Information Acquisition and Strategic Disclosure in Cournot Oligopoly*

Jos Jansen
Social Science Research Center Berlin (WZB),†
and Humboldt University Berlin

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Abstract

We study the incentives of Cournot oligopolists to acquire and disclose information on a common cost (or demand) parameter. Since information acquisition is such that firms may fail to acquire information, firms can credibly conceal unfavorable news while disclosing favorable news. This paper compares the incentives, profits and welfare under such a selective disclosure regime with the regimes where firms commit to share all or no information. We show that, for sufficiently low (high) information acquisition costs, a firm (antitrust authority) prefers strategic disclosure to precommitment. Moreover, incentives and expected profits are often non-monotonic in the amount of information disclosed.

Keywords: Cournot competition, information acquisition, information sharing, commitment, common value
JEL Codes: D82, D83, L13, L40

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†WZB, Research Unit MP2 (CIC), Reichpietschufer 50, D-10785 Berlin, Germany,
Tel. +49-30-25491.451, Fax. +49-30-25491.444, E-mail: <jansen@wz-berlin.de>, URL: <http://www.wz-berlin.de/~jansen/>

1 Introduction

A firm that introduces a new product in a market does not always know the demand for the product or its production cost. The firm can do market research to learn the demand or cost. Doing market research is both costly and risky. The firm needs to invest in the acquisition of relevant information. An investment in information acquisition may generate the valuable information, but may also fail to do so.[1]

The firm may also learn about the properties of the new product through information disclosed by the firm's competitors. But competitors know the role their information plays for the firm, and will bias the information they share to their strategic advantage. Clearly, the firm's incentives to acquire and share information are related, and have an impact on the firm's production incentives. This paper studies the interaction between information acquisition, information sharing, and output supply, and analyzes the consequences for the firms' profits and social welfare. How much information will a Cournot oligopolist disclose to its rivals? And how much information should a welfare-maximizing antitrust authority allow firms to share? Should firms be mandated to disclose all information, should they be required to conceal all, or should coordination on information sharing be forbidden, and let firms disclose strategically?

These questions are addressed in the literature on information sharing in oligopolistic markets since the 1980s.[2] Most papers in that literature analyze the incentives of firms under two extreme information disclosure regimes: full information sharing, and no pooling of information. Such an analysis is especially appropriate if firms can precommit to information sharing, e.g. by establishing a trade association, or through government regulation. But, even without precommitment, there are conditions under which one of these extreme disclosure regimes emerges endogenously from the strategic information sharing choices of firms. For example, Ziv (1993) observes that strategic firms will not reveal their information truthfully, if information is non-verifiable and revelation is costless. On the other hand, if there are no verification and disclosure costs, and if it is known that firms have information, then often the unraveling result holds. If this powerful result applies, then strategic firms will dis-

[1] For instance, an internet book store once invited me to participate in a survey on my reading habits in exchange for a gift certificate. If the amount on the gift certificate is low, it is likely that consumers decline to participate, and nothing is learned. Alternatively, if the retailer invests little effort in the survey design, it is likely that an error is made in the design, and no relevant information is obtained. The higher the amount on the gift certificate, and the more care is invested in designing the survey, the greater the likelihood that information is acquired.

[2] For recent surveys of this literature, see Kühn and Vives (1995), Raith (1996), and Vives (1999). In particular, our model is related to Clarke (1983), Vives (1984), Gal-Or (1985), and Li (1985).

close all information, since they cannot credibly conceal unfavorable news, e.g. see Milgrom (1981), Milgrom and Roberts (1986), and Okuno-Fujiwara *et al* (1990).

However, in markets for new products, where information acquisition plays an important role, the focus on the two extreme information regimes may be too restrictive. If a firm's market research can turn out to be fruitless, in which case the firm remains uninformed, it is no longer known whether firms are informed. Consequently, the unraveling result may fail to hold, as e.g. Dye (1985) and Farrell (1986) observe. In that case, firms can credibly conceal unfavorable news (by claiming to be uninformed), while they disclose favorable news. The economic properties of such a regime of strategic disclosure in oligopolistic markets are not well established. This paper intends to fill the gap.

We study how incentives and profits of firms under strategic information disclosure compare with the incentives and profits under the two precommitment regimes. Naturally, strategic disclosure is chosen by firms that cannot precommit. Moreover, we show that, even if firms can precommit to full or no sharing, there are instances where firms prefer strategic disclosure to precommitment.

We analyze a Cournot oligopoly with homogeneous goods where firms invest in performing market research to learn a common cost or demand parameter. If market research is successful, firms learn the cost or demand for their new product. But if market research fails, firms do not learn. Naturally, the probability of success increases in the amount that a firm invests in research. Hence, if it is too costly to invest in certain success, there is uncertainty about whether a firm is informed. In such an environment firms have an incentive to selectively disclose information they learned, i.e. they disclose bad news (high cost or low demand), while they conceal good news (low cost or high demand) to discourage their rivals. Under such a selective disclosure regime firms disclose more information than under no pooling of information, since bad news is disclosed, but less than under full information sharing, since good news is concealed. That is, the amount of disclosed information in the market is between full sharing and no sharing of information. Does this imply that the firms' incentives and profits will be between those under full and no sharing? Interestingly, we show that this is often not the case.

We find that, for a given level of information acquisition investments, the expected equilibrium profit under strategic information disclosure may be lowest. That is, we can find levels of information acquisition investments for which the expected equilibrium profit under both precommitment regimes exceeds the expected profit under strategic disclosure. Furthermore, we show that a firm's expected equilibrium profit under strategic disclosure is lower than under one of the precommitment regimes, for given levels of information acquisition investment. Hence, if the probability of receiving information were exogenous, firms would be better off by precommitting to either full or no information sharing. If the probability of receiving information is endogenously determined by firms' information acquisition investments, however, this preference for precommitment can be reversed.

In particular, we show that overall profits, i.e. the expected profit given equilibrium levels of information acquisition, are highest under strategic information disclosure for sufficiently low costs of information acquisition. Hence, for low costs of investment firms are better off if they do *not* precommit to either of the extreme information sharing rules. Conversely, for high costs of investment, overall expected profits are lowest under strategic disclosure. And for any cost of information acquisition the overall expected equilibrium profits under full and no disclosure are identical in our model.[3] That is, overall expected profits are never monotonic in the amount of disclosed information.

Endogenizing the probability with which firms receive information matters greatly for welfare as well. The introduction of costly information acquisition investments, reverses the welfare ranking of equilibria under full and no information sharing. Moreover, if information acquisition is very costly, expected welfare may be greatest under strategic disclosure. Strategic disclosure may therefore arise, because a welfare-maximizing antitrust authority prohibits precommitment to information sharing rules. Whether information arrives exogenously, or is actively acquired by firms is therefore of crucial importance for welfare-maximizing policy makers.

The incentives to acquire information are not always monotonic in the amount of information disclosed in the industry either. It seems intuitive that the more information firms share, the greater the free-rider incentives, and, consequently, the lower the firms' information acquisition investments. For low costs of information acquisition, we do, indeed, obtain this intuitive result. But for intermediate costs of investment the free-rider effect of public information does not always play a dominant role, as we show in section 5. For these cost levels firms invest more in information acquisition under strategic disclosure than under no disclosure.

Papers in the accounting literature, such as Darrough (1993) and Sankar (1995),

[3] In fact, this identity depends on linearity of the cost of information acquisition, as we discuss in section 7. The introduction of information acquisition investments at convex costs typically reverses the ranking of *ex ante* expected profits among the precommitment regimes.

study related models.[4] These papers focus on strategic disclosure incentives, but they do not analyze consequences for expected profits and welfare. Interestingly, also the duopolistic information sharing models in Nalebuff and Zeckhauser (1986, model A) and Malueg and Tsutsui (1998, example 1) are consistent with ours. But, while these papers make profit comparisons for the regimes under disclosure precommitment, they ignore the opportunity for strategic disclosure. Our paper studies the consequences of strategic disclosure for incentives, profits and welfare, by comparing strategic disclosure with the two precommitment regimes.

The aforementioned papers treat the probability of receiving information as exogenous parameters. We show that endogenizing this probability matters greatly for the firms' expected profits and for social welfare. There are papers, such as Li *et al* (1987), Hwang (1995), Hauk and Hurkens (2001), and Sasaki (2001) that study the information acquisition incentives of Cournot oligopolists.[5] These papers assume that firms do not disclose their acquired information, and make complementary comparisons. Conversely, papers, such as Matthews and Postlewaite (1985), Verrecchia (1990), and Shavell (1994), study the interaction between a monopolist's incentives to acquire and disclose information, i.e. these papers ignore externalities from product market competition. Admati and Pfleiderer (2000) and Kirby (2004) study the information acquisition and disclosure incentives of competing firms. In these papers firms commit *ex ante* to disclosure rules, while we also study *interim* disclosure incentives. Moreover, Admati and Pfleiderer study firms' incentives in a different context, i.e. a financial market, and Kirby assumes that firms make their information acquisition and information sharing choices cooperatively.

Empirical findings on strategic information sharing in Krishnan *et al* (1999), Doyle and Snyder (1999), and Genesove and Mullin (1997) are consistent with our assumptions and results. Krishnan *et al* (1999) confirms that financial market participants infer that firms selectively disclose earnings evidence, and adjust their beliefs on the firm's value accordingly, as in Shin (1994, 2003). Doyle and Snyder (1999) finds that US car makers' announcements of production plans are informative, and not mere cheap talk, since they affect market outcomes. Furthermore, the car makers share information about a common demand parameter, which creates the same product market responses as in our paper: "Specifically, rival firms tend to adjust their production upward in response to an announcement of aggressive production" (Doyle and

[4]For recent surveys of this literature, see e.g. Verrecchia (2001), and Dye (2001).

[5]Persico (2000) studies the incentives for secret information acquisition of bidders in auction models with affiliated values.

Snyder, 1999, p. 1329). Genesove and Mullin (1997) makes a related observation on US sugar cane refiners participating in the Sugar Institute trade association between 1928 and 1936. The paper finds no indication that the association's members were making untruthful reports. The authors observe that "it may be too difficult to construct a credible, systematic lie, since a variety of bits of information, both internal and external to the firm, have to be made consistent with any false report" (Genesove and Mullin, 1997, p. 7). This suggests that the reported statistics can be verified. We adopt this as a assumption. Moreover, some instances were found where individual members withheld information from the Sugar Institute. Again, this empirical finding is consistent with the assumptions and results of our paper.

Ackert *et al* (2000) provides experimental support for the strategic disclosure rules that we study in this paper. The experiment confirms that Cournot duopolists do indeed use selective disclosure strategies on a common cost parameter to discourage their rival.

The paper is organized as follows. In the next section we describe the model. Section 3 derives the equilibrium outputs under the regimes of information sharing, full concealment, and selective disclosure, where firms only disclose if the cost is high. Furthermore, we compare equilibrium profits and welfare of the three regimes. Section 4 studies the *interim* information disclosure incentives. In section 5 we analyze the incentives to invest in information acquisition. Moreover, we show there how the profit and welfare analysis is affected by endogenizing information acquisition. Section 6 discusses how the introduction of convex information acquisition costs affects the profit analysis. Finally, section 7 concludes the paper. All proofs are relegated to the Appendix.

2 The Model

We consider an industry where N firms compete in quantities of a homogeneous good ($N \geq 2$). Firms have identical constant marginal production costs, θ. This common cost is unknown to the firms.[6] The cost is either low or high, i.e. $\theta \in \{\underline{\theta}, \overline{\theta}\}$ with $0 \leq \underline{\theta} < \overline{\theta}$, where the probability of having low (high) cost is q (resp. $1-q$), with $0 < q < 1$.

In the first stage firms can learn their cost by acquiring information. Firms choose their information acquisition investments, $r_i \in [0,1]$ for firm i, simultaneously. Infor-

[6]Naturally, this model is conceptually identical to a model with incomplete information about a common demand intercept. Hence, all results hold for this model as well.

mation acquisition investments are not observable. Firm i expects its $N-1$ rivals invest r in information acquisition. The costs of information acquisition are linear in investment: $c(r_i) = \eta r_i$, with $\eta > 0$ for $i = 1,..,N$. After investing in information acquisition firm i receives a signal, Θ_i, about its cost. With probability r_i firm i learns its true cost, $\Theta_i = \theta$, but with probability $1 - r_i$ the firm learns nothing, $\Theta_i = \varnothing$. Hence the more a firm invests in information acquisition, the more likely it is that the firm will be informed. The signals are independent, conditional on θ.[7]

In stage 2 each firm chooses whether to disclose or conceal its signal. The information that firms acquire is verifiable. However, the fact whether or not a firm is informed is not verifiable. If firm i receives information $\Theta_i = \theta$, it chooses the probability with which it discloses this information, $\delta_i(\theta) \in [0,1]$, i.e. with probability $\delta_i(\theta)$ firm i discloses θ, while with probability $1 - \delta_i(\theta)$ firm i sends uninformative message $\varnothing$. An uninformed firm can only send message $\varnothing$. It therefore suffices to denote firm i's disclosure rule as $(\delta_i(\underline{\theta}), \delta_i(\overline{\theta}))$. We denote the message sent by firm i (i.e. the realization of the firm's disclosure rule) as D_i for $i = 1,..,N$. Firms make their disclosure decisions simultaneously.

In the final stage firms simultaneously choose the quantities they supply to consumers, $x_i \geq 0$ for firm i, with $i = 1,..,N$.

