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The Effects of Disclosure Regulation on Innovative Firms: Common Values

Jos Jansen

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Wissenschaftszentrum Berlin für Sozialforschung gGmbH,
Reichpietschufer 50, 10785 Berlin, Germany, Tel. (030) 2 54 91 – 0
Internet: www.wz-berlin.de

ABSTRACT

The Effects of Disclosure Regulation on Innovative Firms: Common Values*

by Jos Jansen

Firms in an R&D race actively manage rivals' beliefs by disclosing and concealing information on their cost of investment. The firms' disclosure strategies affect their incentives to invest in R&D, and to acquire information. We compare equilibria under voluntary disclosure with those under mandated disclosure in a model with perfect positive correlation among the firms' cost of investment. Under voluntary disclosure firms disclose bad news, and conceal good news to discourage their rival. Under mandatory disclosure firms typically expect higher profits for given information acquisition investments, but they acquire less information.

Keywords: R&D competition, information acquisition, disclosure regulation

JEL Classification: D83, L23, O31, O32

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ZUSAMMENFASSUNG

Die Wirkung von Offenlegungsvorschriften auf innovative Firmen: Perfekt korrelierte Werte

Unternehmen, welche an einem F&E -Wettbewerb teilnehmen, managen aktiv die Erwartungen ihrer Konkurrenten, indem sie gezielt entscheiden, ob sie Informationen über ihre Investitionskosten veröffentlichen oder geheim halten. Durch ihre Offenlegungsstrategien beeinflussen sie sowohl die Anreize Ihrer Konkurrenten, Informationen zu sammeln, wie auch deren Anreize, F&E zu betreiben. Anhand eines Modells mit vollständig positiver Korrelation zwischen den Investitionskosten der Unternehmen vergleicht der Beitrag Gleichgewichte in denen die Unternehmen freiwillig wählen, ob sie ihre Informationen offen legen wollen, mit den Gleichgewichten, bei denen Unternehmen ihre Information offen legen müssen. Bei freiwilliger Offenlegung veröffentlichen Unternehmen schlechte Nachrichten und behalten gute für sich, um Mitbewerber zu entmutigen. Bei Offenlegungspflicht erwarten Unternehmen typischerweise höhere Gewinne für vorgegebene Investitionen in Informationskosten, aber sie beschaffen sich weniger Information.

1 Introduction

A basic property of research and development (R&D) is that it generates information for the firms that invest in it. Usually this information is private to the firms and is acquired at a cost. Disclosure or concealment of such intermediate information by competing research labs can have conflicting effects on R&D competition. It is therefore not obvious what incentives firms have to disclose information, and consequently how much firms want to invest in the acquisition of information. This paper, and companion paper Jansen (2001b), discusses what disclosure incentives the firms have, and what effects disclosure regulation has on investments and profits.

For some innovations firms aggressively preannounce their new products to discourage rivals. For example, in the operating system market many people claim that Microsoft (MS) is using preannouncements of its operating system upgrades to drive competition out of their market.[1] Disclosing good news about MS's capabilities of introducing a new product in the market quickly, discourages rivals to invest in developing competing products. The progress of one firm in the race gives the leading firm a strategic advantage, which discourages its rivals to invest in the innovation, e.g. see Grossman and Shapiro (1987), and Harris and Vickers (1987). This is a "strategic effect". If firms can disclose that they made an early intermediate discovery without revealing the contents of their discovery, they would do so. Disclosing good news and concealing bad news makes your rival believe that he is facing a strong R&D competitor, which discourages him.

In other industries we can observe an effect of intermediate information disclosure that conflicts with the strategic effect. For fundamental innovations, for which firms do not have a clear idea of their costs of investment, disclosure of intermediate successes can encourage rival firms to invest. An example of this type of behavior is provided by the responses to major breakthroughs in the development of cold superconductivity and biotechnology.[2] Here one firm's intermediate success gives not only an indication of this firm's capabilities of developing the new product, but also of that of its rivals. Good news for one firm is good news for the whole industry. Then news

[1] See e.g. Lopatka and Page (1995), Prentice (1996), Shapiro (1996), United States v. Microsoft, Civil Action No. 94-1564, and Shapiro and Varian (1999). An extensive anacdotical report on Microsoft's strategies is presented in Wallace and Erickson (1992).

[2] The example of superconductivity is discussed by Choi (1991). For the biotech industry Austin (1993) claims that: "about one-third of the excess return for a WSJ patent (...) may be due to the market's revising upward its valuations of *all* (non-rival) biotechnology firms in the wake of one firm's good patent news."

on the R&D progress by one firm makes all firms more optimistic, and more willing to invest. This is an "informational effect". But when favorable information for one firm also encourages rivals to invest in the project, the firm might want to prevent its rivals from learning this information. Firms would conceal good news about their research progress, and disclose only bad news. Concealing good news and disclosing bad news makes your rivals believe that the industry has high costs of investment, which discourages their investments.

Note that the strategic and informational effect lead to conflicting incentives to disclose information about one's costs of investment. We study the interaction between the two effects in this paper. R&D races are typically contests in which firms learn. Information is actively and endogenously acquired in R&D races. Information need not always flow freely between firms. In many situations firms actively manage the flow of information that they generate. This adds a new dimension to the firms' strategies. The main contribution of this paper is that it provides a theory on firms' incentives to strategically disclose acquired information to rivals. We analyze the trade-off between the incentives to acquire, disclose and further build upon information in an R&D race. As far as I know this has never been done in the literature. Furthermore we discuss the consequences of disclosure regulation. We distinguish between the policy of mandatory and voluntary disclosure, and study their consequences for firms' investments and expected profits.

When correlation between firms' costs of investments is positive, both the informational and strategic effect emerge after disclosure of information. For perfect positive correlation between costs of investments we show that the informational effect dominates the strategic effect in most cases. Firms disclose bad news, and conceal good news to make their rival as pessimistic about costs of investment as possible. There are, however, also special cases in which the strategic effect is more powerful.

The companion paper Jansen (2001b) analyzes the model with independently distributed costs of investment, and studies the consequences of disclosure regulation for investments and profits. With independent costs the informational effect disappears, while the strategic effect remains. Disclosure of good news and concealment of bad news makes rivals expect strong R&D competitors, without affecting their cost expectations. Note that the firms' equilibrium disclosure rule under independently distributed costs is typically exactly the opposite of that under perfect positive correlation.

Related literature: Contests in which firms learn after investing are studied by Hendricks and Kovenock (1989), Choi (1991). These papers assume that information flows freely between competing firms. We show in this paper whether full information disclosure is compatible with the firms incentives, and whether it is desirable for firms.

Recent papers, such as Katsoulacos and Ulph (1998), Gosálbez and Díez (2000), and Rosenkranz (2001), study information disclosure incentives in research joint ventures. Although these studies provide valuable insights in the incentives for information disclosure by innovative firms, they focus on the effects of cooperation between firms. We study the incentives to disclose information in a competitive setting, and focus on the effects of disclosure regulation.

A powerful result in the theory of strategic disclosure of verifiable information is the "unraveling result". Seminal contributions by Grossman (1981), Milgrom (1981), Milgrom and Roberts (1986), and Okuno-Fujiwara *et al.* (1990) study this result. When it is known that the sender of information is informed, and information is costlessly verifiable, he cannot do better than disclose his information, given skeptical equilibrium beliefs of the receiver. This result relies on the assumptions that information is costlessly verifiable and that it is known that the sender is informed. Uncertainty about whether or not the sender is informed and non-verifiability of uninformedness disables the unraveling result in most cases. Austen-Smith (1994) shows that when the receiver is uncertain about the informedness of the sender, the sender can conceal some of his information in equilibrium. In equilibrium good news is disclosed while bad news is concealed from the receiver. This argument is generalized and refined by Shin (1994). Krishnan *et al.* (1996) provide empirical evidence that firms partially disclose earnings information to the financial market. We will use a similar framework of uncertain informedness to study strategic disclosure by racing R&D laboratories.

The incentives to acquire and disclose information have been studied in firm-financial market (see Verecchia, 1990), buyer-seller (see Shavell, 1994) and lobbyist-government (see Lagerlöf, 1997) settings. These papers endogenize the degree of informedness of the sender, but abstract from competition between senders. Papers in which firms strategically disclose information under competition are Admati and Pfleiderer (2000), Dewatripont and Tirole (1999), and Shin (1998). The setup of these papers, however, is such that senders disclose or conceal information to a third party. Both Shavell (1994) and Admati and Pfleiderer (2000) are interested in the effects of disclosure regulation. This is a main theme of this paper too. While Shavell (1994) studies a model with endogenous information acquisition, but ignores the effects of competition, Admati and Pfleiderer study the effects of competition with exogenous information. This paper studies the effects of disclosure regulation on R&D competition and information acquisition.

Our main contribution to the literature is to give an overall analysis of the interaction between incentives for strategic information acquisition, disclosure, and subsequent R&D investment. Information is endogenous in two respects: first, firms invest in the acquisition of information, and, second, firms strategically manage information disclosure.

The paper is organized as follows. In the next section we describe the model. In the third section we characterize the benchmark outcome in which firms maximize joint profits. Section 4 gives the equilibrium strategies of the game for mandatory disclosure, and compares these equilibrium strategies with those in the benchmark. The fifth section discusses the equilibrium investments and disclosure rules when firms voluntarily disclose information, and compares these investments with those under mandated disclosure. In section 6 we perform an overall expected profit comparison between mandated and voluntary disclosure equilibria. Finally, section 7 discusses the results, and section 8 concludes the paper. All proofs are relegated to the Appendix.

2 The Model

Two firms use similar techniques to obtain the innovation. Therefore the firms' costs of R&D investment are perfectly positively correlated. At the beginning of the race firms do not know their cost of investment θ. The firms have either low or high costs of investment, i.e. $\theta \in \{\underline{\theta}, \overline{\theta}\}$ with $0 < \underline{\theta} < \overline{\theta}$. The probability of investing in a project with low (resp. high) cost is p (resp. $1-p$), with $0 < p < 1$.

Firms can learn about the cost of R&D investment by acquiring information in the first stage of the race. In this stage firms choose their information acquisition investments, $R_i \in [0,1]$ for firm i, simultaneously. Information acquisition investments are not observable. Firm i's rival expects investments r_i of firm i. Costs of information acquisition are strictly convex and increasing in investment: $c(R_i) = \frac{1}{2}\rho R_i^2$, with $\rho > 0$ for $i = 1, 2$. After investing in information acquisition each firm receives a signal, Θ_i for firm i, about its cost of R&D investment. With probability R_i firm i learns its true cost of investment, $\Theta_i = \theta$. However, with probability $1 - R_i$ firm i 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 information acquisition stage is summarized in figure 1 below.

