dropping firm-specific subscripts.

Second, we are interested in solving for the SPNE that delivers the highest expected surplus. The ideal payoff is one in which the monopoly profit ($s_t\Pi^*$) is achieved every period (and, due to symmetry, equally shared among all firms in expectation). In such an ideal setting, the total discounted expected future profit, at any period in time t, is expressed as $(1/N)(1+\delta^1+\delta^2+\cdots) = 1/(N(1-\delta))$, or the expected monopoly payoff shared among all firms. We call this payoff the monopoly payoff, which after rescaling with a factor $1-\delta$, gives rise to a (normalized per-period) payoff of $1/N$.

This ideal payoff may or may not be achieved in the repeated game (when taking firm's incentives to compete). Imposing incentive compatibility on the part of firms, we define the efficient tacit cooperation as the SPNE that achieves the highest profit.

Definition 1.1. A SPNE strategy profile σ is efficient if for any other SPNE σ', $u(\sigma) \ge u(\sigma')$.

It is well known in the repeated games literature that the payoff from an efficient SPNE can be implemented using two modes of play. In the *cooperation mode*, firms follow a given disclosure and pricing strategy. Firms begin in the cooperation mode and continue in this mode, unless one or more firms achieve a stage-game payoff lower than it should be under cooperation.[9] If this occurs, firms switch to the *punishment mode*. This mode serves to discipline cooperation, and therefore the optimal punishment should minimize firms' payoff. Hence, we set the punishment mode as a stage-game strategy in which all firms choose $p_k = 0$ in all future periods.

[7] We do not require firms to know the identity of the informed firm when playing this game, in that observing the sequence of price choices is sufficient to detect whether an informed or uninformed firm might have deviated from the profit-maximizing cooperation. As an example, suppose that, for a shock s_t, the informed firm should withhold and set a price p, and the uninformed should set a price $p' < p$. Instead, suppose that the informed firm chooses the price p' and increases its current profit. The uninformed firm will observe that all firms chose p' instead of only $N-1$ firms doing so, thus demonstrating that a deviation has taken place.

[8] Unfortunately, our model cannot accommodate imperfect monitoring in a straightforward manner because costless truthful disclosure rules out imperfect monitoring across periods by manner of assumption: if s_t can be truthfully disclosed by the informed firm in advance, it could also be disclosed at the end of the stage game. In this model, such ex post disclosure would always benefit cooperation.

[9] This condition is slightly stronger than observing a deviation, but avoids equilibria sustained by somewhat arcane strategies that seem practically implausible. To illustrate, suppose that a firm makes an unexpected pricing decision that strictly increases its own profit without hurting the profit of other firms. Competitors could respond to this action by triggering the punishment mode, but doing so is unnatural given that no actual damage would have been borne by any firm.

2. Nondisclosure and Full-Disclosure Benchmarks

2.1. Cooperation Mode

In this section, we analyze the cost and benefits of nondisclosure versus those of full disclosure. The strategy profile of one possible efficient SPNE may call for full disclosure. In this case, our model reduces to RS where, each period, the shock (s) is known to all firms before their pricing choices. Conditional on market size s, a price $P(s)$ can be set and the industry profit $sP(s)D(P(s))$ is shared among all firms. Of note, although disclosures are voluntary, the oligopoly can always enforce full disclosure because any deviation to nondisclosure is publicly observable and triggers the punishment mode.[10]

At the other extreme, the equilibrium strategy profile may call for nondisclosure. In this case, uninformed firms do not have information and set a price p_{nd} independent of s. As for the case of full disclosure, the oligopoly can always enforce nondisclosure by triggering the punishment mode when a disclosure is observed. For each realization of s, the informed firm has three options:

- If $s \in \Omega_{\text{over}}$, the informed firm overprices: setting a price strictly higher than p_{nd} leading to a current profit of zero.
- If $s \in \Omega_{\text{share}}$, the informed firm shares: choosing $p = p_{nd}$ and $z = share$, leading to current profit $sp_{nd}D(p_{nd})/N$.
- If $s \in \Omega_{\text{under}}$, the informed firm undercuts: choosing $p = p_{nd}$ and $z = under$, leading to a current profit $sp_{nd}D(p_{nd})$.

The price p_{nd} and the sets $(\Omega_{\text{over}}, \Omega_{\text{share}}, \Omega_{\text{under}})$ are descriptors of the cooperation mode in a nondisclosure SPNE.

2.2. Incentive Benefit of Nondisclosure

We first examine equilibria in which the tacit cooperation can attain the first-best industry surplus (each firm earns an expected surplus $1/N$ per period).

2.2.1. Nondisclosure Dominates Full Disclosure Under Monopoly Pricing. We begin with full disclosure. For first-best $P(s) = p^*$ to be an equilibrium, no firm must find it desirable to undercut its competitors, leading to the following incentive-compatibility constraint, for all s,

$$(1-\delta)s\Pi^*/N + \delta/N \geq (1-\delta)s\Pi^*. \tag{1}$$

The left-hand side has two components. The first component $s\Pi^*/N$ is the current surplus obtained by playing the cooperation mode and the second component δ/N is the surplus obtained from future periods.[11] The right-hand side has only one component, the deviation profit in the current period; given that such a deviation triggers a permanent price of zero in future periods, there will be zero profit in all future periods. This inequality cannot be satisfied for all $s \in \mathbb{R}^+$ for any $\delta < 1$, which implies that full disclosure cannot achieve monopoly profits for all market sizes.

We compare this benchmark to the nondisclosure case. The incentive-compatibility conditions depend on whether the firm is informed or uninformed. First, consider the prescription for the informed firms to overprice in the region $s \in \Omega_{\text{over}}$. By deviating to $z = under$ and $p = p^*$ (the best possible deviation), the informed firm can obtain $s\Pi^*$ in the current period, but this will trigger a shift by all firms to the punishment mode, making zero profit in future periods. To prevent such deviation, for all $s \in \Omega_{\text{over}}$,

$$(1-\delta)0 + \delta/N \geq (1-\delta)s\Pi^*. \tag{2}$$

This constraint is satisfied when $s \leq s^{\text{over}} \equiv (\delta/(1-\delta)) \cdot (1/(N\Pi^*))$.

Second, a similar condition is derived for all $s \in \Omega_{\text{share}}$ (for which the informed firm shares with the uninformed),

$$(1-\delta)s\Pi^*/N + \delta/N \geq (1-\delta)s\Pi^*. \tag{3}$$

This constraint is satisfied when $s \leq s^{\text{share}} \equiv (\delta/(1-\delta)) \cdot (1/((N-1)\Pi^*))$. It is thus easier to induce sharing than to induce overpricing, as implied by $s^{\text{over}} < s^{\text{share}}$.