The payoffs are as follows. Consumers' gross surplus of consuming quantity X is:

$$S(X) \equiv \alpha X - \frac{1}{2}\beta X^2, \text{ with } X \equiv \sum_{j=1}^{N} x_j. \tag{2.1}$$

Hence, the inverse demand function is linear in total output, i.e. $P(X) = \alpha - \beta X$. Firm i's profit of producing quantity x_i at marginal cost θ is:

$$\pi_i(\mathbf{x}; \theta) = (P(X) - \theta)x_i, \tag{2.2}$$

with $\mathbf{x} = (x_1,..,x_N)$. Firms are risk-neutral. Net consumers' surplus, given total quantity X, equals gross consumers' surplus minus expenditures: $CS(X) = S(X) - P(X)X = \frac{1}{2}\beta X^2$. Social welfare, given total quantity X and marginal cost θ, is the sum of net consumers' surplus and industry profits:

$$W(X) \equiv \frac{1}{2}\beta X^2 + (P(X) - \theta)X. \tag{2.3}$$

In the remainder of the paper we make the normalization $\beta = 1$ to save on notation. We solve the game backwards, and restrict the analysis to symmetric (Bayes perfect) equilibria.

[7] Notice that this model, like most oligopolistic information sharing models, satisfies the linear conditional expectation property.

3 Production

In this section we study the equilibrium outputs, profits and welfare for given symmetric disclosure rules, $(\delta_i(\underline{\theta}), \delta_i(\overline{\theta})) = (\delta(\underline{\theta}), \delta(\overline{\theta}))$ for all i, and information acquisition investments, $r_i = r$ for all $i = 1, .., N$.

3.1 Equilibrium Outputs

First, we study the equilibrium outputs and profits under complete information. Whenever one of the firms sends an informative signal, $D_j = \theta$ for some $j \in \{1, .., N\}$ and $\theta \in \{\underline{\theta}, \overline{\theta}\}$, all firms know that the cost is θ. Firm i's first-order condition of profit maximization with respect to output x_i, given $\theta \in \{\underline{\theta}, \overline{\theta}\}$, is as follows:

$$2x_i(\theta) = \alpha - \theta - \sum_{j \neq i} x_j(\theta). \tag{3.1}$$

for $i, j = 1, .., N$. These first-order conditions give the following equilibrium outputs:

$$x^f(\theta) = \frac{\alpha - \theta}{N + 1}, \tag{3.2}$$

with $\theta \in \{\underline{\theta}, \overline{\theta}\}$. This result is standard.

Second, we consider the equilibrium after no firm disclosed any information, i.e. $(D_1, .., D_N) = (\varnothing, .., \varnothing)$. We restrict attention to beliefs consistent with symmetric expected information acquisition investments and disclosure rules. In that case, an informed firm with $\Theta_i = \theta$ assigns probability $R(\theta)$ to competing against an informed rival j ($\Theta_j = \theta$), and probability $1 - R(\theta)$ to facing an uninformed rival ($\Theta_j = \varnothing$), where:

$$R(\theta) \equiv \frac{r\left[1 - \delta(\theta)\right]}{1 - r\delta(\theta)}. \tag{3.3}$$

Each uninformed firm ($\Theta_i = \varnothing$) has the following beliefs. The firm expects cost $\widetilde{E}(\theta|\varnothing) \equiv Q(\boldsymbol{\delta})\underline{\theta} + (1 - Q(\boldsymbol{\delta}))\overline{\theta}$, with posterior belief:

$$Q(\boldsymbol{\delta}) \equiv \frac{q\left[1 - r\delta(\underline{\theta})\right]^{N-1}}{q\left[1 - r\delta(\underline{\theta})\right]^{N-1} + (1 - q)\left[1 - r\delta(\overline{\theta})\right]^{N-1}}, \tag{3.4}$$

with $\boldsymbol{\delta} = (\delta(\underline{\theta}), \delta(\overline{\theta}))$. An uninformed firm assigns probability $Q(\boldsymbol{\delta})R(\underline{\theta})$ (respectively $(1 - Q(\boldsymbol{\delta}))R(\overline{\theta})$) to competing against an informed firm j with $\Theta_j = \underline{\theta}$ (resp. $\Theta_j = \overline{\theta}$). With the remaining probability, $1 - Q(\boldsymbol{\delta})R(\underline{\theta}) - (1 - Q(\boldsymbol{\delta}))R(\overline{\theta})$, firm j is believed to be uninformed. Hence, firm i's first-order conditions after no information disclosure, and beliefs consistent with symmetric information acquisition investments and disclosure rules, are as follows (for $i, j = 1, .., N$ and $\Theta_i \in \{\underline{\theta}, \overline{\theta}, \varnothing\}$ where $\widetilde{E}(\theta|\theta) = \theta$):

$$2x_i(\Theta_i) = \alpha - \widetilde{E}(\theta|\Theta_i) - \widetilde{E}\left\{ \sum_{j \neq i} \left(R(\theta)x_j(\theta) + [1 - R(\theta)]\, x_j(\varnothing) \right) \middle| \Theta_i \right\}. \qquad (3.5)$$

Using symmetry we derive the following equilibrium outputs (for $\Theta_i \in \{\underline{\theta}, \overline{\theta}, \varnothing\}$):

$$x^*(\Theta_i; \boldsymbol{\delta}) = \widetilde{E}\left\{ x^f(\theta) + \frac{(N-1)\,[1 - R(\theta)]\left(\widetilde{E}(\theta|\varnothing) - \theta\right)}{(N+1)[2 + (N-1)\left(QR(\overline{\theta}) + (1-Q)R(\underline{\theta})\right)]} \middle| \Theta_i \right\}, \qquad (3.6)$$

In the remainder of this subsection we briefly analyze the properties of the equilibrium outputs under three disclosure regimes. First, we characterize outputs under the two regimes that are extensively studied in the literature on information sharing in oligopoly, i.e. the full information sharing regime, f, and the no sharing regime, o. In the full sharing regime the firms commit to share all available information, i.e. $(\delta(\underline{\theta}), \delta(\overline{\theta})) = (1, 1)$. If there is an informed firm j with $\Theta_j = \theta$, all firms know that the cost is θ, and supply $x^f(\theta)$ as in (3.2). If all firms are uninformed, i.e. $(\Theta_1, .., \Theta_N) = (\varnothing, .., \varnothing)$, each firm supplies $x^f(\varnothing) \equiv x^*(\varnothing; 1, 1) = E\{x^f(\theta)\}$, since $R(\theta) = 0$ for any θ and $Q(1, 1) = q$ in (3.6).

In the no sharing regime disclosure rules are uninformative, i.e. $(\delta(\underline{\theta}), \delta(\overline{\theta})) = (0, 0)$. Under this regime firm i with signal Θ_i supplies $x^o(\Theta_i) \equiv x^*(\Theta_i; 0, 0)$ in equilibrium, with $R(\theta) = r$ for any θ and $Q(0, 0) = q$ in (3.6), and $\Theta_i \in \{\underline{\theta}, \overline{\theta}, \varnothing\}$. We call regimes f and o the precommitment regimes, since they may emerge if firms can commit *ex ante* to disclosure rules.

Besides the precommitment regimes, we characterize production under selective information sharing regime p. Under selective disclosure firms conceal low cost information while they disclose high cost information, i.e. the firms' disclosure rules are $(\delta(\underline{\theta}), \delta(\overline{\theta})) = (0, 1)$. We show in section 4 that such a selective disclosure regime is chosen in equilibrium if firms do not precommit. Naturally, whenever there is a firm that discloses a high production cost, all firms supply $x^f(\overline{\theta})$. If no firm discloses information, then firms infer that there is no firm that received a high cost signal ($\Theta_j \neq \overline{\theta}$ for all $j = 1, .., N$), i.e. $R(\underline{\theta}) = r$ while $R(\overline{\theta}) = 0$, and $Q(0, 1) = \widetilde{q}$ with

$$\widetilde{q} \equiv \frac{q}{q + (1-q)(1-r)^{N-1}}. \qquad (3.7)$$

In that case, firm i with signal $\Theta_i \in \{\underline{\theta}, \varnothing\}$ supplies $x^p(\Theta_i) \equiv x^*(\Theta_i; 0, 1)$ in equilibrium, with x^* as in (3.6).

The comparison of outputs x^f, x^o, and x^p is summarized in the following lemma.

Lemma 1 *For all* $r \in (0,1)$*, the equilibrium outputs are such that:*
(i) $x^f(\underline{\theta}) < x^p(\underline{\theta}) < x^o(\underline{\theta})$*,* $x^f(\overline{\theta}) = x^p(\overline{\theta}) > x^o(\overline{\theta})$*, and* $x^f(\varnothing) = x^o(\varnothing) < x^p(\varnothing)$*;*
(ii) $\partial x^o(\underline{\theta})/\partial r < 0$*,* $\partial x^o(\overline{\theta})/\partial r > 0$*, and* $\partial x^p(\underline{\theta})/\partial r < 0$*,* $\partial x^p(\varnothing)/\partial r > 0$*.*
(iii) For $r_i = r$ *ex ante expected equilibrium prices are equal, i.e.* $E\{X^\ell(\Theta)\} = Nx^f(\varnothing)$ *for all* $\ell \in \{f, o, p\}$*.*
Furthermore, if $r = 0$*,* $x^p(\Theta) = x^o(\Theta)$ *for* $\Theta \in \{\underline{\theta}, \varnothing\}$*, and* $x^f(\overline{\theta}) = x^p(\overline{\theta})$*, while if* $r = 1$*,* $x^f(\underline{\theta}) = x^p(\underline{\theta}) = x^p(\varnothing) = x^o(\underline{\theta})$*, and* $x^f(\overline{\theta}) = x^o(\overline{\theta})$*.*

The comparison between $x^f(\theta)$ and $x^o(\theta)$ results from comparing the first-order conditions (3.1) and (3.5) for $\Theta_i = \theta$ and $R(\theta) = r$. A firm with a low (high) cost signal expects more pessimistic (optimistic) rivals under no information sharing than under full sharing, and, consequently, produces more (less) in equilibrium, i.e. $x^o(\underline{\theta}) > x^f(\underline{\theta})$, and $x^o(\overline{\theta}) < x^f(\overline{\theta})$.

Subsequently, we obtain insights in the comparison between x^o and x^p by comparing the first-order conditions (3.5) under the two regimes. An informed, efficient firm has the same first-order condition under partial disclosure as under no information sharing. An uninformed firm is more optimistic about its cost of production under partial disclosure, but expects more optimistic, "aggressive" rivals than under the precommitment regimes. We show in lemma 1 (i) that the cost effect dominates, i.e. $x^f(\varnothing) = x^o(\varnothing) < x^p(\varnothing)$. This implies in turn, through first-order condition (3.5) for $\Theta_i = \underline{\theta}$ and $R(\underline{\theta}) = r$ that informed, efficient firms produce less under partial disclosure than under no disclosure, i.e. $x^p(\underline{\theta}) < x^o(\underline{\theta})$.

An increase of the expected information acquisition investment, r, has the following effects on equilibrium outputs. The only effect of an increase in r under no information sharing, is that a firm considers it more likely that its competitors are informed. Hence, an informed firm with a low (high) cost expects more (less) "aggressive" competitors, and consequently reduces (expands) its output. Under partial information sharing an informed, efficient firm has similar incentives as under no sharing, and therefore the firm's output decreases in r. An uninformed firm faces the following trade-off under partial information sharing. On the one hand, the firm becomes more optimistic about its production cost ($\partial\widetilde{q}/\partial r > 0$), but, on the other hand, it expects more "aggressive" competitors. In lemma 1 (ii) we show that the former effect dominates the latter, i.e. $\partial x^p(\varnothing)/\partial r > 0$.

Finally, the *ex ante* expected industry outputs (and prices) are identical under regimes f, o and p since outputs are linear in cost parameter θ. We show this formally in lemma 1 (iii).

Under each regime ℓ, given information $\Theta \in \{\underline{\theta}, \overline{\theta}, \varnothing\}$ and equilibrium output $x^\ell(\Theta)$, a firm's expected equilibrium profit equals: $\pi^\ell(\Theta) = x^\ell(\Theta)^2$ for $\ell \in \{f, o, p\}$. Hence, the comparisons of lemma 1 (i)-(ii) also hold for expected profits. These comparisons play therefore an important role in the analysis below.

3.2 Expected Profits

In this subsection we compare expected equilibrium profits under the three disclosure regimes for given (symmetric) information acquisition investments. This analysis is instructive to evaluate the effect of endogenizing information acquisition investments on the expected equilibrium profits (see section 5).