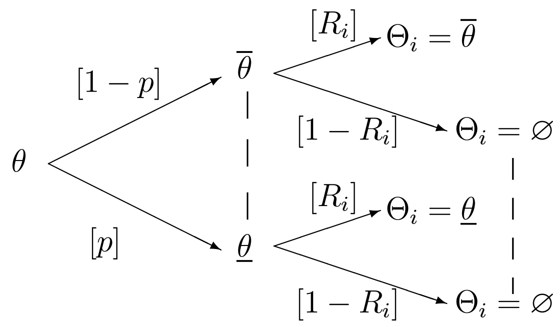

Figure 1: Firm i's information acquisition stage

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 θ, it can choose to either disclose or conceal this, i.e. the firm chooses its communication $\delta_i(\theta)$ from the set $\{\theta, \varnothing\}$. An uninformed firm can only state $\delta_i(\varnothing) = \varnothing$. It therefore suffices to denote firm i's disclosure rule as $(\delta_i(\underline{\theta}), \delta_i(\overline{\theta}))$. We denote the realization of rule $\delta_i(.)$ as δ_i^*, with $\delta_i^* \in \{\delta_i(\Theta_i)|\Theta_i \in \{\underline{\theta}, \overline{\theta}, \varnothing\}\}$. That is, δ_i^* is the message from firm i to j, for $i, j = 1, 2$ and $i \neq j$

In the second stage firms invest in developing their innovation by investing $D_i \in [0, 1]$ for firm i. Costs of R&D investment increase in investment and cost parameter θ: $C(D_i; \theta) = \frac{1}{2}\theta D_i^2$. With probability D_i firm i invents a product, with probability $1 - D_i$ it invents nothing. In this paper we study a "winner-take-all" race. A firm gets payoff W, when it is the only firm that invents. When both firms are successful, both firms receive payoff T. When a firm does not invent a new product, it gets no payoff. Naturally, we take $W \geq 2T \geq 0$. Define $\Delta \equiv W - T$ as the prize difference between winning and tying in the race. Because T is non-negative and cannot exceed $\frac{1}{2}W$, we obtain that $\frac{1}{2}W \leq \Delta \leq W$. For convenience we assume that $\underline{\theta} > 2\Delta$, since this enables us to focus on interior R&D investment solutions.

Firms are risk-neutral. Given the cost of investment θ, and sunk costs of information acquisition investments, firm i's expected R&D profit is:

$$\pi_i(\mathbf{D}; \theta) = D_i(1 - D_j)W + D_i D_j T - \frac{1}{2}\theta D_i^2 = D_i(W - D_j\Delta) - \frac{1}{2}\theta D_i^2, \qquad (2.1)$$

with $\mathbf{D} = (D_i, D_j)$. We solve the game backwards, and restrict the analysis to symmetric, pure strategy equilibria.

3 Benchmark: Joint-Profit-Maximization

In this section we solve for the joint-profit-maximizing outcome of the race. Note that for joint profits full disclosure is never worse than any other disclosure rule — firms can always choose to ignore certain disclosed information. It is therefore optimal to take $\delta_i(\Theta_i) \equiv \Theta_i$ for $i = 1, 2$. First we derive the joint-profit-maximizing R&D investments for any given combination of information acquisition investments. Second we analyze the information acquisition investments that maximize joint profits.

3.1 Joint-Profit-Maximizing R&D

In this subsection we derive the joint-profit-maximizing R&D investments, given full information disclosure and any information acquisition investments.

Since the costs of R&D investment are perfectly positively correlated, firms learn about their own cost of investment from their own acquired signal, and from disclosed information by their rival. We distinguish two cases. The first case is one in which firms invest under complete information. Whenever one of the firms receives an informative signal, both firms are fully informed about their cost of investment. For firms with cost θ we denote this case by $\Theta = \theta$. Formally we have:

$$\Theta = \theta, \text{ if } (\Theta_i, \Theta_j) \in \{(\theta, \theta), (\theta, \varnothing), (\varnothing, \theta)\}, \text{ for } \theta \in \{\underline{\theta}, \overline{\theta}\}. \tag{3.1}$$

Second, there is the no-information case, denoted by $\Theta = \varnothing$, if $(\Theta_i, \Theta_j) = (\varnothing, \varnothing)$. In this case firms cannot update beliefs about R&D costs, and maximize joint *ex ante* profits. The expected cost parameter is:

$$\theta^E(\Theta) = \begin{cases} \theta, \text{ if } \Theta = \theta, \text{ for } \theta \in \{\underline{\theta}, \overline{\theta}\}, \text{ and} \\ E(\theta) \equiv p\underline{\theta} + (1-p)\overline{\theta}, \text{ if } \Theta = \varnothing. \end{cases} \tag{3.2}$$

Total expected R&D profit, given case Θ, is:

$$E_\theta\left\{\sum_{\ell=1}^{2} \pi_\ell(\mathbf{D};\theta)\middle|\,\Theta\right\} = W\sum_{\ell=1}^{2} D_\ell - 2\Delta D_i D_j - \frac{1}{2}\theta^E(\Theta)\sum_{\ell=1}^{2} D_\ell^2. \tag{3.3}$$

Maximizing this profit with respect to D_i gives the following R&D investment, $\overline{D}_i$ for firm i:

$$\overline{D}_i(\Theta) = \frac{W}{\theta^E(\Theta) + 2\Delta}, \text{ for } i = 1, 2. \tag{3.4}$$

Note that the firms' R&D investments decrease in their expected cost parameter $\theta^E(\Theta)$. The more pessimistic firms are about their costs of investment the less they invest in obtaining the innovation. Firm i's maximum expected R&D profit is as follows:

$$\overline{\pi}_i(\Theta) \equiv E_\theta \left(\pi_i(\overline{\mathbf{D}};\theta)\,|\Theta\right) = \frac{1}{2}W\overline{D}_i(\Theta), \text{ for } i = 1, 2. \tag{3.5}$$

3.2 Joint-Profit-Maximizing Information Acquisition

In the first stage of the race firms choose information acquisition investments. By doing so, they choose the probability of getting informed about their cost of R&D investment. The total expected profit, given information acquisition investments (R_i, R_j), and R&D investments $(\overline{D}_i, \overline{D}_j)$, is:

$$\begin{aligned}\sum_{\ell=1}^{2}\Pi_\ell(R_i,R_j) &= [1-(1-R_i)(1-R_j)]\sum_{\ell=1}^{2}E\left\{\overline{\pi}_\ell(\theta)\right\}+ \\ &+(1-R_i)(1-R_j)\sum_{\ell=1}^{2}\overline{\pi}_\ell(\varnothing)-\frac{1}{2}\rho\sum_{\ell=1}^{2}R_\ell^2.\end{aligned} \tag{3.6}$$

First assume that it maximizes total profits to have only firm i acquiring information. Joint profit maximization results in first-order condition: $\rho R_i \leq \overline{\Psi}$, where:

$$\overline{\Psi} \equiv \sum_{\ell=1}^{2}[E\{\overline{\pi}_\ell(\theta)\} - \overline{\pi}_\ell(\varnothing)] = E\left\{\frac{W^2}{\theta+2\Delta}\right\} - \frac{W^2}{E(\theta)+2\Delta}, \tag{3.7}$$

and $\overline{\Psi} > 0$.[3]. This first-order condition is sufficient for all $0 < \rho < \overline{\Psi}$, which gives joint-profit-maximizing investment $\overline{R}_i = 1$. For $\rho \geq \overline{\Psi}$ total profits are maximized when both firms invest in information acquisition. Maximization with respect to R_i gives first-order condition $\rho R_i = (1-R_j)\overline{\Psi}$. Joint-profit-maximizing information acquisition investments are determined by the trade-off between the marginal cost of investment, ρR_i, and the expected marginal revenue of becoming informed. This marginal revenue is the total expected profit added to the industry from becoming informed instead of remaining uninformed. The joint-profit-maximizing information acquisition investments are (for $i, j = 1, 2$ and $i \neq j$):

$$(\overline{R}_i, \overline{R}_j) = \begin{cases} (1,0), \text{ for all } 0 < \rho < \overline{\Psi}, \\ \left(\frac{\overline{\Psi}}{\rho+\overline{\Psi}}, \frac{\overline{\Psi}}{\rho+\overline{\Psi}}\right), \text{ otherwise.}\end{cases} \tag{3.8}$$

[3]Since the function $f(\theta) = \frac{1}{\theta+2\Delta}$ is strictly convex for all $\theta > 0$, $E\{f(\theta)\} > f(E\{\theta\})$. And therefore $\overline{\Psi} > 0$.

4 Mandatory Disclosure Equilibrium

In this section we study the equilibrium in which noncooperative firms are required to disclose their information (Θ_i, Θ_j). Such a disclosure regulation could be implemented by the threat of severe penalties after withholding of information is discovered. Observe that the only difference between the benchmark and this case is that firms do not coordinate their information acquisition and R&D investment choices.

4.1 Mandatory Disclosure R&D Equilibrium

Equilibrium R&D investments are determined by the trade-off between marginal revenues and costs of R&D investment. Firm i's first-order condition of profit maximization with respect to investment D_i, given Θ and D_j, is as follows:

$$\theta^E(\Theta)D_i = W - \Delta D_j, \text{ for } i = 1, 2. \tag{4.1}$$

Both firms' first-order conditions for profit maximization give the following equilibrium investments:

$$\widehat{D}_i(\Theta) = \frac{W}{\theta^E(\Theta) + \Delta}, \text{ for } i = 1, 2. \tag{4.2}$$

Again equilibrium investments decrease in the expected costs of R&D. Note that these equilibrium investments are greater than the joint-profit-maximizing investments $\overline{D}_i(\Theta)$. Competing firms do not internalize the adverse effect that an increase in their R&D investment has on the chances of their rival to win the race. Therefore firms overinvest in R&D. This is a standard observation in R&D races where investments are strategic substitutes. Firm i's expected equilibrium profits are as follows:

$$\widehat{\pi}_i(\Theta) = \frac{1}{2}\theta^E(\Theta)\widehat{D}_i(\Theta)^2, \text{ for } \Theta \in \{\underline{\theta}, \overline{\theta}, \varnothing\} \tag{4.3}$$

4.2 Mandatory Disclosure Information Acquisition

Firm i chooses information acquisition investment R_i such that it maximizes its expected profit, given the equilibrium information acquisition investment of the rival firm, $\widehat{R}_j$, and anticipating equilibrium R&D investments, $(\widehat{D}_i, \widehat{D}_j)$. Firm i's expected revenue of learning cost of investment, $\Theta_i = \theta$, is $E\{\widehat{\pi}_i(\theta)\}$. Its expected revenue of receiving an uninformative signal, $\Theta_i = \varnothing$, is $R_j E\{\widehat{\pi}_i(\theta)\} + (1 - R_j)\widehat{\pi}_i(\varnothing)$. The marginal revenue of obtaining an informative signal for firm i is therefore $(1-R_j)\widehat{\Psi}$, where:

$$\widehat{\Psi} \equiv E\{\widehat{\pi}_i(\theta)\} - \widehat{\pi}_i(\varnothing) = \frac{1}{2}W^2\left(E\left\{\frac{\theta}{(\theta+\Delta)^2}\right\} - \frac{E(\theta)}{(E(\theta)+\Delta)^2}\right). \tag{4.4}$$

Note that the firm's marginal revenue of information acquisition decreases in the probability with which its rival is informed.[4] The higher the likelihood that firm j is informed, the lower firm i's incentive to invest in information acquisition itself. The firms' second-order conditions for profit maximization are satisfied for all $\rho > 0$. Firm i's equilibrium information acquisition investments are such that marginal cost of investment equals its marginal revenue:

$$\rho R_i = (1-R_j)\widehat{\Psi}, \text{ or } \widehat{R}_i = \frac{\widehat{\Psi}}{\rho+\widehat{\Psi}}. \tag{4.5}$$

When we compare these equilibrium investments with the joint-profit-maximizing information acquisition investments, we obtain the following. Since each firm's information acquisition investment only contributes to its profit when its rival did not acquire information, each firm free-rides on the information acquired by its rival. Joint-profit-maximizing information acquisition investments internalize this externality. This is stated in the proposition below.