The last incentive-compatibility consideration applies to the uninformed. These firms should be given incentives not to deviate to a price slightly lower than the price p_{nd} set by all competitors:

$$(1-\delta)\left(\int_{\Omega_{\text{over}}} sh(s)\,ds \frac{\Pi^*}{N-1} + \int_{\Omega_{\text{share}}} sh(s)\,ds \frac{\Pi^*}{N}\right) + \delta\frac{1}{N} \geq (1-\delta). \tag{4}$$

In Equation (4), the right-hand side corresponds to the expected profit obtained by undercutting all other firms.[12] Since, in this case, the uninformed firm who is contemplating a deviation does not know s, it will anticipate an expected profit $\mathbb{E}(s\Pi^*) = 1$. The left-hand side corresponds to the profit expected by staying on the cooperation mode, where the profit of the uninformed will depend on s and the strategy of the informed firm.

Pooling together these constraints, the next proposition establishes the value of the nondisclosure regime.

[10] This statement holds true under the baseline assumption that there is no uncertainty about information endowment but some other considerations need be imposed if no firm might be informed. This extension is presented in §4.1.

[11] Recall that these are expressed in a per-period basis and need to be divided by $1-\delta$ to obtain the discounted surplus.

[12] Formally, this incentive-compatibility condition states that the right-hand side of Equation (4) should be greater than any deviation, i.e., greater than $(1-\delta)\sup_{p<p^*} \mathbb{E}(s)pD(p)$. This expression is equal to $(1-\delta)\,\mathbb{E}(s)p^*D(p^*) = 1-\delta$, as stated above.

Proposition 2.1. *Under full disclosure, monopoly payoffs cannot be attained. Under nondisclosure, there exists a threshold $\delta_{nd} < 1$, increasing in the number of firms N, such that the industry monopoly payoffs can be attained if and only if $\delta \geq \delta_{nd}$.*

Compared to full disclosure, the oligopoly is better able to dampen the incentives to deviate when current demand is high by leaving most competitors uninformed. Intuitively, when market size is large, disclosing makes deviation more attractive to *all* firms so firms need to be sufficiently patient to refrain from undercutting. Under nondisclosure, $N-1$ firms do not know whether market size is high and assume the average market size when contemplating a deviation, lowering the benefit of deviating. As a result, secrecy is valuable to the oligopoly, not because it necessarily benefits the uninformed firm in the current period, but because it better motivates cooperation among oligopoly members in the long-term. This is the first main intuition derived from the model.

2.2.2. Properties of Nondisclosure Equilibria. We describe next the cooperation mode that can sustain the nondisclosure equilibrium under the widest range of discount rates.[13] The cooperation mode must set the actions of the informed firm to reduce incentives by the uninformed to cut prices. Clearly, this involves choosing to overprice whenever incentive compatible, i.e., when $s \leq s^{\text{under}}$, then choosing to share, i.e., when $s \in [s^{\text{under}}, s^{\text{over}}]$, and only falling back to undercutting when no other action can be elicited, i.e., when $s > s^{\text{over}}$.

Corollary 2.1. *When $\delta \geq \delta_{nd}$, there exists a unique strategy that achieves industry monopoly surplus. That unique strategy is given as follows:*

(i) *For $s \leq s^{\text{over}}$ (low market size), only the uninformed sell at a price p^*.*

(ii) *For $s \in (s^{\text{over}}, s^{\text{share}}]$ (medium market size), all firms sell at a price p^*.*

(iii) *For $s > s^{\text{share}}$ (large market size), only the informed firm sells.*

These results point to how information environment can explain the distribution of market shares as a function of shocks to the industry. To elicit cooperation among uninformed firms, the informed firm gives away when the market is low (similar to a "fat cat" competitive stance, e.g., Fudenberg and Tirole 1984). Our model also predicts undercutting in the cooperation mode in that, when the market is large, the informed firm takes the entire market. Unlike models in the area (Green and Porter 1984), this behavior does not trigger a price war.

[13] This approach is standard in the repeated games literature (see Mailath and Samuelson 2006).

When $\delta < \delta_{nd}$, monopoly profits cannot be achieved in an equilibrium with nondisclosure. In fact, as demonstrated in the following proposition, the profits are nil in any nondisclosure equilibrium.

Proposition 2.2. *If $\delta < \delta_{nd}$, any nondisclosure equilibrium yields zero profit for all firms.*

This result reflects the inflexibility of nondisclosure: it either achieves monopoly profits for all states (when firms are patient enough) or fails completely and leads to zero-profit outcome for all states (when firms are just slightly impatient).

2.3. Price Coordination Benefit of Full Disclosure

In contrast to the nondisclosure equilibrium strategy, the equilibrium with disclosure can yield strictly positive profits. In fact, we show that disclosure helps firms in their tacit price coordination by allowing them to set state-contingent collusive prices. This price-coordination role was absent when $\delta \geq \delta_{nd}$ leading to the monopoly industry profit achieved through nondisclosure each period. Denote $P(s)$ as the price set by all firms (with $z = share$ always) and V_{fd} be the expected surplus received by firms in the SPNE:

$$V_{fd} = \frac{\int sP(s)D(P(s))h(s)\,ds}{N}. \tag{5}$$

Similar to the previous case (but using V_{fd} instead of $1/N$), it must be incentive compatible for all firms to choose $p = P(s)$ and $z = share$ (versus deviating to choosing $p = P(s)$ and $z = under$):

$$(1-\delta)\frac{sP(s)D(P(s))}{N} + \delta\frac{V_{fd}}{N} \geq (1-\delta)sP(s)D(P(s)). \tag{6}$$

Comparing the above incentive-compatibility constraint to that for monopoly pricing case (Equation (1)), a key difference is that the deviation payoff (i.e., the right-hand side) is now a function of the state-dependent price schedule ($P(s)$). Solving for the optimal price for each s yields the following full-disclosure benchmark.

Proposition 2.3. *In an efficient full-disclosure equilibrium,*

(i) *for $s \leq S$, $P(s) = p^*$;*

(ii) *for $s > S$, $sP(s)D(P(s)) = S\Pi^*$,*

where S is the maximal positive s' solution to

$$s' = \frac{\delta\int_0^{s'} sh(s)\,ds}{(1-\delta)(N-1) - \delta\int_{s'}^{+\infty} h(s)\,ds}. \tag{7}$$

Notice that even when firms are not patient enough to achieve the monopoly surplus, monopoly profits are earned in some region of s (i.e., $s < S$). When market size is too large, however, the gains from undercutting are too important and thus, at p^*, firms would prefer to undercut. One way firms can avoid such deviations is to agree to a lower price when market size is large, artificially reducing total industry profits and therefore removing incentives to undercut. This is precisely the insight from RS, where market size is assumed to be public knowledge. In our model, it leads the informed firm to voluntarily disclosing the industry demand information (s) in order to make price coordination possible. This is the second main intuition in our analysis.[14]

Although highly stylized, the analysis of this section suggests that industries with high profits but high discount rate should feature more disclosure than those with lower discount rate. In other words, the model provides some support for an association between a number of observable industry-level variables: disclosure should be prevalent in environments where prices are more volatile, firms discount future cash flows more heavily, or the industry is less concentrated.

3. Partial Disclosure

3.1. Cooperation Mode

In this section, we consider cases where certain forms of partial disclosure may emerge as a repeated equilibrium behavior. The key to partial disclosure is that it combines advantages of both nondisclosure (incentive compatibility of the uninformed) and full disclosure (price coordination).