The expected equilibrium profits of firm i under regime ℓ, given information acquisition investment r_i and expected investments r, are (for $i = 1, .., N$ and $\ell \in \{f, o, p\}$):

$$\Pi^\ell(r_i, r) = E\left\{\pi^\ell(\theta)\right\} - \psi^\ell(r) + r_i\left[\psi^\ell(r) - \eta\right], \tag{3.8}$$

where

$$\begin{aligned} \psi^f(r) &\equiv (1-r)^{N-1}\left[E\left\{\pi^f(\theta)\right\} - \pi^f(\varnothing)\right], & (3.9)\\ \psi^o(r) &\equiv E\{\pi^o(\theta)\} - \pi^o(\varnothing), \text{ and} & (3.10)\\ \psi^p(r) &\equiv q\left[\pi^p(\underline{\theta}) - \pi^p(\varnothing)\right] + (1-q)(1-r)^{N-1}\left[\pi^p(\overline{\theta}) - \pi^p(\varnothing)\right]. & (3.11) \end{aligned}$$

The first part of expression (3.8), i.e. $E\left\{\pi^\ell(\theta)\right\} - \psi^\ell(r)$, is the expected profit of information acquired through the disclosure by rivals. For example, disclosure by competitors yields expected profit $[1-(1-r)^{N-1}]E\{\pi^f(\theta)\} + (1-r)^{N-1}\pi^f(\varnothing)$ for a firm under full disclosure, while it yields only $\pi^o(\varnothing)$ under no disclosure. The second part of (3.8), i.e. $r_i[\psi^\ell(r) - \eta]$, is the expected profit earned from the firm's own information acquisition investment. In fact, the functions $\psi^\ell(r)$ in (3.9)-(3.11) are the firm's marginal revenues of information acquisition under regime ℓ with $\ell \in \{f, o, p\}$. These functions will play a central role in section 5, where we discuss the information acquisition incentives of firms. The comparison of expected profits under the different regimes yields the following proposition.

Proposition 1 *If $r_i = r$ for all $i = 1, .., N$, with $0 < r < 1$, then critical value r_N^* exists, with $0 < r_2^* < r_3^* < r_n^* = 1$ for $n \geq 4$, such that ex ante expected profits are greater (smaller) under full concealment than under full disclosure iff $r < r_N^*$ (resp. $r > r_N^*$), i.e. $\Pi^f(r, r) \lesseqgtr \Pi^o(r, r)$ if $r \lesseqgtr r_N^*$. Furthermore, if $N \in \{2, 3\}$, then the firms' ex ante expected profits are always greater under precommitment than under partial information sharing, i.e. $\max\{\Pi^f(r, r), \Pi^o(r, r)\} > \Pi^p(r, r)$ for all $r \in (0, 1)$.*

In fact, numerical examples suggest that with exogenous, symmetric probabilities of receiving information firms expect to be best off under precommitment also for $N \geq 4$. In section 5 we show that this result changes drastically after we endogenize the firms' probabilities of receiving information.

The comparison of expected profits Π^f and Π^o gives the following trade-off. On the one hand, a firm's expected profit, conditional on receiving no information from competitors, is greater under full concealment than under full disclosure, i.e. $r_i E\{\pi^o(\theta)\} + (1 - r_i)\pi^o(\varnothing) > r_i E\{\pi^f(\theta)\} + (1 - r_i)\pi^f(\varnothing)$. On the other hand, firms are more likely to be informed under full disclosure for given levels of information acquisition. The expected profit gain of obtaining information through disclosure by others is positive, since $E\{\pi^f(\theta)\} > \pi^f(\varnothing)$. Notice that this trade-off is similar to the basic trade-off in the information sharing literature. For symmetric information acquisition investments and fulfilled beliefs, i.e. $r_i = r$, the trade-off results in a critical value r_N^*, with $0 < r_N^* \leq 1$. For information acquisition investments below r_N^* expected profits are highest under full concealment. For investments above r_N^* expected profits are highest under full information sharing, as we show in proposition 1 above. In fact, we can show that $r_2^* \approx 0.30$ and $r_3^* \approx 0.62$, while $r_N^* = 1$ for all $N \geq 4$. Nalebuff and Zeckhauser (1986), and Malueg and Tsutsui (1998) obtain this result for the duopoly model. Our contribution is to show that this result is somewhat special, since it disappears in oligopolies with more than three firms. In oligopolies with more than three firms the expected profits are always greatest under no pooling of information, as in related information sharing models, e.g. Clarke (1983), Vives (1984), Gal-Or (1985), and Li (1985).

The comparison between expected profits under full and partial information sharing results in the following trade-off. On the one hand, the expected profit, conditional on receiving no low cost information from rivals, is higher under partial disclosure than under full disclosure, i.e. $r_i \left[\widetilde{q}\pi^p(\underline{\theta}) + (1 - \widetilde{q})\pi^p(\overline{\theta})\right] + (1 - r_i)\pi^p(\varnothing) > r_i \left[\widetilde{q}\pi^f(\underline{\theta}) + (1 - \widetilde{q})\pi^f(\overline{\theta})\right] + (1 - r_i)\pi^f(\varnothing)$. On the other hand, firms are more likely to receive good news under full disclosure, which increases expected profits under this regime, since $\pi^f(\underline{\theta}) > \pi^f(\varnothing)$. For $r_i = r$ the trade-off between these two conflicting effects gives a critical value $\underline{r}_N$, with $0 < \underline{r}_N < r_N^*$. For all r below (above) $\underline{r}_N$ the expected profit under partial disclosure is greater (smaller) than under full information sharing. While the firms expect higher profits under partial disclosure than under full disclosure for $r < \underline{r}_N$, their expected profits are even higher under the commitment to conceal all information. Therefore, for all $r < r_N^*$, the firms' expected profits are highest under full concealment, as we show in proposition 1 above.

Finally, the difference of expected profits under full concealment and partial disclosure contains the following two principal components. On the one hand, conditional on receiving no information from competitors, firms expect higher profits under partial disclosure, since $rE\{\pi^p(\theta)\} + (1-r)\pi^p(\varnothing) > rE\{\pi^o(\theta)\} + (1-r)\pi^o(\varnothing)$. But, on the other hand, firms are more likely to receive bad news under partial disclosure, which depresses their expected profits, since $\pi^p(\overline{\theta}) < \pi^p(\varnothing)$. Also for this profit comparison with $r_i = r$ we obtain a critical value $\overline{r}_N$, with $r_N^* \leq \overline{r}_N \leq 1$, such that for all r below (above) $\overline{r}_N$ the expected profit under partial disclosure is smaller (greater) than under no pooling of information. Although the expected profit under partial disclosure is higher than under no disclosure for $r > \overline{r}_N$, it does not exceed the expected profit under full disclosure. Hence, expected profits under partial disclosure are never highest, as is shown in the proposition.

Our discussion above does not only have implications for the regimes under which expected equilibrium profits are greatest, but also for the ranking of expected equilibrium profit levels in the remaining regimes. We obtain the following profit ranking:

$$\begin{aligned}
\text{(A) } \Pi^o(r,r) &> \Pi^p(r,r) > \Pi^f(r,r) \text{ for all } 0 < r < \underline{r}_N \\
\text{(B) } \Pi^o(r,r) &> \Pi^f(r,r) > \Pi^p(r,r) \text{ for all } \underline{r}_N < r < r_N^* \\
\text{(C) } \Pi^f(r,r) &> \Pi^o(r,r) > \Pi^p(r,r) \text{ for all } r_N^* < r < \overline{r}_N \\
\text{(D) } \Pi^f(r,r) &> \Pi^p(r,r) > \Pi^o(r,r) \text{ for all } \overline{r}_N < r < 1.
\end{aligned}$$

In figures 0.a-c below we illustrate these cases for $N \in \{2,3,4\}$. In these figures, regions A_N-D_N correspond to cases (A)-(D), respectively.

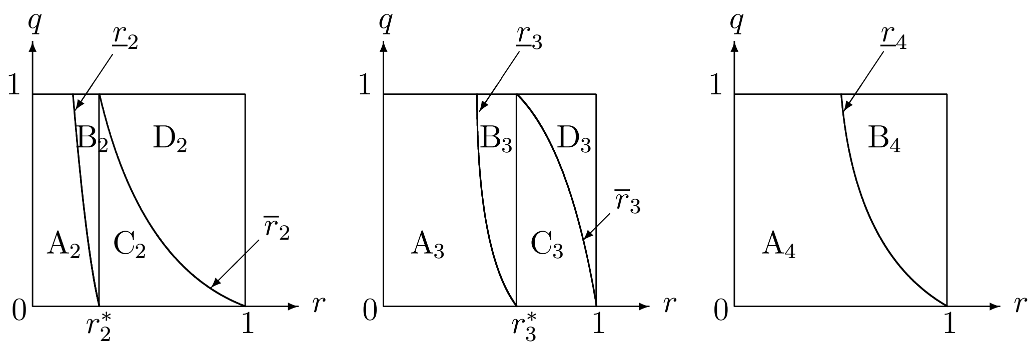

Figure 0.a: $N = 2$ Figure 0.b: $N = 3$ Figure 0.c: $N = 4$

[*Ex Ante* Expected Profits]

Numerical examples suggest that if the number of firms in the industry grows beyond four, then the frontier $\underline{r}_N$ rotates anti-clockwise around (1,0), i.e. $A_4 \supset A_5 \supset ... \supset A_\infty = \emptyset$ and $B_4 \subset B_5 \subset ... \subset B_\infty = [0,1]^2$ (and $C_N = D_N = \emptyset$ for all $N \geq 4$).

Figures 0.a-c illustrate that there are always values of r such that expected equilibrium profits are non-monotonic in the amount of information that is disclosed by the firms. In particular, for all $\underline{r}_N < r < \overline{r}_N$ (i.e. $(r,q) \in B_N \cup C_N$ in figures 0.a-c), we obtain that $\min\{\Pi^f(r,r), \Pi^o(r,r)\} > \Pi^p(r,r)$.

3.3 Expected Welfare

Given symmetric information acquisition investments and fulfilled expectation, i.e. $r_i = r$ for all $i = 1,..,N$, the expected net consumers' surpluses under information sharing, no pooling of information, and partial information sharing are as follows:

$$
\begin{aligned}
CS^f(r) &= \frac{1}{2}N^2\left(\left[1-(1-r)^N\right]E\left\{x^f(\theta)^2\right\} + (1-r)^N x^f(\varnothing)^2\right), && (3.12)\\
CS^o(r) &= \frac{1}{2}\sum_{m=0}^{N}\binom{N}{m} r^m(1-r)^{N-m}E\left\{[mx^o(\theta)+(N-m)x^o(\varnothing)]^2\right\}, && (3.13)\\
CS^p(r) &= \frac{1}{2}N^2(1-q)\left(\left[1-(1-r)^N\right]x^p(\overline{\theta})^2 + (1-r)^N x^p(\varnothing)^2\right)\\
&\quad +\frac{1}{2}q\sum_{m=0}^{N}\binom{N}{m} r^m(1-r)^{N-m}\left[mx^p(\underline{\theta})+(N-m)x^p(\varnothing)\right]^2, && (3.14)
\end{aligned}
$$

respectively. The comparison between $CS^f(r)$ and $CS^o(r)$ gives that the consumers' surplus is highest under information sharing, i.e. $CS^f(r) > CS^o(r)$ for all $r \in (0,1)$ and N. The welfare effect of moving from concealment to information sharing is the net effect of decreasing expected profits and increasing expected consumers' surplus. In fact, the increase in consumers' surplus outweighs the negative profit effect, i.e. $W^f(r) \geq W^o(r)$, where $W^\ell(r) \equiv CS^\ell(r) + N\Pi^\ell(r,r)$. Vives (1984) obtains a similar intuitive result.

Proposition 2 *If $r_i = r \in (0,1)$ for all $i = 1,..,N$, then expected consumers' surplus and welfare are greater under full information sharing than under full concealment, i.e. $W^f(r) > W^o(r)$ for all $r \in (0,1)$.*

4 Information Sharing

In this section we study the firms' incentives to share information after firms received their signals, i.e. we study the firms' *interim* incentives to share information.

First, firms do not have an incentive to share all information. If competitors have beliefs consistent with full information sharing, then an individual firm that learned it is efficient, $\Theta_i = \underline{\theta}$, has an incentive to unilaterally conceal this information. The concealment of low cost information may raise the rivals' expected cost, and, consequently, lower their outputs. This makes concealment of low cost information profitable, given beliefs consistent with full information sharing.

Full concealment is not chosen in equilibrium without *ex ante* commitment either. If competitors have beliefs consistent with full concealment, then it is profitable for an individual firm to unilaterally disclose a high cost signal, $\Theta_i = \overline{\theta}$. A firm that discloses bad news discourages uninformed rivals, which increases the firm's expected profit.

The profitable unilateral deviations from full information sharing and full concealment suggest that firms choose for selective disclosure in equilibrium. This is indeed typically the case, as we show in the following proposition.

Proposition 3 *If $r < 1$, then firms disclose a high production cost, and conceal a low cost, i.e. $(\delta(\underline{\theta}), \delta(\overline{\theta})) = (0, 1)$, in the unique symmetric equilibrium. If $r = 1$, then any disclosure rule may be chosen in equilibrium, and an informed firm with $\Theta_i = \theta$ expects to earn the profit $\pi^f(\theta)$ for any disclosure rule, with $\theta \in \{\underline{\theta}, \overline{\theta}\}$.*

The result for $r < 1$ is consistent with the experimental results in Ackert *et al* (2000), and is intuitive. Hence, the selective disclosure regime, that we previously imposed, emerges endogenously in industries where firms choose not to precommit to information sharing, or where they cannot precommit. If $r = 1$, informed firms are indifferent between disclosure and concealment of their signal. After either disclosure or concealment each firm expects full information sharing outputs from its competitors, since the "unraveling result" applies here.

Proposition 1 shows that, for given (symmetric) levels of information acquisition, strategic disclosure would never be *ex ante* efficient. That is, firms would prefer to precommit to either full sharing or full concealment. However, the *interim* incentives are such that firms typically choose selective disclosure in the unique equilibrium. A firm that makes a strategic disclosure choice does not internalize any externality that its choice inflicts on other types. The *ex ante* commitment to a disclosure rule enables firms to internalize such externalities.