Proposition 1 *In equilibrium under mandatory disclosure firms:*
(i) overinvest in R&D, i.e. $\widehat{D}_i(\Theta) > \overline{D}_i(\Theta)$ *for all* Θ *and* $i = 1, 2$*;*
(ii) remain uninformed with a higher probability than coordinating firms,
i.e. $(1-\widehat{R}_1)(1-\widehat{R}_2) > \left(1-\overline{R}_1\right)\left(1-\overline{R}_2\right)$.

The result of proposition 1 (ii) is the opposite of the result obtained in companion paper Jansen (2001b). If costs of investment are independently distributed, firms cannot free-ride on their rival's information acquisition, and overinvest in information acquisition.

5 Voluntary Disclosure

In the preceding sections firms were required to disclose their information. This section studies the equilibria in which firms disclose information voluntarily. Since

[4] Since the function $g(\theta) = \frac{\theta}{(\theta+\Delta)^2}$ is strictly convex for all $\theta > 2\Delta$, $E\{g(\theta)\} > g(E(\theta))$, and hence $\widehat{\Psi} > 0$.

firms' costs of investment are perfectly positively correlated the informational effect is strongest. Therefore the firms' incentives to conceal good news while disclosing bad news are strongest in this case. We focus on the implications of this disclosure rule for R&D investments, and derive conditions under which concealment of good news and disclosure of bad news is indeed an equilibrium disclosure rule. Subsequently we determine the equilibrium information acquisition investments given the disclosure of bad news and concealment of good news.

5.1 Voluntary Disclosure R&D Equilibrium

In this subsection we characterize firms' R&D investments under partial disclosure. Both firms conceal good news, $\delta_i(\underline{\theta}) = \varnothing$, while they disclose bad news, $\delta_i(\overline{\theta}) = \overline{\theta}$, with $i = 1, 2$. Firms expect information acquisition investments (r_i, r_j).

We first determine the equilibrium beliefs. Since firms' costs of R&D investments are perfectly correlated, there is only incomplete information between firms when neither firm disclosed any information. Obviously, when one firm disclosed high costs of investments, both firms expect $\theta = \overline{\theta}$, and invest $\widehat{\mathbf{D}}(\overline{\theta})$ accordingly. When neither firm discloses, $(\delta_i^*, \delta_j^*) = (\varnothing, \varnothing)$, firms are in one of the following two situations. When firm i receives signal $\Theta_i = \underline{\theta}$, it knows that its costs of R&D investments are low. A firm that receives an uninformative signal, $\Theta_i = \varnothing$, and faces a rival who does not disclose information, $\delta_i^* = \varnothing$, knows that nobody received a high-cost signal. Its rival is either uninformed or conceals a low cost signal. Given this inference and given expected information acquisition investments, r_j, firm i updates its cost expectations by Bayes' rule, which gives the following:

$$\begin{aligned}\Pr[\theta = \underline{\theta} | \delta_j^* = \varnothing] &= \frac{\Pr[\Theta_j \neq \overline{\theta} | \theta = \underline{\theta}] \Pr[\theta = \underline{\theta}]}{\Pr[\Theta_j \neq \overline{\theta} | \theta = \underline{\theta}] \Pr[\theta = \underline{\theta}] + \Pr[\Theta_j \neq \overline{\theta} | \theta = \overline{\theta}] \Pr[\theta = \overline{\theta}]} \\ &= \frac{p}{p + (1 - r_j)(1 - p)} \equiv \alpha_j. \end{aligned} \tag{5.1}$$

Therefore the expected cost of R&D is as follows:

$$E_i(\theta | \varnothing, \varnothing) \equiv E_i(\theta | \Theta_i = \varnothing, \delta_j^* = \varnothing) = \alpha_j \underline{\theta} + (1 - \alpha_j) \overline{\theta}. \tag{5.2}$$

Firm i's belief about firm j's private signal is as follows:

$$\Pr[\Theta_j = \underline{\theta} | \delta_j^* = \varnothing] = \frac{\Pr[\Theta_j = \underline{\theta}]}{\Pr[\Theta_j = \underline{\theta}] + \Pr[\Theta_j = \varnothing]} = \frac{p r_j}{p r_j + 1 - r_j} = \alpha_j r_j. \tag{5.3}$$

If no information is disclosed, firms update their beliefs, and maximize expected profits, which results in the following first-order conditions:

$$\begin{aligned} \underline{\theta}\widetilde{D}_i(\underline{\theta}) &= W - \left(r_j\widetilde{D}_j(\underline{\theta}) + (1-r_j)\widetilde{D}_j(\varnothing)\right)\Delta \qquad (5.4)\\ E_i(\theta|\varnothing,\varnothing)\widetilde{D}_i(\varnothing) &= W - \left(\alpha_j r_j\widetilde{D}_j(\underline{\theta}) + (1-\alpha_j r_j)\widetilde{D}_j(\varnothing)\right)\Delta, \qquad (5.5) \end{aligned}$$

for $i, j = 1, 2$ and $i \neq j$. The solution to this system of linear equations, gives us the four equilibrium R&D investments.

The equilibrium R&D investments of informed firms with low-cost signal, $\widetilde{D}_i(\underline{\theta}; r_i, r_j)$, have the following property. When your rival invests relatively little in information acquisition, you assign relatively low probability to facing an informed, aggressive rival. This gives you a relatively bigger incentive to invest in R&D. The firm that is expected to have invested more (resp. less) in information acquisition, invests more (resp. less) in R&D:

$$\widetilde{D}_i(\underline{\theta}; r_i, r_j) > \widetilde{D}_j(\underline{\theta}; r_j, r_i) \Leftrightarrow r_i > r_j, \qquad (5.6)$$

for $i, j = 1, 2$ and $i \neq j$.

For uninformed firms the reverse holds. When your rival expects that you invested relatively little in information acquisition, this has two effects. On the one hand your rival expects you to become relatively less pessimistic after receiving no information. This gives you a strategic advantage compared to your rival, and increases your incentives to invest in R&D. On the other hand your rival expects to face an uninformed firm relatively more often. This encourages your rival to invest in R&D. The former cost effect dominates the latter competition effect. Therefore an uninformed firm that is expected to invest relatively little in information acquisition invests more aggressively in R&D under partial disclosure:

$$\widetilde{D}_i(\varnothing; r_i, r_j) > \widetilde{D}_j(\varnothing; r_j, r_i) \Leftrightarrow r_i < r_j, \qquad (5.7)$$

for $i, j = 1, 2$ and $i \neq j$.

With symmetric expected information acquisition investments, i.e. $r_i = r$ for $i = 1, 2$, the equilibrium R&D investments under partial disclosure are such that $\widetilde{D}_i(\underline{\theta}; r) \geq \widetilde{D}_i(\varnothing; r)$. When we compare firm i's first-order conditions we note the following. An uninformed firm has higher expected costs, but expects weaker competition. The direct effect of lower costs dominates the indirect competition effect. Therefore firms with low cost signals invest more than uninformed firms in the symmetric R&D equilibrium.

Observe that for symmetric expected information acquisition investments equilibrium R&D investments depend in the following way on the expected information acquisition investments:

$$\frac{\partial \widetilde{D}_i(\underline{\theta}; r)}{\partial r} \leq 0, \text{ and } \frac{\partial \widetilde{D}_i(\varnothing; r)}{\partial r} \geq 0. \tag{5.8}$$

Note that we change both r_i and r_j in equal amounts in the same direction. When both expected information acquisition investments increase, it becomes more likely that firms are informed. This implies that concealing firms expect to face stronger competition in R&D. This discourages R&D investments of firms. Therefore equilibrium investments of low-cost firms decrease in the expected information acquisition investments. An increase in expected information acquisition investments also makes uninformed firms more optimistic about their own costs of R&D. Since your rival is less likely to be uninformed, an uninformative message from him makes it more likely to you that he is actually concealing good news. This positive cost effect dominates the negative effect of expecting fiercer competition for uninformed firms.

When we compare the symmetric R&D investments under strategic disclosure rule $(\delta_i(\underline{\theta}), \delta_i(\overline{\theta})) = (\varnothing, \overline{\theta})$ with those under mandatory disclosure, we observe the following. Given a firm's individual R&D cost signal, each firm invests more under partial disclosure than under full disclosure. That is, $\widetilde{D}_i(\underline{\theta}; r) > \widehat{D}_i(\underline{\theta})$ and $\widetilde{D}_i(\varnothing; r) > \widehat{D}_i(\varnothing)$, for $i = 1, 2$. When firm i knows that it has low R&D costs, it expects weaker competition under partial disclosure than under full disclosure, which encourages higher investments. Under voluntary disclosure an uninformed firm expects lower R&D costs, but expects stronger competition. The (direct) cost effect is the dominating effect. However, this does not mean that the overall overinvestment in R&D is increased. Because a low-cost firm conceals its costs, there are contingencies, $(\underline{\theta}, \varnothing)$ and $(\varnothing, \underline{\theta})$, under which one of the firms remains uninformed under voluntary disclosure. And this uninformed firm invests less in R&D than its informed counterpart: $\widetilde{D}_i(\varnothing; r) < \widehat{D}_i(\underline{\theta})$.

We summarize our results on equilibrium R&D investments under voluntary disclosure in the following proposition:

Proposition 2 *Given disclosure rule $(\delta_i(\underline{\theta}), \delta_i(\overline{\theta})) = (\varnothing, \overline{\theta})$, $r_i < 1$, and $i = 1, 2$, $i \neq j$, the following holds:*
(i) For $r_i < r_j$: $\widetilde{D}_i(\underline{\theta}; r_i, r_j) < \widetilde{D}_j(\underline{\theta}; r_j, r_i)$ and $\widetilde{D}_i(\varnothing; r_i, r_j) > \widetilde{D}_j(\varnothing; r_j, r_i)$,
(ii) For $r_i = r_j = r$ and $r < 1$:
(ii.a) $\widetilde{D}_i(\underline{\theta}; r) > \widetilde{D}_i(\varnothing; r)$, while $\partial \widetilde{D}_i(\underline{\theta}; r)/\partial r < 0$ and $\partial \widetilde{D}_i(\varnothing; r)/\partial r > 0$,

(ii.b) $\widehat{D}_i(\varnothing) \le \widetilde{D}_i(\varnothing; r) < \widehat{D}_i(\underline{\theta}) < \widetilde{D}_i(\underline{\theta}; r)$*, and*
(ii.c) $\widetilde{D}_i(\varnothing; 0) = \widehat{D}_i(\varnothing)$*, while* $\widetilde{D}_i(\underline{\theta}; 1) = \widetilde{D}_i(\varnothing; 1) = \widehat{D}_i(\underline{\theta})$*.*

Finally we define firm i's equilibrium R&D profits for symmetric expected information acquisition investments as:

$$\widetilde{\pi}_i(\theta; r) = \frac{1}{2}\theta \widetilde{D}_i(\theta; r)^2, \text{ for } \theta \in \{\underline{\theta}, \overline{\theta}\}, \text{ and} \tag{5.9}$$

$$\widetilde{\pi}_i(\varnothing; r) = \frac{1}{2}E_i(\theta|\varnothing, \varnothing)\widetilde{D}_i(\varnothing; r)^2. \tag{5.10}$$

5.2 Equilibrium Disclosure Strategies

We presumed partial disclosure, $(\delta_i(\underline{\theta}), \delta_i(\overline{\theta})) = (\varnothing, \overline{\theta})$, in the previous section. In this section we find a condition under which partial disclosure is indeed chosen in equilibrium.