In a general form, the cooperation mode in a partial-disclosure equilibrium can be represented in terms of the following descriptors. The informed firm withholds information when $s \in \Omega$. In this case, uninformed firms choose a price p_{pd} and $z = share$, whereas the informed firm chooses to overprice if $s \in \Omega_{\text{over}}$, share if $s \in \Omega_{\text{share}}$, or undercut if $s \in \Omega_{\text{under}}$. If $s \notin \Omega$, the informed firm discloses and all firms choose a price $P(s)$ and $z = share$. Denote $\Pi_{pd} = p_{pd}D(p_{pd})$ and let $V_{pd} < 1/N$ denote the firms' surplus in the efficient partial-disclosure equilibrium and s_{pd}^{share} in a manner that is entirely analogous to s^{share} considered earlier, i.e., the maximal state s conditional on nondisclosure such that an informed firm prefers not to undercut its competitors.[15]

One added incentive problem introduced by a partial-disclosure regime is that for some s, the informed firm can deviate from disclosing ($m(s) = s$) to not disclosing ($m(s) = \varnothing$), attaining a price p_{pd} possibly greater than $P(s)$. Such deviation was never desirable in the full-disclosure equilibrium because, upon observing a nondisclosure, firms could immediately trigger a price war.

To help resolve this problem, the oligopoly may use two incentive mechanisms. The first is to reduce the nondisclosure price p_{nd}, thus averting some of the temptation to strategically withhold information (that should have been disclosed) because doing so would always lead to lower profits.[16] The second is to let the informed firm withhold favorable information (i.e., large s) and undercut. In turn, this allows the informed firm to collect greater cash flows in states that are more favorable, a feature similar to what occurs in the pure nondisclosure equilibrium derived earlier.

3.2. Partial-Disclosure Equilibrium: Simplified

For the purpose of stating most of the economic intuitions, we first examine an efficient equilibrium within a class of simplified equilibrium strategies. That is, we only consider equilibria in which the informed firm is never required to overprice, i.e., setting $\Omega_{\text{over}} = \varnothing$. As we shall see later (when we lift this requirement), this condition is generally with loss of potential profits to the firms engaging in the tacit agreement but, at a conceptual level, it allows us to emphasize the new forces that appear under partial disclosure without repeating some of the existing forces discussed earlier.

Proposition 3.1. *If a simplified partial-disclosure equilibrium is efficient, there exists an interval (s_1, s_2) such that the informed firm discloses if and only if $s \in (s_1, s_2)$. Furthermore, $0 < s_1 < s_2 \leq \hat{s}_{pd}$.*

Unlike when monopoly surplus can be attained, partial disclosure adds value by providing a balance between price coordination (i.e., setting prices according to $P(s)$) and providing incentives to the uninformed not to deviate when market size is large (i.e., setting prices according to p_{nd}). We find that equilibria with partial disclosure have a simple structure and feature a single disclosure region in which moderate shocks are disclosed but large market movements are withheld.

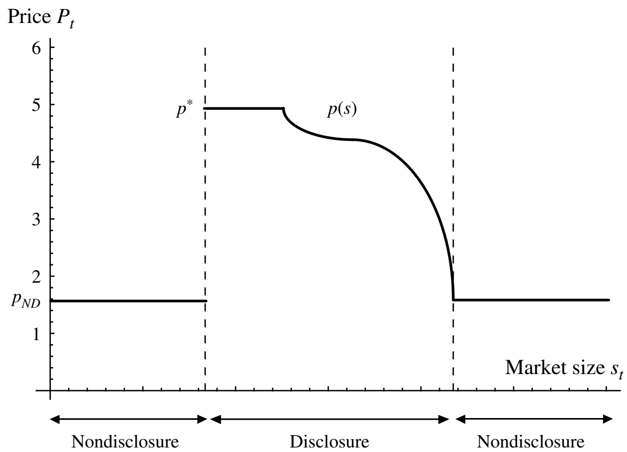
We start with large market sizes (in the region $[s_2, +\infty)$). Here the informed firm is not expected to disclose any information. This feature occurs for two reasons, as explained next. First, asking the informed to disclose is difficult because, in a partial-disclosure equilibrium, withholding does not immediately trigger the punishment mode (unlike under full disclosure). This incentive problem places an upper bound on the disclosure region, which can only be increased at a cost to the entire industry (by reducing the nondisclosure

[14] In our model, by assumption, a disclosure of the demand shock s is not needed to discover the optimal monopoly price. Hence, the benefit of disclosure is solely driven by product market competition.

[15] As in the baseline, the bound s_{pd}^{share} is obtained by binding: $(1-\delta)s\Pi_{pd}/N + \delta V_{pd} \geq (1-\delta)s\Pi_{pd}$.

[16] Indeed, we show that industry prices are always higher in states where a disclosure is made (see Figure 2). This intuition is closely related to the case of uncertain information endowment discussed in §4.1 and stems from the same need to reduce profits when a firm claims not to have received the type of information that should have disclosed.

Figure 2 **An Illustration of Price and Disclosure Behavior (Three Regions)**



prices and Π_{pd}). Second, when s is sufficiently large so that monopoly prices could no longer be obtained conditional on a public disclosure, any disclosure of information causes a decrease in prices. To see this, note that conditional on disclosure, the industry surplus is the minimum of $s\Pi^*$ and $(\delta/(1-\delta))(N/(N-1))V_{pd}$ so that any incremental unit of market size is fully dissipated once s is large. This causes nondisclosure to become relatively more attractive to the oligopoly as s becomes large.

A nondisclosure of large market sizes might only be of interest if uninformed firms are unable to perfectly invert the informational content of a nondisclosure. This creates a benefit, at the other extreme, to withhold low market sizes (in the region $[0, s_1)$). The cost of this disclosure strategy is that the price is reduced from the monopoly price p^* if such information had been disclosed versus the lower p_{pd} price when this information is kept silent. Yet, this potential cost remains relatively small in this region because it is of the order $s(\Pi^* - \Pi_{pd})$.[17]

The remaining set of values that could be disclosed is an interval of intermediate market sizes $s \in (s_1, s_2)$. These market sizes are large enough so that the economic cost of a nondisclosure $s(\Pi^* - \Pi_{pd})$ cannot be ignored, but small enough so that a disclosure can still be elicited. See Figure 2 for an illustration of the pricing and disclosure behavior in such a simplified partial-disclosure equilibrium.

[17] This form of partial disclosure is remindful of Wagenhofer (1990), who pointed out that nondisclosure may occur for extreme shocks. Yet, our main intuition is different in that Wagenhofer considers an exogenously specified entry cost and financial reporting motives. Our setting, on the other hand, recovers both costs and benefits endogenously as a result of product-market competition and, in that respect, links them to testable characteristics of the product market.