Moreover, in contrast to the assumption of proposition 1, in our model the level of information acquisition is not given, but determined endogenously by investment decisions. We study the firms' information acquisition incentives in the next section.

5 Information Acquisition

In this section we compare the equilibrium information acquisition investments under the three disclosure regimes. Subsequently, we compare the overall expected profits, and overall expected welfare under the three regimes.

5.1 Equilibrium Investments

Under any disclosure regime $\ell \in \{f, o, p\}$, firm i's expected equilibrium profit $\Pi^\ell(r_i, r)$, as defined in (3.8), is linear in investment r_i. The profit-maximizing investments are therefore easily derived. The equilibrium information acquisition investments are determined by the trade-off between the marginal cost of investment, η, and the marginal revenue, $\psi^\ell(r)$, as defined in (3.9)-(3.11). For convenience we denote the marginal revenue of information acquisition under regime ℓ when no information is acquired as follows:

$$\psi_0^\ell \equiv \psi^\ell(0), \text{ for } \ell \in \{f, o, p\}.$$

Notice that for extreme investments, we can rank the marginal revenues of information acquisition as follows (see lemma 1):

$$0 = \psi^f(1) = \psi^p(1) < \psi^o(1) = \psi_0^f < \psi_0^o < \psi_0^p.$$

In particular, under full information sharing the trade-off between the marginal cost of information acquisition, η, and marginal revenue $\psi^f(r)$, as defined in (3.9), results in the following symmetric equilibrium investments:

$$r^f = \begin{cases} 1 - \left[\eta \Big/ \psi_0^f\right]^{\frac{1}{N-1}}, \text{ if } \eta \leq \psi_0^f, \\ 0, \text{ otherwise.} \end{cases} \tag{5.1}$$

With no pooling of information firm i's marginal revenue of information acquisition equals $\psi^o(r)$, which is defined in (3.10). The symmetric equilibrium information investment that result from profit-maximization and fulfillment of beliefs is:

$$r^o = \begin{cases} 1, \text{ if } \eta \leq \psi_0^f \\ \frac{2}{N-1}\left[\sqrt{\psi_0^o/\eta} - 1\right], \text{ if } \psi_0^f < \eta < \psi_0^o, \\ 0, \text{ otherwise.} \end{cases} \tag{5.2}$$

Under strategic disclosure the marginal revenue of information acquisition is $\psi^p(r)$, as in (3.11). The trade-off between marginal cost and revenue yields the following equilibrium investments:

$$r^p = \begin{cases} \text{s.t. } \psi^p(r) = \eta, \text{ if } \eta < \psi_0^p, \\ 0, \text{ otherwise.} \end{cases} \tag{5.3}$$

We illustrate the equilibrium information acquisition investments (for $N \geq 3$) in figure 1 below. Notice that equilibrium information acquisition investments are

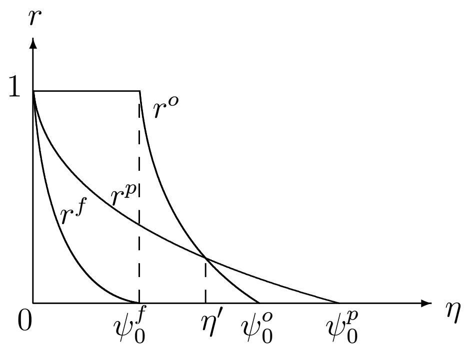

Figure 1: Information Acquisition Investments

non-increasing in the marginal cost of investment η, which is intuitive.

A firm's incentive to acquire information is determined by two factors. First, the value of acquiring information is determined by the expected profits from product market competition. In particular, the difference between the expected profits of being informed and the expected profit of remaining uninformed is an important element in the firm's marginal revenue of information acquisition. Second, the firm's incentive to acquire information is affected by free-rider effects due to information disclosure by rivals. Naturally, the more information is disclosed by rivals, the lower a firm's incentive to acquire information. Both factors play an important role in the analysis of a firm's information acquisition incentives, as is shown in the following proposition.

Proposition 4 *Symmetric equilibria exist in which the information acquisition investments are as in (5.1)-(5.3). The investments under information sharing are lowest, i.e.* $r^f \leq \min\{r^p, r^o\}$. *Furthermore, there are critical values* $\underline{\eta}'$ *and* $\overline{\eta}'$, *with* $\psi_0^f < \underline{\eta}' \leq \overline{\eta}' < \psi_0^o$, *such that firms invest less (more) in information acquisition under selective disclosure than under full concealment for all* $\eta < \underline{\eta}'$ *(respectively,* $\eta > \overline{\eta}'$*).*

The marginal revenue of information acquisition under full information sharing, $\psi^f(r)$, consists of two components. The first component is the value of the firm's own information acquisition in the absence of disclosure, i.e. $E\{\pi^f(\theta)\} - \pi^f(\varnothing)$. This value is reduced by the expected value of information disclosed by rivals, i.e. $[1-(1-r)^{N-1}]\cdot[E\{\pi^f(\theta)\}-\pi^f(\varnothing)]$. This second component reflects the free-rider incentives of acquiring public information. The value of information in the absence of disclosure is greater under the no disclosure regime, i.e. $E\{\pi^o(\theta)\}-\pi^o(\varnothing) > E\{\pi^f(\theta)\}-\pi^f(\varnothing)$ as was shown in lemma 1. Moreover, there are no free-rider incentives in information acquisition when firms do not share information. Both effects imply that the firms' information acquisition incentives under no disclosure exceed those under full disclosure. For the comparison between ψ^f and ψ^p we can make an analogous decomposition of marginal revenue $\psi^f(r)$ in two effects. There may be instances (e.g. for large r) where the first effect gives bigger information acquisition incentives under full information sharing than under partial disclosure. But in those instances the free-rider effect is the dominating effect. Hence, the information acquisition investments are lowest if information is shared, i.e. $r^f \leq \min\{r^p, r^o\}$, as we show formally in proposition 4.

The remaining comparison, between r^o and r^p, is more subtle. Again, the comparison gives a trade-off between two effects. First, we compare the value of a firm's own information acquisition in the absence of disclosure, i.e. $E\{\pi^\ell(\theta)\}-\pi^\ell(\varnothing)$ for $\ell\in\{o,p\}$. Second, for $\ell=p$ this value is reduced by the value of information disclosed by the firm's rivals, $(1-q)[1-(1-r)^{N-1}][\pi^p(\overline{\theta})-\pi^p(\varnothing)]$, which is negative. This term represents the informational free-rider effect under strategic disclosure. On the one hand, if r is sufficiently close to one, the value of information is greatest under full concealment. In particular, if $r\to 1$, the unraveling result applies under strategic disclosure, which reduces the value of information to zero. If firms do not share information, then the unraveling result does not apply, and information is still valuable even if $r\to 1$. Hence, $\psi^p(1)=0<\psi^o(1)$. On the other hand, if r is sufficiently close to zero, then the marginal revenue of information acquisition under strategic disclosure is greater than under no disclosure. In the limit when $r\to 0$, the information free-rider effect under strategic disclosure disappears, since rivals do not acquire information. The information acquisition incentives in both regimes are then only determined by the expected profits from product market competition. And, these profits are such that $\psi^p(0)>\psi^o(0)$, since firms expect fiercer product market competition under full concealment, i.e. $\pi^p(\overline{\theta})>\pi^o(\overline{\theta})$ and $\pi^p(\Theta)=\pi^o(\Theta)$ for $\Theta\in\{\underline{\theta},\varnothing\}$ and $r\to 0$ (see lemma 1). This implies that the relative size of information acquisition investments under strategic and no disclosure, depends on the marginal cost of information acquisition, η. For sufficiently low costs, i.e. $\eta<\underline{\eta}'$, firms invest most in information acquisition under no disclosure. But for sufficiently high costs, i.e. $\eta > \overline{\eta}'$, firms have greater incentives to acquire information under partial disclosure. In fact, numerical examples suggest that $\underline{\eta}' = \overline{\eta}' = \eta'$, as in figure 1.

We conclude from these results that for sufficiently small costs of information acquisition, $\eta < \underline{\eta}'$, the information acquisition incentives are monotonic in the amount of information disclosed in the industry. For these costs the free-rider incentives are sufficiently great. However, for intermediate costs of information acquisition, $\overline{\eta}' < \eta < \psi_0^o$, we obtain a non-monotonicity result. The value of information is greatest under strategic disclosure, since expected product market profits under strategic disclosure are greatest, while the value of information from free-riding on rivals' information is negative.

5.2 Overall Expected Profits

For given levels of information acquisition investments, firms generically prefer not to pool their information. After we substitute the equilibrium investments in the relevant profit functions, we obtain the following overall expected profits (for $\mathbf{r}^\ell \equiv (r^\ell, r^\ell)$ with $\ell \in \{f, o, p\}$):

$$\Pi^f(\mathbf{r}^f) = \Pi^o(\mathbf{r}^o) = \begin{cases} E\left\{\pi^f(\theta)\right\} - \eta, \text{ if } \eta < \psi_0^f \\ \pi^f(\varnothing), \text{ otherwise.} \end{cases} \tag{5.4}$$

Notice that the expected profits under information sharing and no-sharing are identical.[8] If costs of investment are sufficiently low ($\eta < \psi_0^f$), firms are indifferent between acquiring and not acquiring information under full disclosure, i.e. $\psi^f(r^f) = \eta$. Therefore, fully disclosing firms expect the profit $E\left\{\pi^f(\theta)\right\} - \eta$ from disclosure by rivals, and zero profits from their own information acquisition investments. Under no information sharing the marginal revenue of information acquisition exceeds its marginal cost, if $\eta < \psi_0^f$. Hence, firms acquire information with certainty, which generates an expected profit of $E\left\{\pi^f(\theta)\right\} - \psi^o(1)$ from disclosure by rivals, and $\psi^o(1) - \eta$ from own information acquisition. For higher costs of investment firms are uninformed under full disclosure, while they are either indifferent or prefer to remain uninformed under no disclosure. In either case firms earn profit $\pi^f(\varnothing)$. Hence, if firms could commit to share or conceal information before they invest in information acquisition, they would always be indifferent between the two.

[8] This "knife edge" result depends on the assumption of linear information acquisition costs, as we discuss in the next section.

The expected overall profit under strategic disclosure equals:

$$\Pi^p(\mathbf{r}^p) = \begin{cases} E\left\{\pi^p(\theta)\right\}|_{r=r^p} - \eta, \text{ if } \eta < \psi_0^p \\ \pi^f(\varnothing), \text{ otherwise.} \end{cases} \tag{5.5}$$

We illustrate the overall expected profits in figure 2 below. This figure suggests

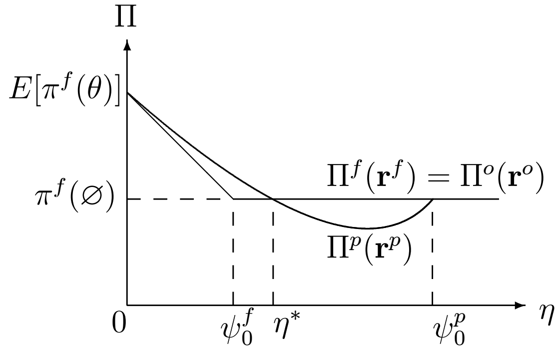

Figure 2: Overall Expected Profits

the following comparison between overall expected profits under precommitment and under strategic disclosure.

Proposition 5 *For all $\eta > 0$ overall expected profits under full information sharing and no sharing are identical, i.e. $\Pi^f(\mathbf{r}^f) = \Pi^o(\mathbf{r}^o)$. Furthermore, there are critical values $\underline{\eta}^*$ and $\overline{\eta}^*$ with $\psi_0^f < \underline{\eta}^* \leq \overline{\eta}^* < \psi_0^p$, such that expected equilibrium profits are highest (lowest) under strategic information sharing if $0 < \eta < \underline{\eta}^*$ ($\overline{\eta}^* < \eta < \psi_0^p$).*

For low marginal costs of investment firms acquire information with probabilities close to one. We showed in the discussion of proposition 1 that the expected profit is greater under full disclosure than under strategic disclosure, for given, high levels of information acquisition investments, i.e. $\Pi^f(\mathbf{r}^p) > \Pi^p(\mathbf{r}^p)$. On the other hand, we showed in proposition 4 that firms invest less in information acquisition than under strategic disclosure. This effect lowers the expected profits net of information acquisition costs under full disclosure, i.e. $\Pi^f(\mathbf{r}^f) < \Pi^f(\mathbf{r}^p)$, since $r^f < r^p$. The latter effect dominates the former effect for sufficiently low costs of information acquisition. In fact, there exists a critical cost level, $\underline{\eta}^*$ with $\psi_0^f < \underline{\eta}^* < \psi_0^p$, such that the overall expected profit under strategic disclosure is greatest, i.e. $\Pi^p(\mathbf{r}^p) > \Pi^f(\mathbf{r}^f) = \Pi^o(\mathbf{r}^o)$ for all $0 < \eta < \underline{\eta}^*$, as shown in proposition 5.