Given expected information acquisition investments (r_i, r_j), cost signals (Θ_i, Θ_j), and anticipated equilibrium R&D investments $(\widetilde{D}_i, \widetilde{D}_j)$, we determine firms' equilibrium disclosure rules. First, we establish the following negative result:

Lemma 1 *For* $r_i < 1$*, with* $i = 1, 2$*, the following symmetric combinations of disclosure rules are not chosen in equilibrium:*
(i) Full disclosure of information, $(\delta_i(\underline{\theta}), \delta_i(\overline{\theta})) = (\underline{\theta}, \overline{\theta})$*,*
(ii) Disclosure of low cost only, $(\delta_i(\underline{\theta}), \delta_i(\overline{\theta})) = (\underline{\theta}, \varnothing)$*,*
(iii) No disclosure of any information, $(\delta_i(\underline{\theta}), \delta_i(\overline{\theta})) = (\varnothing, \varnothing)$*.*

Full disclosure cannot be an equilibrium, since firms prefer to deviate by concealing good news. Nor can full concealment be an equilibrium disclosure rule, because a high-cost firm prefers to unilaterally disclose its information.

In general firms have an incentive to manipulate the disclosed information such that it makes their rival most pessimistic about his cost of R&D investment. This is a consequence of the dominating informational effect. The indirect, strategic effect of such a disclosure rule is that it makes the rival more optimistic about the concealing firm's R&D investments. The strategic effect is however outweighed by the informational effect in this setting. This suggests that disclosing only high costs of investment could be an equilibrium disclosure rule. In the next proposition we find a condition under which this is indeed the case.

Proposition 3 *If*

$$p \geq \frac{(\overline{\theta} - \Delta)\Delta}{(\overline{\theta} - \Delta)\Delta + (\underline{\theta} - \Delta)\underline{\theta}}, \tag{C.1}$$

then partial disclosure $(\widetilde{\delta}_i(\underline{\theta}), \widetilde{\delta}_i(\overline{\theta})) = (\varnothing, \overline{\theta})$ *is an equilibrium disclosure rule for any expected information acquisition investments* (r_i, r_j).

From this proposition we can conclude that under sufficient condition (C.1) the informational effect dominates the strategic effect of information disclosure. By disclosing bad news, and concealing good news, firms make their rival pessimistic about the actual costs of R&D investment. If the condition is not met, only asymmetric and possibly mixed-strategy disclosure equilibria exist. Section 7 discusses condition (C.1) in greater detail, and gives illustrating examples of cases in which the strategic effect dominates the informational effect.

This rule is the opposite of the equilibrium disclosure rule in companion paper Jansen (2001b), where costs are independently distributed. Since there is no informational effect of information disclosure in that paper, the strategic effect dominates, and firms only disclose good news, as in lemma 1 (ii). Cost correlation therefore has a dramatic effect on the equilibrium disclosure rules.

5.3 Voluntary Disclosure Information Acquisition

In this subsection we assume that condition (C.1) is met. We can therefore focus attention on equilibrium candidates in which firms anticipate disclosure rule $(\widetilde{\delta}_i(\underline{\theta}), \widetilde{\delta}_i(\overline{\theta}))$ and R&D investments $\widetilde{D}_i$ for $i = 1, 2$.

Firm i's expected profits, given information acquisition investments, (R_i, R_j), equilibrium disclosure rules, R&D investments and beliefs, are as follows:

$$\begin{aligned} E_\theta \left\{ \pi_i(\widetilde{\mathbf{D}}; \theta) \middle| \mathbf{R} \right\} &= pR_i\pi_i \left(\widetilde{D}_i(\underline{\theta}; r), \widetilde{D}_j; \underline{\theta} \right) + p(1 - R_i)\pi_i \left(\widetilde{D}_i(\varnothing; r), \widetilde{D}_j; \underline{\theta} \right) + \\ &\quad + (1 - p) \left(R_i + (1 - R_i)R_j \right) \pi_i \left(\widetilde{D}_i(\overline{\theta}), \widetilde{D}_j; \overline{\theta} \right) + \\ &\quad + (1 - p)(1 - R_i)(1 - R_j)\pi_i \left(\widetilde{D}_i(\varnothing; r), \widetilde{D}_j; \overline{\theta} \right) - \frac{1}{2}\rho R_i^2. \end{aligned} \tag{5.11}$$

When we take the first-order condition with respect to R_i, and let firms' expectations be realized and symmetric, $r_i = R_i = R$, we get equilibrium condition $\rho\widetilde{R} = \widetilde{\Psi}(\widetilde{R})$, with:

$$\widetilde{\Psi}(R) = p \left[\widetilde{\pi}_i(\underline{\theta}; R) - \widetilde{\pi}_i(\varnothing; R) \right] + (1 - p)(1 - R) \left[\widetilde{\pi}_i(\overline{\theta}; R) - \widetilde{\pi}_i(\varnothing; R) \right]. \tag{5.12}$$

Clearly the firms' second-order conditions for profit maximization are satisfied for all $\rho > 0$. With probability p firms have low costs of R&D. In that case a firm's rival never discloses information. Therefore a marginal increase in information acquisition investment could change a firm's revenue from that of an uninformed to that of a low-cost firm's revenue. When firms have high costs of investment, a firm's information acquisition investments only makes a difference if its rival did not obtain an informative signal on the costs. Because if the rival would get a high-cost signal, he would disclose it in equilibrium.

The comparison of the information acquisition investments under mandatory and voluntary disclosure, result in the following proposition.

Proposition 4 *Suppose that firms anticipate equilibrium disclosure rules* $(\widetilde{\delta}_i, \widetilde{\delta}_j)$ *and R&D investments* $(\widetilde{D}_i, \widetilde{D}_j)$. *Then firms invest more in information acquisition under voluntary information disclosure than under mandatory information disclosure:* $\widetilde{R}_i \geq \widehat{R}_i$ *for* $i = 1, 2$. *Strict inequality holds for interior equilibrium information acquisition investments.*

The intuition for this result is as follows. Since high R&D costs are always disclosed in equilibrium, the incentives to acquire information on high costs are the same under mandated and voluntary disclosure. We can therefore ignore high cost signals in comparing information acquisition incentives under voluntary and mandatory disclosure. The incentives to learn low R&D costs differ between mandatory and voluntary disclosure. When firm i's information acquisition investment results in a low cost signal, $\Theta_i = \underline{\theta}$, this generates greater expected profit for a concealing firm than for a firm that is required to disclose this signal (see proposition 2, iib). This clearly increases firms' incentives to acquire information under voluntary disclosure. However, an uninformative signal gives rise to the following trade-off. When firm i's information acquisition investment did not result in a low cost signal, then either firm j received good news, $\Theta_j = \underline{\theta}$, or no firm received any information. If firm j received good news, firm i cannot take a free-ride on this acquired information under voluntary disclosure. This gives firms under voluntary disclosure an incentive to invest in information acquisition. On the other hand, if both firms remain uninformed, firms become less pessimistic about their R&D costs, and generate a bigger expected R&D profit under voluntary disclosure than under mandatory disclosure. This gives firms a disincentive to invest in information acquisition under voluntary disclosure. The information acquisition incentive of foregoing information free-riding outweighs the disincentive from lower pessimism of uninformed firms under voluntary disclosure. Therefore the overall information acquisition incentive is bigger under voluntary disclosure than under mandatory disclosure.

While companion paper Jansen (2001b) obtained a similar result for certain parameter values, proposition 4 holds for all parameter values.

6 Overall Profit Comparison

So far we compared equilibrium investments under mandatory disclosure with those under voluntary disclosure. A remaining question is how expected profits compare between the regimes.

First we compare expected equilibrium profits for a given information acquisition level. When the firms have symmetric and *exogenous* information acquisition investment levels, (R, R), firm i's expected equilibrium profit under mandatory disclosure is:

$$\widehat{\Pi}_i(R;\rho) = (1-(1-R)^2)E_\theta\left\{\widehat{\pi}_i(\theta)\right\} + (1-R)^2\widehat{\pi}_i(\varnothing) - \frac{1}{2}\rho R^2. \quad (6.1)$$

Under voluntary disclosure firm i's expected equilibrium profit is:

$$\begin{aligned}\widetilde{\Pi}_i(R;\rho) &= Rp\widetilde{\pi}_i(\underline{\theta};R) + (1-(1-R)^2)(1-p)\widetilde{\pi}_i(\overline{\theta}) + \\ &\quad +(1-R)[p+(1-p)(1-R)]\widetilde{\pi}_i(\varnothing;R) - \frac{1}{2}\rho R^2. \quad (6.2)\end{aligned}$$

The difference between these expected profit levels simplifies to:

$$\begin{aligned}&\widehat{\Pi}_i(R;\rho) - \widetilde{\Pi}_i(R;\rho) = (1-R)\frac{1}{2}\left(p\underline{\theta} + (1-p)(1-R)\overline{\theta}\right)\left[\widehat{D}_i(\varnothing)^2 - \widetilde{D}_i(\varnothing;R)^2\right] + \\ &+pR\frac{1}{2}\underline{\theta}\left[\widehat{D}_i(\underline{\theta})^2 - \widetilde{D}_i(\underline{\theta};R)^2\right] + p(1-R)R\frac{1}{2}\underline{\theta}\left[\widehat{D}_i(\underline{\theta})^2 - \widehat{D}_i(\varnothing)^2\right]. \quad (6.3)\end{aligned}$$

This expression contains the following three terms. First, given that firms do not discover R&D costs, firm i's R&D investments under voluntary disclosure exceed those under mandated disclosure. Therefore the first term is negative. The second term is also negative, and reflects the informational effect for an informed firm. Third, there is an expected profit gain of mandatory disclosure when R&D costs are low and firm i's rival is the only firm who is informed. The gain is the difference between the expected profits of becoming informed, which happens under mandatory disclosure, and the expected profits of remaining uninformed, as happens under voluntary disclosure. The third term is therefore positive.