3.3. Partial-Disclosure Equilibrium: The General Case

We move now to the efficient equilibrium, considering a tacit cooperation that could involve overpricing by the informed firm when there is a nondisclosure and the market size is small enough. The trade-offs described earlier carry over to this setting but with the addition of an additional benefit of overpricing and not disclosing when the market size is very low. This, in turn, causes an additional benefit for nondisclosure and thus may create an additional interior nondisclosure region over low market sizes.

Proposition 3.2. *If a partial-disclosure equilibrium is efficient, it can be constructed as follows: let* $0 < s_0 \le s_1 \le s_2 \le s_3$.

(i) *For* $s \in [0, s_0) \cup [s_1, s_2) \cup [s_3, +\infty)$, *the informed firm does not disclose.*

(ii) *For* $s \in [s_0, s_1] \cup [s_2, s_3)$, *the informed firm discloses. Furthermore, the disclosure region must be a single interval in any equilibrium such that* $\Pi_{pd} \ge N/(N-1)\Pi^*$ *(i.e., the nondisclosure price is not too small).*

When considering overpricing, there is, in addition to the regions described earlier, a potential region $[s_1, s_2)$ in which information is not disclosed. In this region, it can be beneficial not to disclose information because, when this is the case, the informed firm overprices and transfers more surplus to the uninformed, thus easing the uninformed incentive-compatibility condition. Indeed, the greater the market size s, the more this strategy can benefit the uninformed and thus the more it can be optimal to withhold information. As s becomes even larger, however, overpricing is no longer feasible and thus the dominant forces revert to those discussed earlier.

4. Extensions

4.1. Uncertain Information Endowment

Although the baseline model is solved under the assumption that a firm is always informed, a few additional considerations must be considered if no firm might receive information, as in the case of uncertain information endowment in Dye (1985) and Jung and Kwon (1988). Assume now that with probability $q \in (0, 1)$, no firm observes s and whether a firm does or does not observe s is not known to an uninformed firm.

We begin by considering the case in which p^* is incentive compatible in all periods. Clearly, full disclosure (still) cannot implement p^* because there is a nonzero probability that large realizations of s are disclosed. Implementing a nondisclosure equilibrium, albeit still attractive for the reasons presented earlier, does require proper consideration of states in which no firm is informed. An informed firm could withhold its disclosure and claim to have been uninformed.

Indeed, such action is desirable if the informed firm is expected to overprice and would rather share the industry profit by claiming to be uninformed. From this logic, it follows now that overpricing is no longer incentive compatible.

We are left to state the incentive-compatibility condition for the uninformed:

$$(1-\delta)\left(q\frac{1}{N}+(1-q)\int_0^{s^{\text{share}}} sh(s)\,ds\right)\frac{\Pi^*}{N}+\delta\frac{1}{N} \\ \geq (1-\delta). \tag{8}$$

The following Proposition follows from rewriting this inequality in terms of δ.

Proposition 4.1. *Suppose no firm is informed with probability $q \in (0,1)$. With full disclosure, monopoly payoffs cannot be attained. With nondisclosure, there exists a threshold $\delta_{nd}^q < 1$, increasing in N and decreasing in q, such that monopoly payoffs can be attained if and only if $\delta \geq \delta_{nd}^q$.*

The result in Proposition 4.1 is remindful of Dye (1985), in which a lower probability of information endowment tends to further dampen disclosure even when information is received. The rationale for the observation in our environment is slightly different, however. In financial reporting models, a lower probability of information endowment allows more informed firms to hide behind those who cannot disclose. By contrast, here, an uncertain information endowment perturbs the monitoring of the informed firm's pricing decision, putting greater pressure on prices and, therefore, giving incentives to the uninformed to preemptively reduce prices. An uncertain information endowment thus tends to reduce situations in which nondisclosure is optimal.

We do not prove the result that nondisclosure leads to zero profit if $\delta < \delta_{nd}^q$ since the proof is identical to the case of $q = 0$. Yet, uncertainty about the information endowment can also be problematic to implement full disclosure because a firm could avoid reporting its information and claim to have been uninformed. Considering this potential deviation, we solve next for a full-disclosure equilibrium with uncertain information endowment.

Proposition 4.2. *If $\delta < \delta_{nd}^q$, any equilibrium with nondisclosure yields zero profit to all firms. In the efficient full-disclosure equilibrium, firms set a price equal to zero if nondisclosure is made and, otherwise, set a price $P(s) = p^*$ if $s \leq S$ and $P(s)$ such that $sP(s)D(P(s)) = S\Pi^*$ if $s > S$.*

To make full disclosure incentive compatible, a full-disclosure equilibrium must reduce the potential cash flows when nondisclosure is made to avoid the temptation to claim that no information has been received. Yet, even though full disclosure can be preferred over nondisclosure, it can nevertheless be very costly to implement. To see this, notice that any full-disclosure equilibrium *must* require perfect competition when no firm is informed. If this were not the case, then an informed firm with s very large would be better off not making a disclosure and earning a cash flow $sp_{nd}D(p_{nd})$, thus contradicting a strategy that involves full disclosure. As a result, the full-disclosure equilibrium has a form that is similar to the baseline as long as one firm is informed but features perfect competition when no firm is informed.

4.2. Mandatory Disclosure

We have, to this point, examined disclosure policies that are under the control of each firm, although disciplined by the tacit cooperation. The objective of this section is to extend the analysis to mandatory disclosure requirements, in which a regulator could enforce specific disclosures over a certain subset of events. Focusing, again, on the collectively optimal equilibria, we examine the consequences of such disclosures requirements on firms' profit as well as consumer and total surplus.

Since the kind of competition considered here is Bertrand competition, we know that firms' surplus is increasing in prices, whereas consumer and total surplus are decreasing in prices (hereafter, we save space by using the terminology of "social surplus" for both consumer and total surplus). We shall now establish that the regulation of disclosure can provide a powerful tool for regulators to offset some of the detrimental welfare consequences of tacit cooperation in an oligopoly.

Assume that a regulation takes the form of a nonempty set $\Omega_r \subseteq \mathbb{R}$ of market sizes that must be disclosed. As an example, a set of the form $\Omega_r = [0, x]$ could represent a need to report an impairment when anticipating adverse market conditions. If a market shock is not subject to the regulation, firms can still disclose it voluntarily and we refer to a nondisclosure equilibrium as an equilibrium in which all nonmandated disclosures are withheld. In the next proposition, we describe the effect of regulations when industry concentration is high.

Proposition 4.3. *Suppose that $\delta \geq \delta_{nd}$ (i.e., monopoly prices would be set absent any regulation), then mandatory disclosure always weakly decreases firms' surplus and weakly increases social surplus, strictly so if and only if either one of these conditions hold:*

(i) *Ω_r includes some events greater than s^{share}; or*

(ii) *$\delta \leq \delta_r$, where δ_r is a bound strictly greater than δ_{nd} and increasing in Ω_r (in the sense of the inclusion).*

Mandatory disclosure can have two adverse effects on the tacit agreement. When disclosing large realizations of the market shock s (case (i)), the mandatory disclosure requirement reduces the benefits of nodisclosure and triggers more competition. This, in turn, benefits consumers and total surplus by reducing prices toward marginal cost.