For sufficiently high costs of information acquisition, the investments in information acquisition are low. For given, low levels of information acquisition the expected profit under full disclosure is lower than the expected profit under strategic disclosure, as follows from the discussion of proposition 1. However, firms invest less in information acquisition under full disclosure than under strategic disclosure. In particular, $r^f = 0$ while $r^p > 0$ for η sufficiently close to (and below) ψ_0^p. This increases the firms' revenues under strategic disclosure even further. But, on the other hand, firms under full disclosure forego the substantial cost of information acquisition, ηr^p, that firms under strategic disclosure have to bear. For η sufficiently close to ψ_0^p, this cost outweighs the higher revenues that firms earn under strategic disclosure. Therefore, overall profits are lower under strategic disclosure. We show in proposition 5 above that there is a critical cost of investment, $\overline{\eta}^*$ with $\underline{\eta}^* \leq \overline{\eta}^* < \psi_0^p$, such that the overall expected profit under strategic information sharing is smallest, i.e. $\Pi^p(\mathbf{r}^p) < \Pi^f(\mathbf{r}^f) = \Pi^o(\mathbf{r}^o)$ for all $\overline{\eta}^* < \eta < \psi_0^p$. In fact, numerical examples suggest that $\underline{\eta}^* = \overline{\eta}^* = \eta^*$, as in figure 2.

We conclude from proposition 5 that the overall expected profits are often non-monotonic in the amount of information disclosed by the firms. If the costs of information acquisition are sufficiently low, then firms prefer not to precommit to information disclosure. Hence, strategic disclosure does not only emerge in markets where firms cannot precommit, but it can also emerge since firms choose not to precommit. However, for high costs of investment firms would prefer to precommit to full information sharing or full concealment.[9]

5.3 Overall Expected Welfare

The welfare comparison is less straightforward. On the one hand, expected welfare for given levels of information acquisition investment is higher under information sharing. But, on the other hand, firms invest more in information acquisition under full concealment, which increases expected welfare. The positive effect of information concealment on the information acquisition incentives outweighs the negative effect, i.e. $W^f(r^f) \leq W^o(r^o)$. Hence, endogenizing information acquisition reverses the welfare result of section 3. Persico (2000) makes a related observation for auction models with affiliated values. For a given information structure the second price auction yields a higher expected revenue to an auctioneer than the first price auction. But the first price auction gives a greater incentive to acquire information, which may reverse the expected revenue ranking.

[9]Obviously, if the costs of information acquisition are prohibitively high, i.e. $\eta \geq \psi_0^p$, firms are indifferent between disclosure regimes, since they never acquire any information, and expected profits equal $\pi^f(\varnothing)$ under all regimes.

We can find also cases in which overall expected welfare is lower under precommitment than under strategic disclosure. This result is due to the non-monotonicity of information acquisition incentives in the cost η. If the information acquisition cost is between ψ_0^o and ψ_0^p, then firms are uninformed under the precommitment regimes ($r^f = r^o = 0$), while they are informed with a positive probability under strategic disclosure ($r^p > 0$). We show below that in such a case the expected welfare under partial disclosure may exceed the welfare of remaining uninformed.

Proposition 6 *The overall expected welfare under full information sharing never exceeds the overall expected welfare under no information sharing, i.e.* $W^f(r^f) \leq W^o(r^o)$*, and the inequality is strict iff* $\eta < \psi_0^o$*. Furthermore, there exist critical values* $\eta^o < \psi_0^p$ *and* $N^o \in \{2, 3, 4, ...\}$*, such that for all* $N > N^o$ *and* $\eta^o < \eta < \psi_0^p$ *overall expected welfare is highest under strategic disclosure, i.e.* $W^o(r^o) < W^p(r^p)$*.*

Hence, there are cases where expected welfare is greatest under strategic disclosure. In these cases a welfare-maximizing antitrust authority should prohibit the formation of trade associations that facilitate commitment to share or conceal information. In proposition 5 we showed that for a high cost of information acquisition firms prefer to precommit to either fully share or fully conceal their information. Therefore, there is a conflict of interest between the firms and a welfare-maximizing antitrust authority for sufficiently high information acquisition costs. Whereas firms prefer to precommit, the antitrust authority prefers to prohibit such precommitment. These results would call for the intervention by an antitrust authority if the cost of information acquisition is high. That is, there are cases where strategic disclosure may arise because an antitrust authority prefers to prohibit agreements by firms on information sharing.

A second implication of this proposition is that overall expected welfare is never maximized by full disclosure. A welfare-maximizing antitrust authority should therefore always prohibit agreements which enable firms to precommit to share all their information, if information acquition is uncertain.

6 Discussion

The analysis of the previous section is made easier by the assumption of linear costs of information acquisition. In this section we check whether the main profit results (proposition 5) are robust to changes in the specification of the information acquisition cost function. In particular, we consider the model where each firm has the following convex cost of information acquisition: $C(r_i;\eta) \equiv \eta \cdot c(r_i)$, with $\eta > 0$, and $c'(r) > 0$, $c''(r) \geq 0$, and $c'(0) = c''(0) = 0$, for $i = 1,..,N$. Firm i's expected profit under regime ℓ is now (for $i = 1,..,N$ and $\ell \in \{f,o,p\}$):

$$\Pi^{\ell}(r_i, r) = E\left\{\pi^{\ell}(\theta)\right\} - (1 - r_i)\psi^{\ell}(r) - C(r_i;\eta). \tag{6.1}$$

Again, the trade-off between the marginal revenue and marginal cost of information acquisition determines the equilibrium information acquisition investment, i.e. r^{ℓ} is such that for any $\ell \in \{f,o,p\}$:

$$\psi^{\ell}(r^{\ell}) = \eta c'(r^{\ell}), \text{ if } \psi^{\ell}(1) \leq \eta c'(1), \tag{6.2}$$

and $r^{\ell} = 1$, otherwise. The qualitative comparison of equilibrium investments from proposition 4 is robust to the introduction of cost convexity. This observation follows immediately from the monotonicity of the marginal cost and revenue functions, and the fact that the comparison of proposition 4 is driven by the comparison of marginal revenues only.

Comparison of expected profits $\Pi^f(\mathbf{r}^f)$, $\Pi^o(\mathbf{r}^o)$, and $\Pi^p(\mathbf{r}^p)$ yields the following.

Proposition 7 *If firms have strictly convex costs of information acquisition, $C(r_i;\eta)$, the following holds. Critical value $\eta^c \geq \psi_0^f / c'(1)$ exists such that for all $\eta \leq \eta^c$ the overall expected equilibrium profit under full information sharing is greater than under full concealment, i.e. $\Pi^o(\mathbf{r}^o) < \Pi^f(\mathbf{r}^f)$ for all $\eta \leq \eta^c$. Furthermore, if $N = 2$, a critical value $\eta^s > 0$ exists such that for all $\eta \leq \eta^s$ the overall expected equilibrium profit is highest under strategic information sharing, i.e. $\Pi^f(\mathbf{r}^f) < \Pi^p(\mathbf{r}^p)$ for all $\eta \leq \eta^s$.*

First, we notice that a firm with convex information acquisition costs is no longer indifferent between the precommitment regimes. In particular, firms that share information expect a higher overall profit. The information acquisition cost saving under full information sharing now outweighs the typical expected profit loss for a given information acquisition investment of switching from no sharing to full sharing. That is, endogenizing a firm's signal precision typically reverses the firm's profit ranking among the precommitment regimes. Whereas firms with exogenous signal precisions are typically better off under full concealment (proposition 1), they prefer full information sharing when the precision is endogenous.

Second, for sufficiently small costs of information acquisition the firms' preference for strategic information sharing (proposition 5) is not affected by the introduction of convex costs. This preference for strategic disclosure was already driven by investment incentives for information acquisition. The introduction of convex information acquisition costs only strengthens this dominant effect. That is, the firms' expected overall profit remains highest under strategic disclosure. This observation suggests that the overall profit result of proposition 5 for high values of η should also be robust to the introduction of convex information acquisition costs. For high investment cost parameters the cost saving under disclosure precommitment is the dominant effect in comparing expected profits under disclosure precommitment with strategic disclosure. The introduction of convex costs of investment would only strengthen this result.

7 Conclusion

We have studied production, disclosure, and information acquisition incentives of Cournot oligopolists. We have seen that the endogeneity of information acquisition and information disclosure affects the industry's profits and welfare substantially. Antitrust authorities should take this into account when they choose a disclosure regulation regime for oligopolistic markets. The paper suggest a number of conditions that are important for a policy maker's evaluation of information disclosure regimes.

The emergence of selective disclosure in equilibrium is consistent with theoretical studies, such as Darrough (1993), and the experimental results of Ackert *et al* (2001). Moreover, we have been able to characterize the profit and welfare effects of the disclosure strategies obtained in these studies. We have shown that, even in markets where firms can precommit, strategic disclosure may emerge since firms prefer not to choose either precommitment disclosure regime. Furthermore, there are cases where welfare is maximized under strategic disclosure. Hence, a welfare-maximizing antitrust authority should rule against precommitment to share or conceal information (e.g. through the establishment of a trade association) in such cases.

A Appendix

This Appendix contains the proofs of the main propositions of the paper.

A.1 Proof of Lemma 1

(i) We show that $x^f(\varnothing) < x^p(\varnothing)$:

$$\begin{aligned} & (N+1)[2+(1-\widetilde{q})(N-1)r][x^p(\varnothing)-x^f(\varnothing)] \\ = \; & [2+(N-1)r]\left(E(\theta)-\widetilde{E}(\theta)\right)-(N-1)r\widetilde{q}\,(E(\theta)-\underline{\theta}) \\ = \; & [2(\widetilde{q}-q)-(N-1)rq(1-\widetilde{q})]\,(\overline{\theta}-\underline{\theta}) = \frac{q(1-q)(\overline{\theta}-\underline{\theta})}{q+(1-q)(1-r)^{N-1}}D_N(r), \end{aligned}$$

with

$$D_N(r) \equiv [1-(1-r)^{N-1}]2-(1-r)^{N-1}(N-1)r > 0 \text{ for all } N \geq 2, \tag{A.1}$$

since $D_1(r) = 0$, and $D_{N+1}(r) - D_N(r) = r(1-r)^{N-1}(1+Nr) > 0$. This inequality, together with first-order condition (3.5) for $\Theta_i = \underline{\theta}$ and $R(\underline{\theta}) = r$ gives $x^p(\underline{\theta}) < x^o(\underline{\theta})$. All remaining inequalities are straightforward.

(ii) First, using the following properties

$$\frac{\partial \widetilde{q}}{\partial r} = \frac{(N-1)\widetilde{q}(1-\widetilde{q})}{1-r}, \text{ and} \tag{A.2}$$

$$x^p(\underline{\theta}) = x^f(\overline{\theta}) + \frac{[2+(1-\widetilde{q})(N-1)](\overline{\theta}-\underline{\theta})}{(N+1)[2+(1-\widetilde{q})(N-1)r]}, \tag{A.3}$$

it is straightforward to show that:

$$\frac{\partial x^p(\underline{\theta})}{\partial r} = \frac{-(1-\widetilde{q})(N-1)[2+(1+\widetilde{q})(N-1)](\overline{\theta}-\underline{\theta})}{(N+1)[2+(1-\widetilde{q})(N-1)r]^2} < 0. \tag{A.4}$$

Second, since we can rewrite $x^p(\varnothing)$ as follows

$$x^p(\varnothing) = x^f(\overline{\theta}) + \frac{2\widetilde{q}(\overline{\theta}-\underline{\theta})}{(N+1)[2+(1-\widetilde{q})(N-1)r]}, \tag{A.5}$$

we obtain:

$$\frac{\partial x^p(\varnothing)}{\partial r} = \frac{2\widetilde{q}(1-\widetilde{q})(N-1)[1+Nr](\overline{\theta}-\underline{\theta})}{(1-r)(N+1)[2+(1-\widetilde{q})(N-1)r]^2} > 0. \tag{A.6}$$

The remaining monotonicity results, $\partial x^o(\underline{\theta})/\partial r < 0$ and $\partial x^o(\overline{\theta})/\partial r > 0$, follow directly from expression (3.6) with $Q(0,0) = q$ and $R(\theta) = r$, for $\Theta_i = \underline{\theta}$ and $\Theta_i = \overline{\theta}$, respectively. The equalities for $r \in \{0,1\}$ are obvious.