For $R = 0$ and $R = 1$ the profit losses from the informational effect exactly equal the profit gain from being more informed, i.e. both $\widehat{\Pi}_i(0;\rho) = \widetilde{\Pi}_i(0;\rho)$ and $\widehat{\Pi}_i(1;\rho) = \widetilde{\Pi}_i(1;\rho)$. For intermediate information acquisition investments, the trade-off between profit gain and losses is more subtle. Proposition 5 summarizes the trade-off. First we introduce the following condition:

$$(E(\theta) - \Delta)(\underline{\theta}^2 - 2\underline{\theta}\Delta - \Delta^2) \geq 4\underline{\theta}\Delta^2 \tag{C.2}$$

Proposition 5 *Under condition (C.2), $\widehat{\Pi}_i(R;\rho) > \widetilde{\Pi}_i(R;\rho)$ for all $R \in (0,1)$. Otherwise, there is an $R' \in (0,1)$ such that $\widehat{\Pi}_i(R;\rho) < \widetilde{\Pi}_i(R;\rho)$ for all $R \in (0,R')$, while $\widehat{\Pi}_i(R;\rho) > \widetilde{\Pi}_i(R;\rho)$ for all $R \in (R',1)$.*

In our model information acquisition investments are *endogenous*. An overall profit comparison should therefore compare expected profit level $\widehat{\Pi}_i(\widehat{R};\rho)$ with $\widetilde{\Pi}_i(\widetilde{R};\rho)$. This profit comparison is not obvious for all parameter values. On the one hand, it follows from proposition 5 that in many cases firms expect higher profits under mandatory disclosure than under voluntary disclosure for a given R. In particular, for $R = \widetilde{R}$ we obtain $\widehat{\Pi}_i(\widetilde{R};\rho) > \widetilde{\Pi}_i(\widetilde{R};\rho)$ in many cases. On the other hand, proposition 4 established that firms invest less in information acquisition under mandatory disclosure than under voluntary disclosure, i.e. $\widehat{R}_i < \widetilde{R}_i$. Moreover, under mandatory disclosure the firms' expected equilibrium revenues increase in R, i.e. $\widehat{\Pi}_i'(R;0) = 2(1-R)\widehat{\Psi} > 0$. Therefore $\widehat{\Pi}_i(\widehat{R};\rho) < \widehat{\Pi}_i(\widetilde{R};\rho)$ for sufficiently low ρ. These two observations make the comparison between $\widehat{\Pi}_i(\widehat{R};\rho)$ and $\widetilde{\Pi}_i(\widetilde{R};\rho)$ not obvious in many cases.

A similar trade-off emerges for independently distributed costs of investment, as companion paper Jansen (2001b) illustrates. With independent R&D costs firms expect higher profits under mandatory disclosure for given information acquisition investments. But firms acquire less information in some cases.

For extreme costs of information acquisition, the following observations are immediate. When information acquisition is costless, i.e. $\rho = 0$, firms invest the maximum amount in information acquisition under both mandatory and voluntary disclosure: $\widehat{R} = \widetilde{R} = 1$. In that case expected profits are equal, i.e. $\widehat{\Pi}_i(1;0) = \widetilde{\Pi}_i(1;0) = E_\theta\{\widehat{\pi}_i(\theta)\}$. For positive but small cost parameter ρ we observe the following. Proposition 5 shows that if exogenous information acquisition investments are close to one, firms always expect higher profits under mandated disclosure, i.e. $\widehat{\Pi}_i(\widetilde{R};\rho) > \widetilde{\Pi}_i(\widetilde{R};\rho)$ for $\widetilde{R}$ close to 1. It is easy to verify that the marginal revenues of information acquisition converge to zero if the information acquisition investments approach one, i.e.

$d\widehat{\Pi}_i(1;0)/dR = d\widetilde{\Pi}_i(1;0)/dR = 0$. Consequently a reduction of information acquisition investment from $\widetilde{R}$ to $\widehat{R}$ does not drastically reduce the expected profit under mandatory disclosure. We do therefore conjure that firms' overall equilibrium profits are higher under mandatory disclosure for sufficiently small costs of information acquisition. We proof this conjecture in proposition 6 (i).

At the other extreme, when information acquisition is infinitely expensive ($\rho \to \infty$), firms acquire no information in equilibrium, i.e. $\widehat{R} = \widetilde{R} = 0$. For zero equilibrium information acquisition investments firms receive identical expected profits under voluntary disclosure and under mandatory disclosure, since $\widehat{\Pi}_i(0;\rho) = \widetilde{\Pi}_i(0;\rho) = \widehat{\pi}_i(\varnothing)$. For intermediate costs of investment, we introduce the following constant:

$$C_0 \equiv 3\widehat{\Psi}^2 + 2\widetilde{\Psi}(0)\left[\frac{d\widetilde{\Psi}(0)}{dR} - p\underline{\theta}\widetilde{D}(\underline{\theta};0)\frac{\partial \widetilde{D}_i(\underline{\theta};0)}{\partial r}\right] - \widetilde{\Psi}(0)^2, \tag{6.4}$$

and obtain the following result.

Proposition 6 *(i) There is a* $\widehat{\rho} > 0$ *such that for all* $0 < \rho < \widehat{\rho}$ *expected profit under mandated disclosure exceeds expected profit under voluntary disclosure:* $\widehat{\Pi}_i(\widehat{R}(\rho);\rho) > \widetilde{\Pi}_i(\widetilde{R}(\rho);\rho)$. *(ii) If* $C_0 < 0$ *(resp.* $C_0 > 0$*), there is a* $\widetilde{\rho} < \infty$ *such that for all* $\rho > \widetilde{\rho}$ *expected profit under voluntary disclosure is bigger (resp. smaller) than under mandated disclosure:* $\widetilde{\Pi}_i(\widetilde{R}(\rho);\rho) > \widehat{\Pi}_i(\widehat{R}(\rho);\rho)$ *(resp.* $\widetilde{\Pi}_i(\widetilde{R}(\rho);\rho) < \widehat{\Pi}_i(\widehat{R}(\rho);\rho)$*).*

We can conclude from proposition 6 (i) that firms expect to be best off under mandatory disclosure, if information acquisition is not costly. If, on the other hand, information acquisition is extremely costly, as in proposition 6 (ii), then the overall effect of disclosure regulation on expected profits depends on parameter values.

7 Discussion

After the characterization of equilibrium investments in the regular case of disclosure rule $(\widetilde{\delta}_i(\underline{\theta}), \widetilde{\delta}_i(\overline{\theta}))$, we discuss in more detail the conditions under which this disclosure rule is indeed chosen in equilibrium. Condition (C.1) is a sufficient condition for obtaining the disclosure rule given any feasible combination of expected information acquisition investments. Necessary and sufficient conditions under which firms only disclose high costs in equilibrium are stated in the following proposition.

Proposition 7 *Firms disclose only high cost information,* $(\widetilde{\delta}_i(\underline{\theta}), \widetilde{\delta}_i(\overline{\theta})) = (\varnothing, \overline{\theta})$ *for* $i = 1, 2$, *in equilibrium iff:*

$$r_j \leq \min \left\{ 1, \frac{\underline{\theta}\left(p\underline{\theta} + (1-p)\overline{\theta} - \Delta\right)}{(1-p)(\overline{\theta} - \Delta)\left(\underline{\theta} + (1 - r_i)\Delta\right)} \right\} \tag{C.3}$$

and

$$r_j \geq \max \left\{ 0, \frac{(\underline{\theta} - \Delta)\left(p\underline{\theta} - (1-p)\Delta\right) + (1-p)(1-r_i)\left(\underline{\theta}\overline{\theta} - \Delta^2\right)}{(1-p)\left((1-r_i)(\overline{\theta} - \underline{\theta}) - r_i(\underline{\theta} - \Delta)\right)\Delta} \right\} \tag{C.4}$$

for $i, j = 1, 2$ $(i \neq j)$.

Observe the tight link between expected information acquisition investments and equilibrium disclosure rules. Not only do the information acquisition investments depend on the anticipated equilibrium disclosure rules, but also the equilibrium disclosure rules depend in a nontrivial way on the expected information acquisition investments.

In figure 2 we illustrate the conditions of the proposition for parameter values $p = \frac{1}{50}$, $\Delta = \frac{1}{2}$, $W = 1$, $\underline{\theta} = 2$, $\overline{\theta} = 3$. Along the horizontal axis we put firm i's expected information acquisition investment, r_i, while along the vertical axis we put r_j. When one of the conditions is violated, the strategic effect is the dominating effect for one of the firms. The solid boundaries represent the boundaries of condition (C.3). When condition (C.3) is not met, unilateral disclosure of good news becomes profitable given beliefs that are consistent with partial disclosure. Parameter values for which this occurs are north-west and south-east of the solid lines in figure 2. The dashed boundaries represent boundaries of condition (C.4). Unilateral concealment of bad news becomes profitable when condition (C.4) is not met, given beliefs consistent with partial disclosure. The set of parameter values for which this is profitable are north-west and south-east of the dashed lines in figure 2. In the remaining area the informational effect dominates the strategic effect of information disclosure. For this numerical example condition (C.3) is stronger than condition (C.4). For other parameter values the reverse can hold.

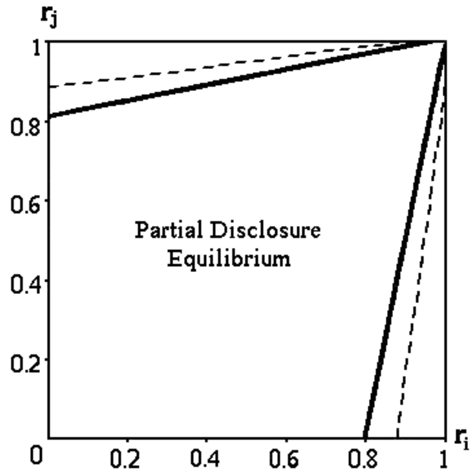

Figure 2: Partial disclosure region

A firm has an incentive to unilaterally disclose (resp. conceal) to make its rival realize (resp. believe) that he is facing a "strong" competitor in the R&D stage of the race. In these situations firms' expected information acquisition investments and beliefs are such that the informational effect plays a minor role, and the strategic effect dominates. In the remainder of this subsection we discuss the intuition behind firms' incentives to deviate from partial disclosure in more detail. We discuss two cases. In the first case there is a firm that has an incentive to disclose good news. And in the second case there is a firm that has an incentive to conceal bad news.

■ First we consider the case in which firm i prefers to deviate from disclosure rule $\widetilde{\delta}_i$ by *disclosing a low cost signal*. Take $\theta = \underline{\theta}$, and $r_i = \varepsilon$, $r_j = 1-\varepsilon$, with $\varepsilon, p > 0$ small. Suppose that firm j has equilibrium beliefs and investments, and firm i received an informative signal, $\Theta_i = \underline{\theta}$. When p is close to zero, an uninformed firm expects to have approximately high R&D costs $\overline{\theta}$, and does not expect to compete against a low-cost rival. An uninformed firm will therefore approximately invest $\widehat{D}_i(\overline{\theta})$, and be a weak competitor in the R&D stage.

If firm j receives a low-cost signal, it assigns probability ε to facing a low-cost rival, and probability $1-\varepsilon$ to facing a weak, uninformed firm. Since firm j puts high probability $(1-\varepsilon)$ on facing an uninformed rival, it becomes an aggressive investor in the R&D stage. Informed firm i, however, assigns high probability $(1-\varepsilon)$ to facing such a low-cost, aggressive rival, and probability ε to facing a weak, uninformed rival. This gives firm i a disincentive to invest in R&D. For low enough ε firm i's incentives to invest in R&D under information concealment are lower than those under information disclosure. Therefore firm i's expected profits under concealment are lower than his profit under disclosure. Firm i surprises its rival with the news that it will be an aggressive investor in the R&D stage by disclosing its low-cost signal. That is, informed firm j revises its beliefs about firm i's R&D investments drastically, which lowers its incentives to invest substantially. For small enough p and ε this strategic effect outweighs the informational effect of disclosure. This gives firm i an incentive to unilaterally disclose low costs, given the proposed equilibrium beliefs and expected information acquisition investments.