There is a second incentive benefit achieved by mandating disclosure (case (ii)). A public disclosure of low events does not necessarily reduce prices conditional on disclosure (since it leads to p^*) but it does raise uninformed firm's expectations about market size for other events that are not disclosed. In turn, this tends to make it more difficult to sustain monopoly prices conditional on a nondisclosure and, as before, can benefit consumers and total surplus.[18] This finding supports the theory that large firms in concentrated markets are typically opposed to disclosure because of proprietary cost considerations.

Consider next the case of less concentrated industries. One possibility is that the industry chooses full disclosure in which case the regulation does not have any effect. Another possibility is that the industry chooses nondisclosure for any event not subject to the regulation. We consider here the effect of mandatory disclosure in these settings.

Proposition 4.4. *Suppose that $\delta < \delta_{nd}$. Then, any mandatory disclosure always weakly increases firms' surplus and weakly decreases social surplus, strictly so if $V_{fd} > 0$ and the regulation is an interval $\Omega_r = (s_1, s_2) \subset \mathbb{R}^+$ with s_1 sufficiently large.*

When considering tacit agreements that feature nodisclosure and full disclosure, mandatory disclosure benefits firms, at the detriment of consumers and social surplus, when $\delta < \delta_{nd}$. This implies that firms might demand more regulation in industries that are more competitive. The intuition for this finding is that mandatory disclosure can discipline firms to disclose favorable information that would, otherwise, have been withheld. This is done more easily through regulation than within a tacit agreement because, if done through a tacit agreement, an informed firm with very high market size would always deviate not to disclose. Consequently, we predict that the regulation of disclosure can be detrimental to social surplus in more competitive settings.

The effect of regulation under partial disclosure is generally ambiguous, because partial disclosures combine the trade-offs described in Propositions 4.3 and 4.4. On one hand, a regulation that mandates disclosure of high realizations of s helps discipline the informed firm to report such realizations, and thus benefits the tacit cooperation. On the other hand, as in the case of nondisclosure, firms prefer withholding low realizations of s and thus mandated disclosure over low market sizes benefits consumers.

[18] Unlike a more direct regulatory intervention with price controls, increasing disclosure would not require regulators to know details of the industry (such as the marginal cost) or decide over operating decisions.

5. Concluding Remarks

In this paper, we explore the relationship between disclosure, industry fluctuations, and product-market competition in an oligopoly where firms can sustain collectively optimal equilibria (or tacit cooperation). We determine what forms of disclosure maximize industry profits, and relate firm profits to whether a firm is informed and discloses that information early. In our model, the optimal disclosure policy is endogenous and driven by concerns about future competition. In particular, we find the following:

1. Policies with nondisclosure are desirable in industries with a low discount rate or high concentration.
2. Policies with partial or full disclosure are desirable in industries with a high discount rate or low concentration.
3. In regimes with partial disclosure, informed firms withhold sufficiently favorable or unfavorable information and disclose intermediate news.
4. Disclosure of favorable market conditions imply high profits for informed firms, but not necessarily for uninformed competitors.
5. Mandatory disclosure decreases firm profits and increases social surplus in highly concentrated industries, but the reverse is true in highly competitive industries.

We hope that our study will provide some first steps—with a model that puts the focus on the product market—to understand how and why disclosure interacts with the demand fluctuations of an industry. However, broadening the scope to other disclosure paradigms, and most notably financial reporting concerns, it is clear that more research is necessary to fully understand how private information is disseminated as a function of the current and long-term conditions of an industry.

Acknowledgments
The authors thank Tim Baldenius, Mark Bagnoli, Ron Dye, Pingyang Gao, Jon Glover, Bjorn Jorgensen, Christian Leuz, DJ Nanda, Korok Ray, Bill Rogerson, and Phil Stocken, as well as seminar participants at Carnegie Mellon University, Northwestern University, the 2008 Danish Center for Accounting and Finance Conference at Copenhagen, the 2013 Laboratory for Aggregate Economics and Finance Conference at the University of California Santa Barbara, and the 2008 Chicago–Minnesota Theory Conference. This paper originated from several discussions at the Tepper Repeated Games Reading Group, and the authors thank its participants, Edwige Cheynel, Laurens Debo, and Richard Lowery, for helpful feedback on this project.

Appendix. Omitted Proofs

Proof of Proposition 2.1. We derive the optimal strategy (i.e., the sets Ω_{over}, Ω_{share}, and Ω_{under}), and then solve for the minimum discount rate δ_{nd} stated in Proposition 2.1.

Note first that any $s \in \Omega_{\text{over}}$ must be such that $s \le s^{\text{over}}$ and any $s \in \Omega_{\text{share}}$ must be such that $s \le s^{\text{share}}$. Therefore, in the left-hand side of Equation (4),

$$(1-\delta)\left(\int_{\Omega_{\text{over}}} sh(s)\,ds \frac{\Pi^*}{N-1} + \int_{\Omega_{\text{share}}} sh(s)\,ds \frac{\Pi^*}{N}\right) + \delta\frac{1}{N} \ge (1-\delta)E_s[sp^*D(p^*)] = (1-\delta).$$

To maximize the left-hand side, one should set $\Omega_{\text{over}} = [0, s^{\text{over}}]$ and $[\Omega_{\text{share}} = s^{\text{over}}, s^{\text{share}}]$. The minimum discount rate consistent with monopoly pricing is obtained by binding Equation (4):

$$(1-\delta_{nd})\left(\int_0^{s^{\text{over}}} sh(s)\,ds \frac{\Pi^*}{N-1} + \int_{s^{\text{over}}}^{s^{\text{share}}} sh(s)\,ds \frac{\Pi^*}{N}\right) + \delta_{nd}\frac{1}{N} = (1-\delta_{nd}).$$

That is,

$$\delta_{nd}\left(\frac{N+1}{N} - \int_0^{s^{\text{over}}} sh(s)\,ds \frac{\Pi^*}{N-1} - \int_{s^{\text{over}}}^{s^{\text{share}}} sh(s)\,ds \frac{\Pi^*}{N}\right) = 1 - \int_0^{s^{\text{over}}} sh(s)\,ds \frac{\Pi^*}{N-1} - \int_{s^{\text{over}}}^{s^{\text{share}}} sh(s)\,ds \frac{\Pi^*}{N}.$$

And solving for δ_{nd}

$$\delta_{nd} = \frac{N(N-1) - N\int_0^{s^{\text{over}}} sh(s)\,ds\Pi^* - (N-1)\int_{s^{\text{over}}}^{s^{\text{share}}} sh(s)\,ds\Pi^*}{(N+1)(N-1) - N\int_0^{s^{\text{over}}} sh(s)\,ds\Pi^* - (N-1)\int_{s^{\text{over}}}^{s^{\text{share}}} sh(s)\,ds\Pi^*}.$$

This is the desired equation for δ_{nd}. $\square$

Proof of Proposition 2.2. In a nondisclosure SPNE, (i) the uninformed firms choose $p_{nd} \le p^*$; (ii) for $s \in \Omega_{\text{over}}$, the informed firm chooses $p > p_{nd}$ (overprices); (iii) for $s \in \Omega_{\text{share}}$, the informed firm chooses $p = p_{nd}$ and shares; and (iv) for $s \notin \Omega_{\text{over}} \cup \Omega_{\text{share}}$, the informed firm chooses $p = p_{nd}$ and undercuts.