(iii) The expected equilibrium output under full and no disclosure are:

$$\begin{aligned} E\{X^f\} &= [1-(1-r)^N]NE\{x^f(\theta)\} + (1-r)^N N x^f(\varnothing) = N x^f(\varnothing), \\ E\{X^o\} &= rNE\{x^o(\theta)\} + (1-r)N x^o(\varnothing) = N x^f(\varnothing), \text{ respectively.} \end{aligned}$$

Under partial disclosure the expected equilibrium industry output equals:

$$\begin{aligned} E\{X^p\} &= q\sum_{m=0}^{N}\binom{N}{m} r^m (1-r)^{N-m}\left[m x^p(\underline{\theta}) + (N-m)x^p(\varnothing)\right] \\ &\quad + N(1-q)\left((1-r)^{N-1}x^p(\varnothing) + [1-(1-r)^N]x^p(\overline{\theta})\right) \\ &= N\left(rqx^p(\underline{\theta}) + (1-r)[q+(1-q)(1-r)^{N-1}]x^p(\varnothing)\right. \\ &\quad \left. + (1-q)[1-(1-r)^N]x^p(\overline{\theta})\right) = N x^f(\varnothing). \end{aligned}$$

We conclude from these expressions that: $E\{X^f\} = E\{X^o\} = E\{X^p\} = Nx^f(\varnothing)$. □

A.2 Proof of Proposition 1 (Expected Profit)

We first compare the expected profits under full disclosure and no disclosure. Since $\pi^f(\varnothing) = \pi^o(\varnothing)$, and since $\psi^f(r)$ and $\psi^o(r)$, as defined in (3.9) and (3.10), can be written as follows

$$\psi^f(r) = (1-r)^{N-1} \cdot \frac{q(1-q)(\overline{\theta}-\underline{\theta})^2}{(N+1)^2} \text{ and } \psi^o(r) = \frac{q(1-q)(\overline{\theta}-\underline{\theta})^2}{[2+(N-1)r]^2}, \tag{A.7}$$

we can rewrite the difference between the profits under no and full information sharing as follows (for $r_i = r$):

$$\begin{aligned} \Pi^o(r,r) - \Pi^f(r,r) &= r\left[\psi^o(0) - \psi^f(r)\right] + (1-r)\left[1-(1-r)^{N-1}\right]\psi^f(0) \\ &= r\psi^o(r) - \left[1-(1-r)^N\right]\psi^f(0) \\ &= \frac{q(1-q)(\overline{\theta}-\underline{\theta})^2}{(N+1)^2[2+(N-1)r]^2} G_N(r), \end{aligned} \tag{A.8}$$

with

$$G_N(r) \equiv r(N+1)^2 - [1-(1-r)^N][2+(N-1)r]^2. \tag{A.9}$$

Hence, $\Pi^o(r,r) > \Pi^f(r,r)$ iff $G_N(r) > 0$. For $N = 2$ we obtain: $G_2(r) = r(1-r)(1-3r-r^2)$, and consequently $\Pi^o(r,r) > \Pi^f(r,r)$ iff $r < r_2^*$, where r_2^* is the root of $1-3r-r^2 = 0$. Similarly, $G_3(r) = 4r(1-r)^2(1-r-r^2)$, which gives $\Pi^o(r,r) > \Pi^f(r,r)$ iff $r < r_3^*$, where r_3^* is the root of $1-r-r^2 = 0$. For $N \geq 4$ we rewrite inequality $G_N(r) > 0$ as follows:

$$[2+(N-1)r]\sqrt{\frac{1-(1-r)^N}{r}} < N+1, \tag{A.10}$$

and we show that inequality (A.10) holds for all $r \in (0,1)$, since its left hand side is increasing in r, and $\Pi^f(r,r) = \Pi^o(r,r)$ for $r=1$. Differentiation of the left hand side of (A.10) gives:

$$\frac{\partial}{\partial r}\left([2+(N-1)r]\sqrt{\frac{1-(1-r)^N}{r}}\right) = \frac{F_N(r)\cdot\sqrt{\frac{1-(1-r)^N}{r}}}{2r\left[1-(1-r)^N\right]}, \text{ with}$$
$$F_N(r) \equiv (1-r)^{N-1}\left[(N^2-1)r^2+(N-1)r+2\right]-[2-(N-1)r]. \quad (A.11)$$

We show by induction that $F_N(r) > 0$ for all r and $N \geq 4$. First, it is easy to show that: $F_4(r) = r^2[12-38r+42r^2-15r^3] > 0$ for all r. Furthermore, for any N: $F_{N+1}(r)-F_N(r) = r[1-f_N(r)]$, with $f_N(r) \equiv (1-r)^{N-1}\left[N(N+2)r^2-(N+1)r+1\right]$. Function $f_N(r)$ has local maxima for $r=0$ and $r=\frac{2}{N+1}$, since:

$$f'_N(r) = -N(1-r)^{N-2}[(N+1)r-2][(N+2)r-1].$$

Hence, we obtain: $f_N(r) \leq \max\left\{f_N(0), f_N(\frac{2}{N+1})\right\} = 1$ for all r. This implies that $F_{N+1}(r)-F_N(r) \geq 0$, and $\Pi^o(r,r) > \Pi^f(r,r)$, for all $N \geq 4$.

Second, the difference between the expected profit under full disclosure and partial disclosure equals:

$$\begin{aligned}&\Pi^f(r_i,r)-\Pi^p(r_i,r) = \\ &r_i q\left[\pi^f(\underline{\theta})-\pi^p(\underline{\theta})\right]+(1-r_i)\left[q+(1-q)(1-r)^{N-1}\right]\left[\pi^f(\varnothing)-\pi^p(\varnothing)\right] \\ &+(1-r_i)q\left[1-(1-r)^{N-1}\right]\left[\pi^f(\underline{\theta})-\pi^f(\varnothing)\right]. \qquad (A.12)\end{aligned}$$

The terms in expression (A.12) can be written as follows:

$$\begin{aligned}\pi^f(\underline{\theta})-\pi^p(\underline{\theta}) &= x^f(\underline{\theta})^2-\left(x^f(\underline{\theta})+\frac{(N-1)(1-r)(\widetilde{E}(\theta)-\underline{\theta})}{(N+1)[2+(1-\widetilde{q})(N-1)r]}\right)^2 \\ \pi^f(\varnothing)-\pi^p(\varnothing) &= \left(x^f(\underline{\theta})-\frac{E(\theta)-\underline{\theta}}{N+1}\right)^2-\left(x^f(\underline{\theta})-\frac{[2+(N-1)r](\widetilde{E}(\theta)-\theta)}{(N+1)[2+(N-1)r]}\right)^2 \\ \pi^f(\underline{\theta})-\pi^f(\varnothing) &= x^f(\underline{\theta})^2-\left(x^f(\underline{\theta})-\frac{E(\theta)-\underline{\theta}}{N+1}\right)^2.\end{aligned}$$

Substitution of these terms in (A.12) gives:

$$\Pi^f(r,r)-\Pi^p(r,r) = \frac{(1-r)(1-\widetilde{q})q(1-q)(\overline{\theta}-\underline{\theta})^2}{(N+1)^2[2+(1-\widetilde{q})(N-1)r]^2}\left(r\frac{\widetilde{q}}{q}H_N(r)-G_N(r)\right), \quad (A.13)$$

with

$$\begin{aligned}H_N(r) \equiv\ &\left[p+(1-p)(1-r)^{N-1}\right][(N+1)^2-2(N-1)(2+(N-1)r)] \\ &-[(1-r)^N+pr^2](N-1)^2. \qquad (A.14)\end{aligned}$$

$H_N(r)$ is linear in p, with $H_N(r) = (1-r)^{N-1}\,[4 - r(N-1)^2]$ for $p = 0$, and $H_N(r) = (N-1)\left[(1-r)^N(N-1) + r(N-1) + 4\right] > 0$ for $p = 1$. Clearly, if $N \in \{2,3\}$, then $H_N(r) > 0$ for all $p, r \in (0,1)$. Moreover, we showed before that if $N \in \{2,3\}$ and $r \geq r_N^*$, then $G_N(r) \leq 0$. Consequently, if $N \in \{2,3\}$ and $r \geq r_N^*$, then $\Pi^f(r,r) > \Pi^p(r,r)$.

Finally, the difference of expected profits under full concealment and partial disclosure is:

$$\begin{aligned}
\Pi^o(r,r) - \Pi^p(r,r) &= \left[\Pi^o(r,r) - \Pi^f(r,r)\right] + \left[\Pi^f(r,r) - \Pi^p(r,r)\right] \\
&= \frac{q(1-q)(\overline{\theta} - \underline{\theta})^2}{(N+1)^2[2+(N-1)r]^2[2+(1-\widetilde{q})(N-1)r]^2} A_N(r) \cdot G_N(r) \\
&\quad + \frac{r(1-r)(1-\widetilde{q})\widetilde{q}(1-q)(\overline{\theta} - \underline{\theta})^2}{(N+1)^2[2+(1-\widetilde{q})(N-1)r]^2} H_N(r),
\end{aligned} \tag{A.15}$$

where

$$\begin{aligned}
A_N(r) &\equiv [2+(1-\widetilde{q})(N-1)r]^2 - (1-r)(1-\widetilde{q})[2+(N-1)r]^2 \\
&= (1-\widetilde{q})r\left[(N-1)^2r^2 + (4-(N-1)\widetilde{q})\,(N-1)r + 4\right] + 4\widetilde{q}.
\end{aligned} \tag{A.16}$$

Hence, if $N \leq 5$, then $A_N(r) \geq 0$ for all $r \in (0,1)$. Recall that if $N \in \{2,3\}$ and $r < r_N^*$, then $H_N(r) \geq 0$ and $G_N(r) > 0$. Therefore, if $N \in \{2,3\}$ and $r < r_N^*$, $\Pi^o(r,r) > \Pi^p(r,r)$. We showed previously that if $N \in \{2,3\}$ and $r \geq r_N^*$, then $\Pi^f(r,r) > \Pi^p(r,r)$. Hence, $\max\{\Pi^f(r,r), \Pi^o(r,r)\} > \Pi^p(r,r)$ for all $r \in (0,1)$. □

A.3 Proof of Proposition 2 (Expected Welfare)

The consumers' surpluses under full and no information sharing can be rewritten as follows (using $E\{x^o(\theta)\} = x^o(\varnothing)$):

$$\begin{aligned}
CS^f(r) &= \frac{1}{2}N^2\left(\left[1-(1-r)^N\right]E\left\{x^f(\theta)^2\right\} + (1-r)^N x^f(\varnothing)^2\right) \\
&= \frac{1}{2}N^2\left(\pi^f(\varnothing) + \left[1-(1-r)^N\right]\psi^f(0)\right), \text{ and}
\end{aligned} \tag{A.17}$$

$$\begin{aligned}
CS^o(r) &= \frac{1}{2}\sum_{m=0}^{N}\binom{N}{m}r^m(1-r)^{N-m}E\left\{\left[Nx^o(\varnothing) + m\left(x^o(\theta) - x^o(\varnothing)\right)\right]^2\right\} \\
&= \frac{1}{2}\left(N^2x^o(\varnothing)^2 + \sum_{m=0}^{N}\binom{N}{m}r^m(1-r)^{N-m}m^2\left[E\{x^o(\theta)^2\} - x^o(\varnothing)^2\right]\right) \\
&= \frac{1}{2}\left(N^2\pi^o(\varnothing) + Nr[1+(N-1)r]\psi^o(r)\right).
\end{aligned} \tag{A.18}$$

Hence, after substituting the expressions of (A.7) in (A.17) and (A.18), the difference between expected consumers' surplus under full and no information sharing reduces to:

$$CS^f(r) - CS^o(r) = \frac{1}{2}Nq(1-q)(\overline{\theta}-\underline{\theta})^2 \left(\frac{N[1-(1-r)^N]}{(N+1)^2} - \frac{r[1+(N-1)r]}{[2+(N-1)r]^2}\right). \tag{A.19}$$

The difference in welfare under full disclosure and full concealment equals therefore:

$$\begin{aligned} W^f(r) - W^o(r) &= CS^f(r) + N\Pi^f(r,r) - [CS^o(r) + N\Pi^o(r,r)] \\ &= \frac{1}{2}Nq(1-q)(\overline{\theta}-\underline{\theta})^2 \left(\frac{(N+2)[1-(1-r)^N]}{(N+1)^2} - \frac{r[3+(N-1)r]}{[2+(N-1)r]^2}\right) \\ &= \frac{\frac{1}{2}Nq(1-q)(\overline{\theta}-\underline{\theta})^2}{(N+1)^2[2+(N-1)r]^2} \cdot K_N(r), \end{aligned} \tag{A.20}$$

with

$$K_N(r) \equiv (N+2)[1-(1-r)^N][2+(N-1)r]^2 - [3+(N-1)r]r(N+1)^2. \tag{A.21}$$

We show by induction that $K_N(r) > 0$. First, $K_2(r) = r(1-r)(1+2r)(5+2r) > 0$. Second, $K_{N+1}(r) - K_N(r)$ can be written as follows:

$$\begin{aligned} K_{N+1}(r) - K_N(r) &= (1-r)\left(k_N(r) + (1-r)^{N-1}r^2\left[N^2+9N+2+N^2(N+3)r\right]\right), \\ \text{with} \qquad k_N(r) &\equiv \left[1-(1-r)^{N-1}\right]4 + r\left[2N+3-(1-r)^{N-1}4(N-1)\right]. \end{aligned}$$

We use induction again to show that $k_N(r) > 0$: first, $k_2(r) = r(4r+7) > 0$ for all r; second, $k_{N+1}(r) - k_N(r) = 2r\left[1+2Nr(1-r)^{N-1}\right] > 0$ for all r. Since $k_N(r) > 0$ for all N and r, $K_{N+1}(r) > K_N(r)$ for any N and r, and consequently $K_N(r) > 0$ for all N and r. □

A.4 Proof of Proposition 3 (Interim Disclosure Incentives)

Consider an informed firm i, i.e. $\Theta_i = \theta$ for some $\theta \in \{\underline{\theta}, \overline{\theta}\}$ and $i \in \{1,..,N\}$. Suppose firm i's competitors choose disclosure rule $(\delta(\underline{\theta}), \delta(\overline{\theta})) \in [0,1]^2$ and have beliefs consistent with this rule. Firm i's profit from disclosure is: $\pi(\theta|\theta) \equiv x^f(\theta)^2$. The firm's expected profit from concealment of Θ_i is: $\pi(\varnothing|\theta) \equiv \left(1-[1-r\delta(\theta)]^{N-1}\right)x^f(\theta)^2 + [1-r\delta(\theta)]^{N-1}x^*(\theta;\boldsymbol{\delta})^2$. Clearly, if $r<1$, then the comparison of $\pi(\theta|\theta)$ and $\pi(\varnothing|\theta)$ reduces to the comparison of expressions (3.2) and (3.6) for $\Theta_i = \theta$, respectively.