■ In the second case there is a firm that has an incentive to *conceal bad news.* Take $\theta = \overline{\theta}$, and $r_i = \varepsilon$, $r_j = 1 - \varepsilon$, with $\varepsilon, p > 0$ small. Suppose that firm j is uninformed and has equilibrium beliefs and investments, and firm i received a bad signal, $\Theta_i = \overline{\theta}$, and conceals. When ε is close to zero and no information is disclosed, firm j thinks that firm i is almost surely uninformed. If firm i would be uninformed, it would infer R&D costs $\underline{\theta}$ from firm j's uninformative message. Therefore firm j anticipates approximately equilibrium investment $\widehat{D}_i(\underline{\theta})$ from firm i. That is, firm j expects an aggressive rival after receiving an uninformative message, $\delta_i^* = \varnothing$. Furthermore, for ε close to zero firm j expects that firm i is uninformed, which gives firm j an expected R&D cost of $p\underline{\theta} + (1-p)\overline{\theta}$. For low enough prior probability p firm j's expected R&D cost is approximately $\overline{\theta}$. That is, for sufficiently low p and ε firm j expects high R&D costs and an aggressive rival, which depresses its investments. These investments become in fact lower than $\widehat{D}_j(\overline{\theta})$. Therefore, firm i has an incentive to unilaterally conceal a high-cost signal. Concealment makes uninformed firm j expect aggressive R&D competition, which lowers its investments. This strategic effect of concealment dominates its informational effect. Therefore firm i has an incentive to unilaterally conceal its high costs in these cases.

The preceding examples of profitable unilateral deviations rely heavily on asymmetry between firms' expected information acquisition investments. It is immediate that conditions (C.3) and (C.4) are always met for symmetric expected information acquisition investments: $r_i = r_j$.[5] We also saw that the examples worked in particular for small prior probability p. For big enough prior probability p, i.e. p as in condition (C.1), we always get partial disclosure in equilibrium. When expected information acquisition investments are asymmetric and the prior probability is sufficiently small,

[5] This follows directly from studying the conditions (see, e.g. figure 2), and from the characterization of symmetric equilibrium R&D investments under partial disclosure in the previous subsection. In particular, recall that for $r_i = r_j$, $\widetilde{D}_i(\underline{\theta}) \geq \widehat{D}_i(\underline{\theta})$ and $\widetilde{D}_i(\varnothing) \geq \widehat{D}_i(\overline{\theta})$, for $i = 1, 2$.

we would expect asymmetric, and possibly mixed equilibrium disclosure rules. The characterization of the equilibrium disclosure rules for these asymmetric cases awaits future research.

8 Conclusion

In this paper we studied the interaction between information acquisition, strategic disclosure and R&D in a competitive setting. We have seen that disclosure regulation substantially affects firms' investments, both in information acquisition as well as in R&D.

We have explained the increased competition after IBM's breakthrough in the research of superconductivity. Not only did we replicate Choi's (1991) results, but we could also indicate in what direction equilibrium investments and profits change when disclosure is no longer required. Furthermore we have been able to explain how firm's investments and profits are affected by disclosure regulation. In particular, firms typically expect higher profits for given information acquisition investments under mandatory disclosure, but they acquire less information.

In companion paper Jansen (2001b) we show how disclosure regulation affects investments, disclosure, and profits in a model with independently distributed costs of investments. In that model firms preannounce good news in equilibrium, which would be consistent with Microsoft's strategic preannouncements. Cost correlation does not only affect equilibrium disclosure rules, but also has dramatically effects on information acquisition investments.

We studied the effects of disclosure regulation in a "winner-take-all" race. In practice part of the winner's prize spills over to the loser of the race. It would be interesting to study the effects of limited appropriability in this model. Such a problem is studied, with different informational assumptions, in Jansen (2001a). Revenue sharing between a winner and loser of the race creates free-rider incentives between the competing firm. Initially the free-rider incentives correct some of the distorting externalities among competing firms. Subsequently the free-rider effect of revenue sharing erodes the firms' incentives to invest in R&D and information acquisition.

A natural next step would be to study how results change for intermediate degrees of correlations. For intermediate degrees of correlation we would expect a more subtle trade-off between the informational and strategic effect of information disclosure. This extension of the basic analysis awaits future research.

A Appendix

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

A.1 Mandatory Disclosure, Proposition 1

Part (i) of the proposition is obvious. For part (ii) we first show that $\widehat{\Psi} < \overline{\Psi}$. Decompose $\widehat{\Psi}$ as follows:

$$\frac{2\widehat{\Psi}}{W^2} = \left(E\left\{\frac{1}{\theta+\Delta}\right\} - \frac{1}{E(\theta)+\Delta}\right) - \Delta\left(E\left\{\frac{1}{(\theta+\Delta)^2}\right\} - \frac{1}{(E(\theta)+\Delta)^2}\right), \quad \text{(A.1)}$$

and note that

$$\begin{aligned}\frac{\overline{\Psi}-2\widehat{\Psi}}{W^2} &= \Delta\left(E\left\{\frac{1}{(\theta+\Delta)^2}\right\} - \frac{1}{(E(\theta)+\Delta)^2}\right) \\ &\quad -\Delta\left(E\left\{\frac{1}{(\theta+\Delta)(\theta+2\Delta)}\right\} - \frac{1}{(E(\theta)+\Delta)(E(\theta)+2\Delta)}\right) \\ &= \Delta^2\left(E\left\{\frac{1}{(\theta+\Delta)^2(\theta+2\Delta)}\right\} - \frac{1}{(E(\theta)+\Delta)^2(E(\theta)+2\Delta)}\right), \quad \text{(A.2)}\end{aligned}$$

which is positive, since $g(\theta) \equiv \frac{1}{(\theta+\Delta)^2(\theta+2\Delta)}$ is convex in θ, and therefore $E\left(g(\theta)\right) > g\left(E(\theta)\right)$. The equilibrium and total-profit-maximizing probabilities of remaining uninformed equal, respectively:

$$(1-\widehat{R}_1)(1-\widehat{R}_2) = \frac{\rho^2}{\left(\rho+\widehat{\Psi}\right)^2} \text{ and } (1-\overline{R}_1)(1-\overline{R}_2) = \begin{cases} 0, \text{ for all } \rho < \overline{\Psi}, \\ \frac{\rho^2}{\left(\rho+\overline{\Psi}\right)^2}, \text{ otherwise.}\end{cases} \quad \text{(A.3)}$$

Since $\widehat{\Psi} < \overline{\Psi}$, $(1-\widehat{R}_1)(1-\widehat{R}_2) > (1-\overline{R}_1)(1-\overline{R}_2)$ clearly holds for all $\rho > 0$. This proves the proposition.□

A.2 Voluntary Disclosure

We prove proposition 2, lemma 1, and propositions 3 and 4, respectively.

A.2.1 Proof of Proposition 2 (R&D)

First we calculate equilibrium R&D investments under partial disclosure. We substitute equation (5.4) in equation (5.5). Since $p(1-r_j)\alpha_j = (1-r_j)\alpha_j$, this transforms the uninformed firm's reaction function into:

$$pE_i(\theta|\varnothing,\varnothing)\widetilde{D}_i(\varnothing) = pW - \alpha_j\left(W - \underline{\theta}\widetilde{D}_i(\underline{\theta})\right) + (1-p)r_j\alpha_j\widetilde{D}_j(\underline{\theta})\Delta. \quad \text{(A.4)}$$

Substituting this expression in low-signal firm i's reaction function, equation (5.4), results in the following expression:

$$\widetilde{D}_i(\underline{\theta}) = \frac{\left(\theta_j^* + (1-p)r_i(1-r_j)\Delta\right) W - \left(r_j\theta_j^* + (1-r_j)\underline{\theta}\right) \widetilde{D}_j(\underline{\theta})\Delta}{\left(\underline{\theta}\theta_j^* + (1-p)r_i(1-r_j)\Delta^2\right)} \tag{A.5}$$

with $\theta_j^* = p\underline{\theta} + (1-p)(1-r_i)\overline{\theta}$, for $i, j = 1, 2$ $(i \neq j)$. Following a similar procedure for the uninformed firms, we obtain:

$$\alpha_j\underline{\theta}\widetilde{D}_i(\underline{\theta}) = \alpha_j W - \Big(W - E_i(\theta|\varnothing,\varnothing)\widetilde{D}_i(\varnothing)\Big) + \frac{(1-p)(1-r_j)}{pr_j + 1 - r_j}\widetilde{D}_j(\varnothing)\Delta. \tag{A.6}$$

Substitution of this expression in uninformed firm i's reaction function, equation (5.5), gives the following expression:

$$\widetilde{D}_i(\varnothing) = \frac{(\underline{\theta}(1-r_j+pr_j) + (1-p)(1-r_i)r_j\Delta)\, W - \left(r_j\theta_j^* + (1-r_j)\underline{\theta}\right) \widetilde{D}_j(\varnothing)\Delta}{(\underline{\theta}\theta_i^* + (1-p)(1-r_i)r_j\Delta^2)}, \tag{A.7}$$

for $i, j = 1, 2$ $(i \neq j)$. From expressions (A.5) and (A.7) we can derive the equilibrium R&D investments.

(i) After calculating the equilibrium R&D investments, we note that $\widetilde{D}_i(\underline{\theta}) - \widetilde{D}_j(\underline{\theta})$ is proportional to $(1-p)^2\Delta W(1-r_i)(1-r_j)(\overline{\theta}-\Delta)(\overline{\theta}-\underline{\theta})(r_i - r_j)$, which gives the observation directly. We also note that $\widetilde{D}_i(\varnothing) - \widetilde{D}_j(\varnothing)$ is proportional to $p(1-p)\underline{\theta}W(\underline{\theta}-\Delta)(\overline{\theta}-\underline{\theta})(r_j - r_i)$, which provides the characterization directly.