First, we compute the per-firm surplus V_{nd} in this SPNE,

$$\begin{aligned} V_{nd} &= \int h(s)s\Pi_{nd}\,ds/N \\ &= \int h(s)s\Pi^*\,ds\Pi_{nd}/(N\Pi^*) \\ &= \Pi_{nd}/(N\Pi^*). \end{aligned}$$

As before, it is optimal to set Ω_{over} as the largest possible set such that the informed firm overprices; that is, $s \in \Omega_{\text{over}}$ if and only if $s \le s_{nd}^{\text{over}}$, where

$$\delta V_{nd} \ge (1-\delta_{nd}) s_{nd}^{\text{over}} \Pi_{nd}.$$

Therefore, $s_{nd}^{\text{over}} = (\delta/(1-\delta))(V_{nd}/\Pi_{nd}) = s^{\text{over}}$ (does not depend on p_{nd}).

Similarly, $s \in \Omega_{\text{share}}$ if and only $s \in (s^{\text{over}}, s^{\text{share}}]$.

Let us now write the incentive compatibility for the uninformed:

$$(1-\delta)\left(\int_0^{s^{\text{over}}} sh(s)\,ds \frac{\Pi_{nd}}{N-1} + \int_{s^{\text{over}}}^{s^{\text{share}}} sh(s)\,ds \frac{\Pi_{nd}}{N}\right) + \delta\frac{\Pi_{nd}}{\Pi^* N} \ge (1-\delta)\frac{\Pi_{nd}}{\Pi^*}.$$

Suppose that $\Pi_{nd} > 0$. Then, multiplying both sides by Π^*/Π_{nd}, this incentive-compatibility condition is the same as that required in Proposition 2.1. Therefore, $\delta \ge \delta_{nd}$. $\square$

Proof of Proposition 2.3. Since it is optimal to set $P(s)$ as close as possible to p^* while still respecting constraint (6), there must be a threshold, denoted S such that for $s \le S$, $P(s) = p^*$ and for $s > S$, $P(s) < p^*$.

We solve first for S. Set $P(s) = p^*$ and bind Equation (6); that is,

$$(1-\delta)\Pi^* S = (1-\delta)\frac{\Pi^* S}{N} + \delta V_{fd}.$$

Solving for S yields

$$S = \frac{\delta}{1-\delta}\frac{N}{N-1}\frac{V_{fd}}{\Pi^*}.$$

For $s \le S$, $sP(s)D(P(s)) = s\Pi^*$.

For $s > S$, since Equation (6) binds,

$$sP(s)D(P(s)) = \frac{\delta}{1-\delta}\frac{V_{fd}}{N-1}.$$

Then,

$$\begin{aligned} V_{fd} &= \frac{1}{N}\left(\Pi^*\int_0^S sh(s)\,ds + \int_S^{\bar{s}} sP(s)D(P(s))h(s)\,ds\right) \\ &= \frac{1}{N}\left(\Pi^*\int_0^S sh(s)\,ds + \frac{\delta}{1-\delta}\frac{N}{N-1}V_{fd}\int_S^{\bar{s}} h(s)\,ds\right) \\ &= \frac{\Pi^*/N\int_0^S sh(s)\,ds}{1-((\delta/(1-\delta))(1/(N-1)))\int_S^{\bar{s}} h(s)\,ds} \end{aligned}$$

$$S\Pi^*\frac{1-\delta}{\delta}\frac{N-1}{N} = \frac{\Pi^*/N\int_0^S sh(s)\,ds}{1-((\delta/(1-\delta))(1/(N-1)))\int_S^{\bar{s}} h(s)\,ds}.$$

Solving for S yields Equation (7). $\square$

Proof of Proposition 3.1. We examine first characteristics of prices in the disclosure region. In this region, firms arrange a state-dependent price schedule and share industry profits equally. However, these state-dependent prices must satisfy certain properties in order to deter deviation (to either nodisclosure by the informed firm or undercutting by any firm). The following two lemmas describe these properties.

Lemma 1. *Prices over the disclosure region, as denoted by $P(s)$, must satisfy the following*:

(i) *If $s \le s_{pd}^{\text{share}}$ and the informed firm discloses $m(s) = s$, then*

$$sP(s)D(P(s)) = \min\left(s\Pi^*, \frac{\delta}{1-\delta}\frac{N}{N-1}V_{pd}\right).$$

(ii) *The disclosure region cannot include states in which $s > s_{pd}^{\text{share}}$.*

Lemma 2. *The disclosure price schedule $P(s)$ is always greater than the price conditional on nondisclosure p_{pd} and satisfies $P(s_{pd}^{\text{share}}) = p_{pd}$.*

Proof of Lemma 1. To prove the result, we define two auxiliary variables that describe disclosure and pricing strategies on the cooperation mode. First, let $a(s)$ be a binary function such that $a(s)=0$ if the informed firm discloses and $a(s)=1$ if the firm does not disclose. Second, let $b(s)$ be a binary function such that $b(s)=0$ if the informed firm undercuts and $b(s)=1$ if the informed firm shares (we do not need to give a label to overpricing). Note that because of our restriction to equilibria in which all firms price identically after a disclosure, we must have that $b(s)=1$ if $a(s)=0$. Conditional on $a(s)=0$, it must then be incentive compatible for all firms to share; that is,

$$(1-\delta)sP(s)D(P(s))/N+\delta V_{pd}\geq(1-\delta)sP(s)D(P(s)).$$

If $P(s)=p^*$ satisfies this inequality, it is optimal to set $P(s)=p^*$. Otherwise, maximizing $sP(s)D(P(s))$ requires to bind this inequality and set

$$sP(s)D(P(s))=\frac{\delta}{1-\delta}\frac{N}{N-1}V_{pd}.$$

Next, for the informed firm, it must be incentive compatible to disclose over an alternative deviation to not disclose (followed by undercutting). Note that this deviation is only attractive under two conditions: (i) $P(s)<p_{pd}$ (otherwise disclosure and undercutting, as examined earlier dominates nondisclosure) and (ii) the following incentive-compatibility condition is not met:

$$\begin{aligned}(1-\delta)\Pi_{pd}s&\leq(1-\delta)sP(s)D(P(s))/N+\delta V_{pd}\\&\leq(1-\delta)\frac{\delta}{1-\delta}\frac{N}{N-1}\frac{V_{pd}}{N}+\delta V_{pd}\\&\leq\delta V_{pd}\frac{N}{N-1}.\end{aligned}$$