First, the comparison of (3.2) and (3.6) for $\Theta_i = \underline{\theta}$ immediately yields: $x^f(\underline{\theta}) < x^*(\underline{\theta};\boldsymbol{\delta})$, iff $R(\underline{\theta}) < 1$ and $Q(\boldsymbol{\delta}) < 1$. Clearly, if $r<1$, then $R(\underline{\theta}) < 1$ and $Q(\boldsymbol{\delta}) < 1$.

Hence, if $r < 1$, then concealment is a dominant strategy for an informed, efficient firm. Second, the comparison of (3.2) and (3.6) for $\Theta_i = \overline{\theta}$ yields: $x^f(\overline{\theta}) > x^*(\overline{\theta}; \boldsymbol{\delta})$, iff $R(\overline{\theta}) < 1$ and $Q(\boldsymbol{\delta}) > 0$. Clearly, if $r < 1$, then $R(\overline{\theta}) < 1$ and $Q(\boldsymbol{\delta}) > 0$. Hence, if $r < 1$, then disclosure is a dominant strategy for an informed, inefficient firm.

Finally, for $r = 1$, then $R(\theta) = 1$ and $x^*(\theta; \boldsymbol{\delta}) = x^f(\theta)$ for $\theta \in \{\underline{\theta}, \overline{\theta}\}$. Consequently, firm i is indifferent between disclosure and concealment of θ. Hence, any $\left(\delta(\underline{\theta}), \delta(\overline{\theta})\right) \in [0,1]^2$ is an equilibrium rule. □

A.5 Proof of Proposition 4 (Information Acquisition)

First, notice that the expected equilibrium profits in (3.8) are linear in r_i for each regime $\ell \in \{f, o, p\}$. Hence, firm i's profit-maximizing investments are as follows:

$$r_i \in \begin{cases} \{1\}, \text{ if } \eta < \psi^\ell(r) \\ [0,1], \text{ if } \eta = \psi^\ell(r) \\ \{0\}, \text{ otherwise,} \end{cases} \tag{A.22}$$

for each regime $\ell \in \{f, o, p\}$. Hence, the investments in expressions (5.1), (5.3) and (5.2) are chosen in a symmetric equilibrium, if the marginal revenues of information acquisition are decreasing in r. Under full information sharing and no information sharing this is the case, since $\psi^f(r)$ and $\psi^o(r)$ in (A.7) are clearly decreasing in r. Under partial information sharing we need to evaluate:

$$\begin{aligned} \frac{\widetilde{q}/q}{2} \cdot \frac{d\psi^p(r)}{dr} &= \frac{1}{2}\left(\widetilde{q}\frac{\partial \pi^p(\underline{\theta})}{\partial r} - \frac{\partial \pi^p(\varnothing)}{\partial r} + \frac{(N-1)(1-\widetilde{q})}{1-r}\left[\pi^p(\varnothing) - \pi^p(\overline{\theta})\right]\right) \\ &= \widetilde{q}x^p(\underline{\theta})\frac{\partial x^p(\underline{\theta})}{\partial r} - x^p(\varnothing)\frac{\partial x^p(\varnothing)}{\partial r} + \frac{(N-1)(1-\widetilde{q})}{2(1-r)}\left[x^p(\varnothing)^2 - x^p(\overline{\theta})^2\right]. \end{aligned} \tag{A.23}$$

Using the results from lemma 1 (ii), i.e. expressions (A.3), (A.4), (A.5) and (A.6), we can show that:

$$\begin{aligned} &\frac{(1-r)(N+1)^2[2+(1-\widetilde{q})(N-1)r]^2}{2q(1-\widetilde{q})(N-1)} \cdot d\psi^p(r)/dr \\ &= -\left(\alpha - \overline{\theta} + \frac{[2+(1-\widetilde{q})(N-1)]\,(\overline{\theta}-\underline{\theta})}{2+(1-\widetilde{q})(N-1)r}\right)[2+(1+\widetilde{q})(N-1)](1-r) \\ &\quad - \left(\alpha - \overline{\theta} + \frac{2\widetilde{q}(\overline{\theta}-\underline{\theta})}{2+(1-\widetilde{q})(N-1)r}\right)2\left([2+(N-1)r]-(1-r)\right) \\ &\quad + \left(\alpha - \overline{\theta} + \frac{\widetilde{q}(\overline{\theta}-\underline{\theta})}{2+(1-\widetilde{q})(N-1)r}\right)2[2+(1-\widetilde{q})(N-1)r], \end{aligned} \tag{A.24}$$

which clearly is negative for all $r \in [0,1)$.

For the investment comparisons it suffices to compare the marginal revenues of information acquisition, since the marginal cost remains the same in all regimes. First, we prove that $r^f \leq r^p$ by showing that: $\psi^p(r) > \psi^f(r)$ for all $r \in (0,1)$. The difference in marginal revenues under full and partial information sharing can be decomposed as follows:

$$\begin{aligned}\psi^p(r) - \psi^f(r) &= q\left[\pi^p(\underline{\theta}) - \pi^f(\underline{\theta})\right] + q\left[1-(1-r)^{N-1}\right]\left[\pi^f(\underline{\theta}) - \pi^f(\varnothing)\right] \\ &\quad - \left[q + (1-q)(1-r)^{N-1}\right]\left[\pi^p(\varnothing) - \pi^f(\varnothing)\right]. \end{aligned} \tag{A.25}$$

Clearly, the first term of this expression is positive. Hence, it suffices to show that the sum of the second (positive) and third (negative) terms is positive. As shown in the proof of lemma 1, we can rewrite the last term of (A.25) as follows (for $r \in (0,1)$):

$$\begin{aligned}&\left[q + (1-q)(1-r)^{N-1}\right]\left[\pi^p(\varnothing) - \pi^f(\varnothing)\right] \\ &= \frac{q(1-q)(\overline{\theta}-\underline{\theta})D_N(r)\left[x^p(\varnothing) + x^f(\varnothing)\right]}{(N+1)[2+(1-\widetilde{q})(N-1)r]} \\ &< \frac{q\left[1-(1-r)^{N-1}\right](1-q)(\overline{\theta}-\underline{\theta})2\left[x^p(\varnothing) + x^f(\varnothing)\right]}{(N+1)[2+(1-\widetilde{q})(N-1)r]} \\ &< \frac{q\left[1-(1-r)^{N-1}\right](1-q)(\overline{\theta}-\underline{\theta})\left[x^p(\varnothing) + x^f(\varnothing)\right]}{(N+1)} \\ &< q\left[1-(1-r)^{N-1}\right]\frac{(1-q)(\overline{\theta}-\underline{\theta})}{N+1}\left[x^f(\underline{\theta}) + x^f(\varnothing)\right] \\ &= q\left[1-(1-r)^{N-1}\right]\left[\pi^f(\underline{\theta}) - \pi^f(\varnothing)\right].\end{aligned}$$

To complete the proof of $r^f \leq \min\{r^p, r^o\}$, we observe that $r^f < 1 = r^o$ if $0 < \eta \leq \psi_0^f$, $r^f = 0 < r^o$ if $\psi_0^f < \eta < \psi_0^o$, and $r^f = r^o = 0$ for all other η.

Finally, we notice that for all $0 < \eta < \psi_0^p$: $0 < r^p < 1$. Consequently, for all $0 < \eta \leq \psi_0^f$ we have $r^o = 1 > r^p$, while for all $\psi_0^o \leq \eta < \psi_0^p$ investments are such that $r^o = 0 < r^p$. Continuity of marginal revenue functions $\psi^o(r)$ and $\psi^p(r)$ therefore gives the existence of values $\underline{\eta}'$ and $\overline{\eta}'$ immediately. □

A.6 Proof of Proposition 5 (Overall Profits)

First, expression (5.4) follows immediately from substitution of (5.1) in (3.8) for $\ell = f$, and (5.2) in (3.8) for $\ell = o$. Second, for $0 < \eta \leq \psi_0^f$, equilibrium information acquisition investments are such that $r^p \in (0,1)$. Hence, lemma 1 (i) implies that $\pi^p(\underline{\theta}) > \pi^f(\underline{\theta})$, and, consequently, we obtain:

$$\Pi^p(\mathbf{r}^p) = E\left\{\pi^p(\theta)\right\}|_{r=r^p} - \eta > E\{\pi^f(\theta)\} - \eta = \Pi^f(\mathbf{r}^f) = \Pi^o(\mathbf{r}^o). \tag{A.26}$$

Since $\Pi^p(\mathbf{r}^p)$ is continuous in η, there exists a critical value $\underline{\eta}^* > \psi_0^f$ such that $\Pi^p(\mathbf{r}^p) > \Pi^f(\mathbf{r}^f)$ for all $\eta < \underline{\eta}^*$.

Finally, for $\eta \in [\psi_0^f, \psi_0^p)$ we have: $\Pi^f(\mathbf{r}^f) = \Pi^o(\mathbf{r}^o) = \pi^f(\varnothing)$ and $\Pi^p(\mathbf{r}^p) = E\{\pi^p(\theta)|r^p\} - \eta$, with r^p such that $\eta = \psi^p(r)$. The first derivative of $\Pi^p(\mathbf{r}^p)$ to η equals:

$$\begin{aligned}\frac{d\Pi^p(\mathbf{r}^p)}{d\eta} &= q\frac{\partial \pi^p(\underline{\theta})}{\partial r} \cdot \left.\frac{dr^p}{d\eta}\right|_{r=r^p} - 1 = q\frac{\partial \pi^p(\underline{\theta})}{\partial r} \cdot \left.\frac{1}{d\psi^p(r)/dr}\right|_{r=r^p} - 1 \\ &= \left.\frac{-\partial \pi^p(\varnothing)/\partial r + \frac{(N-1)(1-\widetilde{q})}{1-r}\left[\pi^p(\varnothing) - \pi^p(\overline{\theta})\right]}{-d\psi^p(r)/dr \cdot \widetilde{q}/q}\right|_{r=r^p}, \end{aligned} \tag{A.27}$$

since $d\psi^p(r)/dr$ is as in expression (A.23). Using expressions (A.5) and (A.6) of lemma 1, we obtain the following:

$$\begin{aligned}\lim_{\eta\uparrow\psi_0^p} \frac{d\Pi^p(\mathbf{r}^p)}{d\eta} &= \frac{1}{-d\psi^p(0)/dr}\left.\left((N-1)(1-q)\left[\pi^p(\varnothing) - \pi^p(\overline{\theta})\right] - \frac{\partial \pi^p(\varnothing)}{\partial r}\right)\right|_{r=0} \\ &= \frac{q(1-q)(N-1)(\overline{\theta} - \underline{\theta})(\alpha - \overline{\theta})}{-d\psi^p(0)/dr \cdot 2(N+1)^2} > 0, \end{aligned} \tag{A.28}$$

since $d\psi^p(0)/dr < 0$, as was shown in the proof of proposition 4. Moreover, $\lim_{\eta\uparrow\psi_0^p} \Pi^p(\mathbf{r}^p) = \Pi^p(0,0) = \pi^f(\varnothing)$ and $\Pi^p(\mathbf{r}^p)$ is continuous in η. Hence, there exists a critical value $\overline{\eta}^* \in (\psi_0^f, \psi_0^p)$ such that $\Pi^p(\mathbf{r}^p) < \pi^f(\varnothing) = \Pi^f(\mathbf{r}^f)$ for all $\eta \in (\overline{\eta}^*, \psi_0^p)$. □

A.7 Proof of Proposition 6 (Overall Welfare)

(1) The comparison of expected welfare under full and no information sharing reduces to the comparison between expected consumers' surpluses, since $\Pi^f(\mathbf{r}^f) = \Pi^o(\mathbf{r}^o)$ for all η, as proposition 5 shows. First, consider the overall expected consumers' surplus for $0 < \eta \leq \psi_0^f$. In that case the expected overall consumers' surpluses reduce to:

$$\begin{aligned} CS^f(r^f) &= \frac{1}{2}N^2\left[\left(1-(1-r^f)^N\right)E\{x^f(\theta)^2\} + (1-r^f)^N x^f(\varnothing)^2\right] \\ &= \frac{1}{2}N^2\left[E\{\pi^f(\theta)\} - \eta\left(1-r^f\right)\right], \text{ and} \end{aligned} \tag{A.29}$$

$$CS^o(r^o) = CS^o(1) = \frac{1}{2}N^2 E\{\pi^f(\theta)\}. \tag{A.30}$$

Since $r^f < 1$ for $0 < \eta \leq \psi_0^f$, we obtain that $CS^f(r^f) < CS^o(r^o)$. Second, we compare expected consumers' surplus for $\psi_0^f < \eta < \psi_0^o$. In this case, no information is acquired under full disclosure, and consequently expected consumers' surplus equals: $CS^f(r^f) = CS^f(0) = \frac{1}{2}N^2 x^f(\varnothing)^2$. Hence, the difference in expected overall consumers' surpluses (A.29) and (A.30) can be rewritten to:

$$\begin{aligned} CS^f(r^f) - CS^o(r^o) &= \frac{1}{2}\sum_{m=0}^{N}\binom{N}{m}(r^o)^m(1-r^o)^{N-m} \cdot \\ &\quad \cdot \left(N^2 x^f(\varnothing)^2 - E\left\{\left[m x^o(\theta) + (N-m)x^o(\varnothing)\right]^2\right\}\right), \end{aligned} \tag{A.31}$$

where $N^2 x^f(\varnothing)^2 - E\left\{[m x^o(\theta)+(N-m)x^o(\varnothing)]^2\right\}$

$$\begin{aligned} &= N^2 x^f(\varnothing)^2 - E\left\{[N x^o(\varnothing)+m\left(x^o(\theta)-x^o(\varnothing)\right)]^2\right\} \\ &= -E\left\{m\left(x^o(\theta)-x^o(\varnothing)\right)\left[2N x^o(\varnothing)+m\left(x^o(\theta)-x^o(\varnothing)\right)\right]\right\} \\ &= -m^2 E\left\{[x^o(\theta)-x^o(\varnothing)]^2\right\} < 0, \text{ for all } r \text{ and } m>0. \end{aligned}$$

Since $r^o > 0$ for $\eta < \psi_0^o$, this implies: $CS^f(r^f) < CS^o(r^o)$ for $\psi_0^f < \eta < \psi_0^o$. Consequently, for all $0 < \eta \leq \psi_0^o$, we obtain: $W^f(r^f) < W^o(r^o)$. Clearly, for all $\eta \geq \psi_0^o$, firms acquire no information under both regimes, and therefore: $CS^f(r^f) = CS^o(r^o)$. **(2)** For $\psi_0^o < \eta < \psi_0^p$, $r^f = r^o = 0$, while $r^p > 0$ is such that $\psi^p(r^p) = \eta$. For such η welfare under precommitment equals: $W^o(0) = W^f(0) = \frac{1}{2}N(N+2)x^f(\varnothing)^2$. The expected welfare under partial disclosure approaches $W^o(0)$ if $\eta \to \psi_0^p$, i.e. $\lim_{\eta\uparrow\psi_0^p}\{W^p(r^p)\} = W^o(0)$. Hence, there exists a critical cost η^o such that $W^p(r^p) > W^o(0)$ for all $\eta^o < \eta < \psi_0^p$, if $\lim_{\eta\uparrow\psi_0^p}\{dW^p(r^p)/d\eta\} < 0$. We show in the remainder of the proof that this is the case if N is sufficiently big.