(ii) For $r_i = r$ equilibrium R&D investments follow directly from expressions (A.5) and (A.7). In particular these investments are as follows:

$$\widetilde{D}_i(\underline{\theta}; r) = \frac{[p\underline{\theta} + (1-p)(1-r)(\overline{\theta} + r\Delta)]W}{p\underline{\theta}(\underline{\theta}+\Delta) + (1-p)(1-r)(\overline{\theta}+\Delta)(\underline{\theta}+r\Delta)}, \text{ and} \tag{A.8}$$

$$\widetilde{D}_i(\varnothing; r) = \frac{[p\underline{\theta} + (1-p)(1-r)(\underline{\theta} + r\Delta)]W}{p\underline{\theta}(\underline{\theta}+\Delta) + (1-p)(1-r)(\overline{\theta}+\Delta)(\underline{\theta}+r\Delta)}, \tag{A.9}$$

for $i = 1, 2$. Taking first derivatives gives:

$$\frac{\partial\widetilde{D}_i(\underline{\theta}; r)}{\partial r} = \frac{-(1-p)(1-r)\Delta(\overline{\theta}-\underline{\theta})\left((1-p)(1-r)(\overline{\theta}+\Delta) + 2p\underline{\theta}\right) W}{\left[p\underline{\theta}(\underline{\theta}+\Delta) + (1-p)(1-r)(\overline{\theta}+\Delta)(\underline{\theta}+r\Delta)\right]^2} \leq 0. \tag{A.10}$$

$$\frac{\partial\widetilde{D}_i(\varnothing; r)}{\partial r} = \frac{(1-p)p\underline{\theta}(\overline{\theta}-\underline{\theta})\,(\underline{\theta} - (1-2r)\Delta)\, W}{\left[p\underline{\theta}(\underline{\theta}+\Delta) + (1-p)(1-r)(\overline{\theta}+\Delta)(\underline{\theta}+r\Delta)\right]^2} \geq 0. \tag{A.11}$$

Comparisons between investment levels are straightforward. This completes the proof.□

A.2.2 Proof of Lemma 1 (Disclosure Disequilibria)

(i) Suppose full disclosure, i.e. rule $(\delta_i(\underline{\theta}), \delta_i(\overline{\theta})) = (\underline{\theta}, \overline{\theta})$, is chosen in equilibrium. Consequently, firms j's R&D investments are $\widehat{D}_j(\underline{\theta})$, $\widehat{D}_j(\varnothing)$ and $\widehat{D}_j(\overline{\theta})$, with $j = 1, 2$. But when low-cost firm i anticipates these investments, it has an incentive to conceal its information. Given equilibrium beliefs, disclosure choice $\delta_i(\underline{\theta}) = \varnothing$ only affects investments when firm j is uninformed, which happens with probability $1 - r_j > 0$. An uninformed firm j that receives message $\delta_i^* = \varnothing$ from its rival invests $\widehat{D}_j(\varnothing)$, which is less than the investment $\widehat{D}_j(\underline{\theta})$ after disclosure of $\Theta_i = \underline{\theta}$. Firm j's expected R&D investments under concealment are therefore greater than its investment under disclosure. Therefore firm i's optimal deviation investment, and consequently its expected deviation profit, is greater than in the proposed equilibrium. Consequently full disclosure is not part of an equilibrium strategy.
(ii) Intuitive given (i) and (iii).
(iii) Disclosure rule $(\delta_i(\underline{\theta}), \delta_i(\overline{\theta})) = (\varnothing, \varnothing)$ discloses no information about cost signals. In this case firms can only condition their R&D investments on their own observed cost signal. Firm i invests $D_i^o(\underline{\theta})$, $D_i^o(\varnothing)$ and $D_i^o(\overline{\theta})$ in R&D after receiving $\Theta_i = \underline{\theta}$, $\varnothing$ and $\overline{\theta}$, respectively. These investments are determined by the following first-order conditions:

$$\begin{aligned} \underline{\theta} D_i^o(\underline{\theta}) &= W - \left(r_j D_j^o(\underline{\theta}) + (1 - r_j) D_j^o(\varnothing)\right) \Delta & \text{(A.12)} \\ \overline{\theta} D_i^o(\overline{\theta}) &= W - \left(r_j D_j^o(\overline{\theta}) + (1 - r_j) D_j^o(\varnothing)\right) \Delta & \text{(A.13)} \\ E(\theta) D_i^o(\varnothing) &= W - \left(r_j p D_j^o(\underline{\theta}) + r_j (1 - p) D_j^o(\overline{\theta}) + (1 - r_j) D_j^o(\varnothing)\right) \Delta & \text{(A.14)} \end{aligned}$$

Note that

$$E(\theta) D_i^o(\varnothing) = p \underline{\theta} D_i^o(\underline{\theta}) + (1 - p) \overline{\theta} D_i^o(\overline{\theta}). \quad \text{(A.15)}$$

Given these investments and beliefs we can show that a firm with signal $\Theta_i = \overline{\theta}$ has an incentive to disclose its information. If the high-signal firm i would choose investments $D_i^o(\overline{\theta})$ it would receive an expected profit of $\frac{1}{2} \overline{\theta} D_i^o(\overline{\theta})^2$. When this firm discloses its information it gets $\frac{1}{2} \overline{\theta} \widehat{D}_i(\overline{\theta})^2$. Deviating from concealment is therefore profitable whenever $D_i^o(\overline{\theta}) < \widehat{D}_i(\overline{\theta})$. We use expression (A.15) to reduce the R&D

equilibrium conditions under no-disclosure to the following system of equations

$$\begin{aligned}
\underline{\theta} D_i^o(\underline{\theta}) &= W - \left(r_j + (1-r_j)\frac{p\underline{\theta}}{E(\theta)} \right) D_j^o(\underline{\theta})\Delta - (1-r_j)\frac{(1-p)\overline{\theta}}{E(\theta)} D_j^o(\overline{\theta})\Delta, \qquad \text{(A.16)}\\
&= W - \left(\frac{r_j}{p\underline{\theta}} + \frac{1-r_j}{E(\theta)} \right) \left(p\underline{\theta} D_j^o(\underline{\theta}) + (1-p)\overline{\theta} D_j^o(\overline{\theta}) \right)\Delta + \frac{r_j(1-p)\overline{\theta}}{p\underline{\theta}} D_j^o(\overline{\theta})\Delta,\\
\overline{\theta} D_i^o(\overline{\theta}) &= W - r_j D_j^o(\overline{\theta})\Delta - \frac{1-r_j}{E(\theta)} \left(p\underline{\theta} D_j^o(\underline{\theta}) + (1-p)\overline{\theta} D_j^o(\overline{\theta}) \right)\Delta. \qquad \text{(A.17)}
\end{aligned}$$

By substituting equation (A.17) into equation (A.16), we can write the low-signal firm i's optimal R&D investments as a function of firms' high-signal investments only:

$$(1-r_j)p\underline{\theta}^2 D_i^o(\underline{\theta}) = -r_j E(\theta) W + r_j E(\theta) D_j^o(\overline{\theta})\Delta + \left(r_j E(\theta) + (1-r_j)p\underline{\theta} \right) \overline{\theta} D_i^o(\overline{\theta}). \qquad \text{(A.18)}$$

When we substitute this expression back in equation (A.17), we obtain expression:

$$\begin{aligned}
D_i^o(\overline{\theta}) &= \frac{E(\theta)\left[(1-r_i)\underline{\theta} + r_i(1-r_j)\Delta\right] W - A^o D_j^o(\overline{\theta})\Delta}{E(\theta)\left[(1-r_i)\underline{\theta}\overline{\theta} + r_i(1-r_j)\Delta^2\right]}, \text{ with} \qquad \text{(A.19)}\\
A^o &\equiv (1-r_i)\underline{\theta}\left(r_j E(\theta) + (1-r_j)(1-p)\overline{\theta} \right) + (1-r_j)\overline{\theta}\left(r_i E(\theta) + (1-r_i)p\underline{\theta} \right) \geq 0.
\end{aligned}$$

When this function does not intersect with the set $\left\{ \mathbf{D} \in [0,1]^2 \,\middle|\, D_i \geq \widehat{D}_i(\overline{\theta}), i = 1,2 \right\}$, any equilibrium investment $D_i^o(\overline{\theta})$ is smaller than $\widehat{D}_i(\overline{\theta})$. Since the function is non-increasing in $D_j^o(\overline{\theta})$, it suffices to show that a firm's optimal reaction to rival's investment $\widehat{D}_j(\overline{\theta})$ under concealment is smaller than $\widehat{D}_i(\overline{\theta})$. After we evaluate expression (A.19) in $D_j^o(\overline{\theta}) = \widehat{D}_j(\overline{\theta})$ and subtract $\widehat{D}_i(\overline{\theta})$, we obtain:

$$\frac{-p\Delta\underline{\theta}(1-r_i)(1-r_j)(\overline{\theta}-\underline{\theta})W}{(\overline{\theta}+\Delta)E(\theta)\left[(1-r_i)\underline{\theta}\overline{\theta} + r_i(1-r_j)\Delta^2\right]} \leq 0. \qquad \text{(A.20)}$$

Since this expression is negative for $(r_i, r_j) < (1,1)$, unilateral disclosure of $\overline{\theta}$ is profitable for firm i. This completes the proof.□

A.2.3 Proof of Proposition 3 (Disclosure Equilibrium)

The proof to this proposition directly follows from necessary and sufficient conditions (C.3) and (C.4) of proposition 7. Observe that the critical values for r_j of these conditions are increasing in r_i. It therefore suffices to evaluate the critical value of condition (C.3) at $r_i = 0$, and find the prior probabilities p for which the critical value exceeds 1. This results in condition (C.1). For critical value (C.4) it suffices to evaluate it at $r_i = 1$, and find the p for which it does not exceed zero. This happens for $p \geq \frac{\Delta}{\underline{\theta}+\Delta}$, which is satisfied under (C.1). This completes the proof.□

A.2.4 Proof of Proposition 4 (Information Acquisition)

Equilibrium information acquisition investments under voluntary disclosure are bigger than under mandatory disclosure whenever marginal revenues of information acquisition under voluntary disclosure exceed marginal revenues under mandatory disclosure. Since high-cost firms earn identical R&D profits under mandatory and voluntary disclosure, we can ignore these profit levels in the comparison of marginal revenues. Since we focus on symmetric information acquisition equilibria, we take $R_i = r_i = R$ for $i = 1, 2$. We can rewrite the equilibrium marginal revenues of information acquisition under required disclosure, net of high-cost firms' revenues, to:

$$(1-R)\widehat{\Psi} \equiv p\frac{1}{2}\underline{\theta}\widehat{D}_i(\underline{\theta})^2 - \frac{1}{2}\left(p\underline{\theta} + (1-p)(1-R_j)\overline{\theta}\right)\widehat{D}_i(\varnothing)^2 - pR_j\frac{1}{2}\underline{\theta}\left(\widehat{D}_i(\underline{\theta})^2 - \widehat{D}_i(\varnothing)^2\right). \tag{A.21}$$

Equilibrium marginal revenues of information acquisition under voluntary disclosure, net of high-cost firms' revenues, are:

$$\widetilde{\Psi}(R) \equiv p\frac{1}{2}\underline{\theta}\widetilde{D}_i(\underline{\theta};R)^2 - \frac{1}{2}\left(p\underline{\theta} + (1-p)(1-R)\overline{\theta}\right)\widetilde{D}_i(\varnothing;R)^2. \tag{A.22}$$

We must therefore check that for all R:

$$\begin{aligned}\widetilde{\Psi}(R) - (1-R)\widehat{\Psi} &= p\frac{1}{2}\underline{\theta}\left(\widetilde{D}_i(\underline{\theta};R)^2 - \widehat{D}_i(\underline{\theta})^2\right) + pR\frac{1}{2}\underline{\theta}\left(\widehat{D}_i(\underline{\theta})^2 - \widehat{D}_i(\varnothing)^2\right) \\ &\quad -\frac{1}{2}\left(p\underline{\theta} + (1-p)(1-R)\overline{\theta}\right)\left(\widetilde{D}_i(\varnothing;R)^2 - \widehat{D}_i(\varnothing)^2\right) > 0\end{aligned} \tag{A.23}$$

The first term of (A.23) is positive, since $\widetilde{D}_i(\underline{\theta};R) > \widehat{D}_i(\underline{\theta})$. Define the following function:

$$G(R) \equiv \frac{1}{2}\left(p\underline{\theta} + (1-p)(1-R)\overline{\theta}\right)\left(\widetilde{D}_i(\varnothing;R)^2 - \widehat{D}_i(\varnothing)^2\right) - pR\frac{1}{2}\underline{\theta}\left(\widehat{D}_i(\underline{\theta})^2 - \widehat{D}_i(\varnothing)^2\right). \tag{A.24}$$