This last condition boils down to $s\leq s_{pd}^{\text{share}}$. In summary, $a(s)=0$ and $b(s)=1$ is incentive compatible if and only if $P(s)\geq p_{pd}$ or $s\leq s_{pd}^{\text{share}}$. To simplify these conditions further, assume that $s>s_{pd}^{\text{share}}$. Then, the strategy is incentive compatible if and only if $P(s)\geq p_{pd}$. □

Proof of Lemma 2. Evaluating $P(s_{pd}^{\text{share}})$, we obtain that

$$s_{pd}^{\text{share}}P(s_{pd}^{\text{share}})D(P(s_{pd}^{\text{share}}))=\frac{\delta}{1-\delta}\frac{N}{N-1}V_{pd}.$$

Suppose by contradiction that $P(s_{pd}^{\text{share}})\neq p_{pd}$, then

$$\underbrace{s_{pd}^{\text{share}}}_{=(\delta/(1-\delta))(V_{pd}/\Pi_{pd})(N/(N-1))}\Pi_{pd}\neq\frac{\delta}{1-\delta}\frac{N}{N-1}V_{pd}.$$

This is a contradiction. It then follows that $P(s_{pd}^{\text{share}})=p_{pd}$ and, because $P(s)$ is decreasing in s, $P(s)<p_{pd}$ if $s>s_{pd}^{\text{share}}$. The incentive-compatibility condition can thus be simplified as simply requiring that $s\leq s_{pd}^{\text{share}}$. □

Now we turn to proving the statements in the main proposition. We first write the incentive compatibility for the uninformed. Conditional on a realization of s that is not disclosed, the cooperation payoff to the uninformed is given by $s(1-\delta)\Pi_{pd}1_{s\leq s_{pd}^{\text{share}}}(1/N)+\delta V_{pd}$.

Conditional on nondisclosure, the uninformed firm makes a conditional expectation, which yields the following incentive-compatibility condition:

$$\begin{aligned}(1-\delta)\Pi_{pd}\frac{1}{N}\frac{\int_0^{s_{pd}^{\text{share}}}sa(s)h(s)\,ds}{\int a(s)h(s)\,ds}+\delta V_{pd}\\\geq(1-\delta)\Pi_{pd}\frac{\int sa(s)h(s)\,ds}{\int a(s)h(s)\,ds}.\end{aligned}\tag{9}$$

We next state the problem of finding the efficient partial-disclosure equilibrium:

$$\max_{\Pi_{pd}\leq\Pi^*,\,V_{pd},\,a(\cdot)}V_{pd}$$

subject to $a(s)=1$ if $s\geq s_{pd}^{\text{share}}$, and

$$\begin{aligned}V_{pd}&\leq\frac{1}{N}\int h(s)\bigg\{a(s)s\Pi_{pd}+(1-a(s))\\&\qquad\cdot\min\bigg(s\Pi^*,\frac{\delta}{1-\delta}\frac{N}{N-1}V_{pd}\bigg)\bigg\}\,ds\\0&\leq\Pi_{pd}\bigg(\frac{1-N}{N}\int_0^{s_{pd}^{\text{share}}}sa(s)h(s)\,ds-\int_{s_{pd}^{\text{share}}}^{+\infty}sh(s)\,ds\bigg)\\&\qquad+\frac{\delta V_{pd}}{(1-\delta)}\int a(s)h(s)\,ds.\end{aligned}$$

In this problem, the first constraint is the regeneration condition and states that the expected continuation utility should be consistent with what is expected from the strategies played in the game. The second constraint corresponds to Equation (9) after multiplying both sides by $\int a(s)h(s)\,ds/(1-\delta)$. Hereafter, let $S=(\delta/(1-\delta))(N/(N-1))(V_{pd}/\Pi^*)<s_{pd}^{\text{share}}$.

Let L denote the Lagrangian of this problem. Denote λ (respectively, μ) the Lagrange multiplier associated to the first (respectively, second) constraint. The multiplier λ is readily verified to be strictly positive (if not, V_{pd} arbitrarily large would maximize the Lagrangian). Differentiating in $a(s)$ for any $s\leq s_{pd}^{\text{share}}$,

$$\begin{aligned}K(s)=\frac{1}{h(s)}\frac{\partial L}{\partial a(s)}&=s\bigg(\lambda\frac{\Pi_{pd}-1_{s\leq S}\Pi^*}{N}-\mu\Pi_{pd}\frac{N-1}{N}\bigg)\\&\qquad+V_{pd}\frac{\delta}{1-\delta}\bigg(\mu-1_{s>S}\frac{1}{N-1}\lambda\bigg).\end{aligned}$$

Note that

$$\begin{aligned}K(s_{pd}^{\text{share}})&=s_{pd}^{\text{share}}\bigg(\lambda\frac{\Pi_{pd}}{N}-\mu\Pi_{pd}\frac{N-1}{N}\bigg)\\&\qquad+V_{pd}\frac{\delta}{1-\delta}\bigg(\mu-\frac{1}{N-1}\lambda\bigg)\\&=V_{pd}\frac{\delta}{1-\delta}\bigg(\frac{\lambda}{N-1}-\mu\bigg)+V_{pd}\frac{\delta}{1-\delta}\bigg(\mu-\frac{1}{N-1}\lambda\bigg)\\&=0.\end{aligned}$$

Suppose by contradiction that $\mu=0$. Then, this function is strictly negative for any $s\leq S$, implying that $a(s)=0$ for any $s\leq S$. For any $s>S$, $K(s)$ would be increasing in s. It follows that, if one were to set $\mu=0$, the optimum would be set at $a(s)=0$ for all s, a contradiction to $a(s)$ nonzero for some s.

It then follows that $K(0) = V_{pd}(\delta/(1-\delta))\mu > 0$. Further, the function $K(s)$ is linear on $[0, S]$ and on $[S, s_{pd}^{\text{share}}]$ with a root at $s = s_{pd}^{\text{share}}$, therefore it must be the case that $K(s) < 0$ if and only if $s \in (s_1, s_2)$ for $0 < s_1 < s_2 \leq s_{pd}^{\text{share}}$. □

Proof of Proposition 3.2. To save space, note that the problem is identical to that stated in Proposition 3.1, except that the uninformed firm's incentive-compatibility condition is now written

$$0 \leq \Pi_{pd}\left(\frac{2-N}{N-1}\int_0^{s_{pd}^{\text{over}}} sa(s)h(s)\,ds + \frac{1-N}{N}\int_{s_{pd}^{\text{over}}}^{s_{pd}^{\text{share}}} sa(s)h(s)\,ds - \int_{s_{pd}^{\text{share}}}^{+\infty} sh(s)\,ds\right) + \frac{\delta V_{pd}}{(1-\delta)}\int a(s)h(s)\,ds.$$

As before, we denote L the Lagrangian and λ (respectively, μ) the Lagrange multiplier associated to the first (respectively, second) constraint. Differentiating in $a(s)$ for any $s \leq s_{pd}^{\text{share}}$,

$$K(s) = \frac{1}{h(s)}\frac{\partial L}{\partial a(s)} = s\left(\lambda\frac{\Pi_{pd} - 1_{s\leq S}\Pi^*}{N} + \mu\Pi_{pd}\left(-1 + \frac{1_{s\leq s_{pd}^{\text{over}}}}{N-1} + \frac{1_{s\in(s_{pd}^{\text{over}},\, s_{pd}^{\text{share}}]}}{N}\right)\right) + V_{pd}\frac{\delta}{1-\delta}\left(\mu - 1_{s>S}\frac{1}{N-1}\lambda\right).$$