Since $\lim_{\eta\uparrow\psi_0^p} r^p = 0$, the first derivative of welfare with respect to the cost of information acquisition converges to:

$$\begin{aligned} \lim_{\eta\uparrow\psi_0^p}\frac{dW^p(r^p)}{d\eta} &= \lim_{\eta\uparrow\psi_0^p}\left(\frac{dr^p}{d\eta}\cdot\frac{dW^p(r^p)}{dr}\right) \\ &= \frac{1}{d\psi^p(0)/dr}\cdot\left(\frac{dCS^p(0)}{dr}+N\frac{d\Pi^p(0)}{dr}\right). \end{aligned} \tag{A.32}$$

The first derivative of consumers' surplus (3.14) with respect to the information acquisition investment can be rewritten to the following:

$$\begin{aligned} \frac{dCS^p(0)}{dr} &= -\frac{N^2}{2}\left(N(1-q)\left[\pi^p(\varnothing)-\pi^p(\overline{\theta})\right]-\frac{\partial\pi^p(\varnothing)}{\partial r}\right)\Bigg|_{r=0} \\ &\quad +\frac{1}{2}Nq\left[x^p(\underline{\theta})+(2N-1)x^p(\varnothing)\right]\left[x^p(\underline{\theta})-x^p(\varnothing)\right]\Bigg|_{r=0}. \end{aligned} \tag{A.33}$$

Combining this expression with profit derivative (A.28), we obtain the following:

$$\begin{aligned} \frac{dW^p(0)}{dr} &= -\frac{N}{2}[(N+2)(N-1)+N](1-q)\left[\pi^f(\varnothing)-\pi^f(\overline{\theta})\right] \\ &\quad +\frac{N}{2}\left((N+2)\frac{\partial\pi^p(\varnothing)}{\partial r}+q\left[x^o(\underline{\theta})+(2N-1)x^f(\varnothing)\right]\left[x^o(\underline{\theta})-x^f(\varnothing)\right]\right)\Bigg|_{r=0}. \end{aligned}$$

It is straightforward, though tedious, to rewrite this expression to the following:

$$\frac{dW^p(0)}{dr} = \frac{-Nq(1-q)(\overline{\theta}-\underline{\theta})}{8(N+1)^2}\left[4(3N-2)(\alpha-\overline{\theta})-M(N)(\overline{\theta}-\underline{\theta})\right], \tag{A.34}$$

where

$$M(N) \equiv 2(N+1) + (N-1)[2q(2N+1) + (1-q)(N+1)]. \tag{A.35}$$

Since $M(N)$ is quadratic in N, there exists a critical value N^o such that for all $N > N^o$: $dW^p(0)/dr > 0$. This, in combination with the fact that $d\psi^p(0)/dr < 0$, proves the proposition. □

A.8 Proof of Proposition 7 (Convex Costs)

First, we compare the expected overall profits under precommitment. For all cost parameters $\eta \leq \psi_0^f/c'(1)$ the equilibrium information acquisition are such that: $r^o = 1 > r^f$. Hence, the overall expected profits under precommitment are as follows:

$$\begin{aligned} \Pi^f(\mathbf{r}^f) &= E\left\{\pi^f(\theta)\right\} - (1-r^f)\psi^f(r^f) - \eta c(r^f), \\ \Pi^o(\mathbf{r}^o) &= \Pi^o(1,1) = E\left\{\pi^f(\theta)\right\} - \eta c(1). \end{aligned}$$

Since information acquisition investment r^f is such that $\psi^f(r^f) = \eta c'(r^f)$, we can rewrite the expected profit difference as follows:

$$\Pi^f(\mathbf{r}^f) - \Pi^o(\mathbf{r}^o) = \eta \cdot \left[c(1) - c(r^f) - (1-r^f)c'(r^f)\right], \tag{A.36}$$

which is positive if $c(.)$ is strictly convex in r. The existence of critical value $\eta^c \geq \psi_0^f/c'(1)$ follows immediately from continuity of the profit difference in η.

Second, for the comparison of the overall expected equilibrium profits under partial and full information sharing we analyze these profits as functions of cost parameter η for $N = 2$. From (6.1) we obtain that for all $\eta > 0$ and $\ell \in \{f, p\}$:

$$\Pi^\ell(\mathbf{r}^\ell) = E\left\{\pi^\ell(\theta)\right\}\Big|_{r=r^\ell} - (1-r^\ell)\psi^\ell(r^\ell) - \eta c(r^\ell).$$

Clearly, $\lim_{\eta\to 0}\Pi^f(\mathbf{r}^f) = \lim_{\eta\to 0}\Pi^p(\mathbf{r}^p) = E\left\{\pi^f(\theta)\right\}$, since $\lim_{\eta\to 0} r^f = \lim_{\eta\to 0} r^p = 1$.

First derivatives of expected profits with respect to cost parameter η reduce to:

$$\frac{d\Pi^f(\mathbf{r}^f)}{d\eta} = -(1-r^f)\frac{dr^f}{d\eta}\cdot\frac{d\psi^f(r^f)}{dr} - c(r^f), \text{ and} \tag{A.37}$$

$$\frac{d\Pi^p(\mathbf{r}^p)}{d\eta} = \frac{dr^p}{d\eta}\cdot\left(q\,\frac{\partial \pi^p(\underline{\theta})}{\partial r}\bigg|_{r=r^p} - (1-r^p)\frac{d\psi^p(r^p)}{dr}\right) - c(r^p). \tag{A.38}$$

Application of the envelop theorem to identity $\psi^\ell(r^\ell) = \eta c'(r^\ell)$ gives:

$$\frac{dr^\ell}{d\eta} = \frac{c'(r^\ell)}{d\psi^\ell(r^\ell)/dr - \eta c''(r^\ell)}, \tag{A.39}$$

where, for $N = 2$, $d\psi^f/dr = -\psi_0^f$ and $d\psi^p/dr$ as in (A.23), with $\widetilde{q}/q = [q + (1 - q)(1-r)]^{-1}$. Clearly, $d\psi^f(1)/dr$ is finite and negative, and also $d\psi^p(1)/dr$ is finite and negative, as follows from (A.24). This implies that $\lim_{\eta\to 0} dr^\ell/d\eta = c'(1)\cdot\left[d\psi^\ell(1)/dr\right]^{-1} < 0$ and is finite for $\ell \in \{f,p\}$. Moreover, $\lim_{\eta\to 0}\left(\partial\pi^p(\underline{\theta})/\partial r|_{r=r^p}\right) = \partial\pi^p(\underline{\theta})/\partial r|_{r=1} = 0$, as follows from (A.4). Hence, $\lim_{\eta\to 0} d\Pi^f(\mathbf{r}^f)/d\eta = \lim_{\eta\to 0} d\Pi^p(\mathbf{r}^p)/d\eta = -c(1) < 0$.

Finally, the second order derivative of $\Pi^f(\mathbf{r}^f)$ with respect to η is as follows:

$$\frac{d^2\Pi^f(\mathbf{r}^f)}{d\eta^2} = \frac{dr^f}{d\eta}\cdot\left(\frac{dr^f}{d\eta}\cdot\frac{d\psi^f(r^f)}{dr} - c'(r^f)\right) - (1-r^f)\frac{d^2r^f}{d\eta^2}\cdot\frac{d\psi^f(r^f)}{dr}, \tag{A.40}$$

since $d^2\psi^f/dr^2 = 0$ for any r. Using expression (A.39), we derive the following:

$$\frac{d^2r^\ell}{d\eta^2} = \frac{dr^\ell}{d\eta}\cdot\frac{\left(1+\frac{dr^\ell}{d\eta}\right)c''(r^\ell) - \frac{dr^\ell}{d\eta}\left[d^2\psi^\ell(r^\ell)/dr^2 - \eta c'''(r^\ell)\right]}{d\psi^\ell(r^\ell)/dr - \eta c''(r^\ell)}, \tag{A.41}$$

for $\ell \in \{f,p\}$. For $\eta \to 0$ we have: $\lim_{\eta\to 0} d^2r^f/d\eta^2 = c'(1)\left(\psi_0^f + c'(1)\right)c''(1)\Big/\left(\psi_0^f\right)^3$, which is positive and finite, and therefore (A.40) yields $\lim_{\eta\to 0} d^2\Pi^f(\mathbf{r}^f)/d\eta^2 = 0$. The second order derivative of $\Pi^p(\mathbf{r}^p)$ with respect to η is as follows:

$$\begin{aligned}\frac{d^2\Pi^p(\mathbf{r}^p)}{d\eta^2} &= \frac{dr^p}{d\eta}\cdot\left(\frac{dr^p}{d\eta}\cdot\frac{d\psi^p(r^p)}{dr} - (1-r^p)\frac{dr^p}{d\eta}\cdot\frac{d^2\psi^p(r^p)}{dr^2} - c'(r^p)\right)\\ &+\frac{d^2r^p}{d\eta^2}\cdot\left(q\left.\frac{\partial\pi^p(\underline{\theta})}{\partial r}\right|_{r=r^p} - (1-r^p)\frac{d\psi^p(r^p)}{dr}\right) + q\left(\frac{dr^p}{d\eta}\right)^2\left.\frac{\partial^2\pi^p(\underline{\theta})}{\partial r^2}\right|_{r=r^p},\end{aligned}$$

where (A.23) yields

$$\frac{d^2\psi^p(r)}{dr^2} = q\frac{\partial^2\pi^p(\underline{\theta})}{\partial r^2} - [q+(1-q)(1-r)]\frac{\partial^2\pi^p(\varnothing)}{\partial r^2} + 2(1-q)\frac{\partial\pi^p(\varnothing)}{\partial r}.$$

It is straightforward to show that $d^2\psi^p(1)/dr^2$ is finite. These observations imply that: $\lim_{\eta\to 0} d^2\Pi^p(\mathbf{r}^p)/d\eta^2 = \lim_{\eta\to 0} q\left(\frac{dr^p}{d\eta}\right)^2\left.\frac{\partial^2\pi^p(\underline{\theta})}{\partial r^2}\right|_{r=r^p} = q\left(\lim_{\eta\to 0}\frac{dr^p}{d\eta}\right)^2\left.\frac{\partial^2\pi^p(\underline{\theta})}{\partial r^2}\right|_{r=1} > 0$. Hence, $\lim_{\eta\to 0} d^2\Pi^p(\mathbf{r}^p)/d\eta^2 > \lim_{\eta\to 0} d^2\Pi^f(\mathbf{r}^f)/d\eta^2$, which, in combination with $\lim_{\eta\to 0} d\Pi^p(\mathbf{r}^p)/d\eta = \lim_{\eta\to 0} d\Pi^f(\mathbf{r}^f)/d\eta < 0$ and continuity of $d\Pi^\ell(\mathbf{r}^\ell)/d\eta$ for $\ell \in \{f,p\}$, implies that there exists a critical cost parameter $\eta^s > 0$ such that for all $\eta \le \eta^s$: $d\Pi^p(\mathbf{r}^p)/d\eta < \Pi^f(\mathbf{r}^f)/d\eta < 0$. This, in turn (in combination with $\lim_{\eta\to 0}\Pi^p(\mathbf{r}^p) = \lim_{\eta\to 0}\Pi^f(\mathbf{r}^f)$ and continuity of $\Pi^p(\mathbf{r}^p)$ and $\Pi^f(\mathbf{r}^f)$), implies: $\Pi^p(\mathbf{r}^p) > \Pi^f(\mathbf{r}^f)$ for all $\eta \le \eta^s$. $\square$

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