We know from the same argument as in Proposition 3.1 that λ and μ are strictly positive, $K(0) > 0$ and $K(s_{pd}^{\text{share}}) = 0$. To obtain the sign of $K(s)$, note that $K(s)$ is decreasing on $[0, S]$ and linear on the intervals $(\min(S, s_{pd}^{\text{over}}), \max(S, s_{pd}^{\text{over}}))$ and $[\max(s_{pd}^{\text{over}}, S), s_{pd}^{\text{share}}]$ with $K(s_{pd}^{\text{over}}) = 0$. Therefore, it can change sign at most twice on $[0, s_{pd}^{\text{share}}]$. If $K(s)$ is decreasing on $[\max(s_{pd}^{\text{over}}, S), s_{pd}^{\text{share}}]$, it must be that nondisclosure is optimal on this region, and therefore the disclosure region must be an interval with the form (s_1, s_2). Otherwise, we consider two cases.

Case 1. If $s_{pd}^{\text{over}} \leq S$ (i.e., $\Pi_{pd} \geq (N-1)/N\Pi^*$), $K(s)$ is decreasing on $[0, S]$ and increasing on $[S, s_{pd}^{\text{share}}]$, and therefore the disclosure region must have the form $(s_1, s_{pd}^{\text{share}})$.

Case 2. If $s_{pd}^{\text{over}} > S$, $K(s)$ is decreasing on $[0, S]$ and increasing on $[S, s_{pd}^{\text{over}}]$ and on $[s_{pd}^{\text{over}}, s_{pd}^{\text{share}}]$, and therefore the disclosure region must have the form (s_0, s_1) and $(s_2, s_{pd}^{\text{share}})$.

Proof of Proposition 4.1. Inequality (8) can be written as $\delta \geq \delta_{nd}$, where $\delta_{nd} < 1$ is given by

$$\frac{\delta_{nd}^q}{1-\delta_{nd}^q} = N - \left(q + (1-q)\Pi^*\int_{s\geq s^{\text{over}}} sh(s)\,ds\right).$$

Recall that $\Pi^*\int_{s\geq s^{\text{over}}} sh(s)\,ds < \Pi^*\int sh(s)\,ds = 1$, so that the term in parenthesis is increasing in q, implying that the right-hand side decreases in q and therefore δ_{nd}^q decreases in q. □

Proof of Proposition 4.2. Consider the following strategy:

1. The informed firm always discloses its information.
2. When no information is disclosed, all firms choose a price equal to zero (but do not activate the punishment mode).
3. If the information is disclosed, firms choose the pricing strategy that corresponds to the full-disclosure equilibrium in the baseline model. Note that the informed firm is always better off disclosing because not disclosing would generate zero profit in the current period.

To conclude the argument, consider a full-disclosure equilibrium in which firms choose $p_{nd} > 0$ if no firm makes a disclosure. Consider the incentive-compatibility condition of an informed firm in such an equilibrium if $s > S$. If this firm chooses not to disclose, the worst that may occur is that all firms choose zero profit in all future periods as a continuation payoff. On the equilibrium path, the very best that could occur is that the firm achieves its monopoly profit in future periods and a current cash flow strictly less than $(\delta/(1-\delta))(1/(N-1))$. Therefore, for this to be incentive compatible, a necessary inequality is that

$$(1-\delta)\frac{\delta}{1-\delta}\frac{1}{N-1} + \delta\frac{1}{N} \geq (1-\delta)sp_{nd}D(p_{nd}) + \delta 0.$$

Note that this is only a necessary condition, and the actual incentive-compatibility condition is much more demanding. Yet, this condition is already violated for s large enough, therefore p_{nd} must be zero. □

Proof of Proposition 4.3. Suppose that Ω_r includes events $s \geq s^{\text{share}}$. Suppose by contradiction that p^* can be implemented in all periods. Then, conditional on a disclosure of any such event, $P(s) = p^*$ is incentive compatible if and only if

$$(1-\delta)s\Pi^*/N + \delta/N \geq (1-\delta)s\Pi^*.$$

This inequality simplifies that $s \leq s^{\text{share}}$. Therefore, any disclosed event above s^{share} must yield a surplus less than $s\Pi^*$ and reduces firm profits while increasing consumer and total surplus.

Suppose next that $\Omega_r \subseteq (0, s^{\text{share}})$. We need to set p^* in all periods, which, if this conjecture is valid, occurs when any $s \in \Omega_r$ is disclosed. In addition, we need to verify that sharing is incentive compatible for the uninformed when $s \notin \Omega_r$ and the information is not shared (as before, not sharing is optimal for any event that is not subject to a mandatory disclosure). As in Proposition 2.1, this requires that $\delta \geq \delta_r$, where denoting $d(s) = 1_{s\notin\Omega_r}$,

$$\delta_r = \frac{N(N-1) - H}{(N+1)(N-1) - H},$$

where

$$H = -N\int_0^{s^{\text{over}}} sd(s)h(s)\,ds\Pi^* - (N-1)\int_{s^{\text{over}}}^{s^{\text{share}}} sd(s)h(s)\,ds\Pi^*.$$

Note that δ_r is decreasing in H and H is decreasing as Ω_r increases (in the sense of the inclusion). Therefore, δ_r increases as Ω_r increases. □

Proof of Proposition 4.4. Note that if $\delta < \delta_{nd}$, a no-disclosure equilibrium would yield an industry profit $V_{nd} = 0$ absent the regulation, so that regulation is always weakly preferred by firms. To show that this preference is strict, assume that a full-disclosure tacit agreement exists with positive industry profits $V_{fd} > 0$, and therefore it implies $S > 0$. Consider next setting (s_1, s_2) large enough such that conditional on not disclosing $s < s_1$ and $s > s_2$, the monopoly price p^* can be implemented. This can be constructed by finding s_1 close to zero and s_2 large as follows:

$$(1-\delta)\Pi^* \frac{(1/N)\int_0^{s_1} sh(s)\,ds}{\int_0^{s_1} h(s)\,ds + \int_{s_2}^{+\infty} h(s)\,ds} + \delta V_{fd}$$

$$\geq (1-\delta)\Pi^* \frac{\int_0^{s_1} sh(s)\,ds + \int_{s_2}^{+\infty} sh(s)\,ds}{\int_0^{s_1} h(s)\,ds + \int_{s_2}^{+\infty} h(s)\,ds}.$$

By continuity and the fact that the inequality is satisfied strictly for $s_1 = 0$ and $s_2 = +\infty$, one can always find $s_1 > 0$ and $s_2 < +\infty$ such that the inequality is still satisfied. This alternative equilibrium will always yield higher prices than full disclosure in the region $s > s_2$. $\square$

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