Now we need to show that $G(R) \leq 0$ for all R to complete the proof. Observe that for $R = 0$, $\widetilde{D}_i(\varnothing;0) = \widehat{D}_i(\varnothing)$, which makes $G(0) = 0$. For $R = 1$, $\widetilde{D}_i(\varnothing;1) = \widehat{D}_i(\underline{\theta})$, which implies that $G(1) = 0$. Therefore, for $G(R) \leq 0$ for all $R \in (0,1)$, it suffices to show that G is convex in R. Note that

$$\begin{aligned}G''(R) &= \frac{1}{2}\cdot\frac{d^2}{dR^2}\left\{\left(p\underline{\theta} + (1-p)(1-R)\overline{\theta}\right)\widetilde{D}_i(\varnothing;R)^2\right\} \\ &= \widetilde{D}_i(\varnothing;R)\left\{\left(p\underline{\theta} + (1-p)(1-R)\overline{\theta}\right)\frac{d^2\widetilde{D}_i(\varnothing;R)}{dR^2} - 2(1-p)\overline{\theta}\frac{d\widetilde{D}_i(\varnothing;R)}{dR}\right\} + \\ &\quad + \left(p\underline{\theta} + (1-p)(1-R)\overline{\theta}\right)\left(\frac{d\widetilde{D}_i(\varnothing;R)}{dR}\right)^2.\end{aligned} \tag{A.25}$$

It is straightforward to verify that:

$$\begin{aligned}
&\left(p\underline{\theta}+(1-p)(1-R)\overline{\theta}\right)\frac{d^2\widetilde{D}_i(\varnothing;R)}{dR^2}-2(1-p)\overline{\theta}\frac{d\widetilde{D}_i(\varnothing;R)}{dR}\\
=&\ \frac{2W(1-p)p\underline{\theta}(\overline{\theta}-\underline{\theta})\Delta g(R;\overline{\theta})}{\left(p\underline{\theta}(\underline{\theta}+\Delta)+(1-p)(1-R)(\overline{\theta}+\Delta)(\underline{\theta}+R\Delta)\right)^3},
\end{aligned}\tag{A.26}$$

with

$$\begin{aligned}
g(R;\overline{\theta}) \equiv&\ (1-p)^2(1-R)^3\Delta\overline{\theta}^2+(1-p)(1-R)^2\left(3p\underline{\theta}+(1-p)(1-R)\Delta\right)\Delta\overline{\theta}+\\
&+p\underline{\theta}\left(\underline{\theta}^2-(1-3R+p(3R-2))\Delta\underline{\theta}+(1-p)(1-3R+3R^2)\Delta^2\right).
\end{aligned}\tag{A.27}$$

Since

$$\frac{\partial g(R;\overline{\theta})}{\partial\overline{\theta}}=(1-p)(1-R)^2\Delta\left((1-p)(1-R)(2\overline{\theta}+\Delta)+3p\underline{\theta}\right)\geq 0,\tag{A.28}$$

and $\overline{\theta}>\underline{\theta}$, we obtain

$$g(R;\overline{\theta})\geq g(R;\underline{\theta})=\underline{\theta}(\underline{\theta}+\Delta)\left(p\underline{\theta}+(1-p)\Delta(pR^3+(1-R)^3)\right)>0.\tag{A.29}$$

Therefore $G''(R)>0$, which completes the proof.□

A.3 Overall Profit Comparison

We prove propositions 5 and 6.

A.3.1 Proof of Proposition 5 (Exogenous Information Acquisition)

It is straightforward to rewrite expected profit difference (6.3) to the following:

$$\widehat{\Pi}_i(R)-\widetilde{\Pi}_i(R)=\frac{p(1-p)^2R(1-R)^2(\overline{\theta}-\underline{\theta})^2H(R)}{(\underline{\theta}+\Delta)^2(E(\theta)+\Delta)^2[p\underline{\theta}(\underline{\theta}+\Delta)+(1-p)(1-R)(\overline{\theta}+\Delta)(\underline{\theta}+R\Delta)]^2},\tag{A.30}$$

where $H(R)\equiv\alpha_R R^2+\beta R+\gamma$, with:

$$\begin{aligned}
\alpha_R \equiv&\ -[2(\underline{\theta}-\Delta)+R\Delta](1-p)\Delta\left[\underline{\theta}E(\theta)\overline{\theta}-(\underline{\theta}+E(\theta)+\overline{\theta})\Delta^2-2\Delta^3\right] && \text{(A.31)}\\
\beta \equiv&\ (2\underline{\theta}-\Delta)(1-p)\Delta\left[\underline{\theta}E(\theta)\overline{\theta}-(\underline{\theta}+E(\theta)+\overline{\theta})\Delta^2-2\Delta^3\right]+\\
&+p\underline{\theta}(\underline{\theta}+\Delta)^2[E(\theta)(\underline{\theta}-\Delta)-2\Delta^3]+\\
&-\underline{\theta}(E(\theta)+\Delta)\left[(E(\theta)-\Delta)(\underline{\theta}^2-2\underline{\theta}\Delta-\Delta^2)-4\underline{\theta}\Delta^2\right],\ \text{and} && \text{(A.32)}\\
\gamma \equiv&\ \underline{\theta}(E(\theta)+\Delta)\left[(E(\theta)-\Delta)(\underline{\theta}^2-2\underline{\theta}\Delta-\Delta^2)-4\underline{\theta}\Delta^2\right]. && \text{(A.33)}
\end{aligned}$$

It is immediate that $\widehat{\Pi}_i(0) = \widetilde{\Pi}_i(0)$ and $\widehat{\Pi}_i(1) = \widetilde{\Pi}_i(1)$. Moreover, for $R \in (0,1)$, $\widehat{\Pi}_i(R) - \widetilde{\Pi}_i(R)$ can only change sign if $H(R)$ changes sign. Note that $H(1) > 0$, since

$$\alpha_1 + \beta + \gamma = p\underline{\theta}(\underline{\theta} + \Delta)^2[E(\theta)(\underline{\theta} - \Delta) - 2\Delta^3] \geq p\underline{\theta}(\underline{\theta} + \Delta)^3(\underline{\theta} - 2\Delta) > 0. \quad \text{(A.34)}$$

Furthermore, $H(R)$ is concave in R, since:

$$\begin{aligned} H''(R) &\equiv -2\left[2(\underline{\theta} - \Delta) + 3\Delta R\right](1-p)\Delta\left[\underline{\theta}E(\theta)\overline{\theta} - (\underline{\theta} + E(\theta) + \overline{\theta})\Delta^2 - 2\Delta^3\right] \\ &\leq -2\left[2(\underline{\theta} - \Delta) + 3\Delta R\right](1-p)\Delta(\underline{\theta} + \Delta)[\overline{\theta}(\underline{\theta} - \Delta) - 2\Delta^2] \\ &\leq -2\left[2(\underline{\theta} - \Delta) + 3\Delta R\right](1-p)\Delta(\underline{\theta} + \Delta)^2(\underline{\theta} - 2\Delta) < 0 \text{ for all } R. \quad \text{(A.35)} \end{aligned}$$

Therefore $H(R)$ changes sign at most once on domain $[0,1]$. In particular, if $H(0) \geq 0$, then $H(R) > 0$ for all $R > 0$. While, if $H(0) < 0$, then there is a critical value R' such that $H(R) < 0$ for all $R < R'$, $H(R') = 0$, and $H(R) > 0$ for all $R > R'$. Finally it suffices to observe that $H(0) = \gamma \geq 0$ iff condition (C.2) is satisfied, to complete the proof of the proposition.□

A.3.2 Proof of Proposition 6 (Endogenous Information Acquisition)

For each $R \in [0,1]$ there is a cost of information acquisition, $\widetilde{\rho}(R)$, such that $\widetilde{R}(\widetilde{\rho}(R)) = R$. In particular, $\widetilde{\rho}(R) = \widetilde{\Psi}(R)/R$. Since $\widetilde{\rho}(.)$ is monotonic in R, a marginal increase in R corresponds one-to-one to a marginal decrease in the cost of information acquisition ρ. At cost of investment $\widetilde{\rho}(R)$ voluntary disclosing firms invest R and receive expected equilibrium profit $\widetilde{\Pi}_i(R)$, where:

$$\widetilde{\Pi}_i(R) = \widetilde{\Pi}_i\left(R; \frac{\widetilde{\Psi}(R)}{R}\right) = E_\theta\left\{\widetilde{\pi}_i(\theta)\right\} - \left(1 - \frac{1}{2}R\right)\widetilde{\Psi}(R), \quad \text{(A.36)}$$

with $\widetilde{\Psi}(R)$ as in (5.12), and $\widetilde{\Pi}_i(R;\rho)$ as in (6.2). Note that $\widetilde{\Pi}_i(\widetilde{R}(\rho)) = \widetilde{\Pi}_i(\widetilde{R}(\rho);\rho)$. At cost of investment $\widetilde{\rho}(R)$ mandatory disclosing firms invest $\widehat{R}(\widetilde{\rho}(R)) = \frac{\widehat{\Psi}}{\widetilde{\rho}(R)+\widehat{\Psi}}$ in information acquisition, and their expected equilibrium profit is $\widehat{\Pi}_i\left(\widehat{R}(\widetilde{\rho}(R))\right)$, where:

$$\widehat{\Pi}_i(R) = \widehat{\Pi}_i\left(R; \frac{(1-R)\widehat{\Psi}}{R}\right) = E_\theta\left\{\widehat{\pi}_i(\theta)\right\} - \left(1 - \frac{1}{2}R\right)(1-R)\,\widehat{\Psi}, \quad \text{(A.37)}$$

with $\widehat{\Psi}$ as in (4.4) and $\widehat{\Pi}_i(R;\rho)$ as in (6.1), and $\widehat{\Pi}_i(\widehat{R}(\rho)) = \widehat{\Pi}_i(\widehat{R}(\rho);\rho)$.
(i) It is easily verified that $d\widehat{\Pi}_i\left(\widehat{R}(\widetilde{\rho}(1))\right)/dR = d\widetilde{\Pi}_i(1)/dR = -\frac{1}{2}d\widetilde{\Psi}(1)/dR > 0$. Furthermore, it is straightforward to show that:

$$\frac{d^2\widehat{\Pi}_i\left(\widehat{R}(\widetilde{\rho}(1))\right)}{dR^2} - \frac{d^2\widetilde{\Pi}_i(1)}{dR^2} = -p\underline{\theta}\widehat{D}_i(\underline{\theta})\frac{\partial^2\widetilde{D}_i(\underline{\theta};1)}{\partial r^2} < 0. \quad \text{(A.38)}$$

Continuity of the expected profit functions then implies that there exists an $R^{(i)} < 1$ such that for all $R \in (R^{(i)}, 1)$: $d\widehat{\Pi}_i\left(\widehat{R}(\widetilde{\rho}(R))\right)/dR < d\widetilde{\Pi}_i(R)/dR$. And since $\widehat{\Pi}_i\left(\widehat{R}(\widetilde{\rho}(1))\right) = \widetilde{\Pi}_i(1)$, this implies that $\widehat{\Pi}_i\left(\widehat{R}(\widetilde{\rho}(R))\right) > \widetilde{\Pi}_i(R)$ for all $R \in (R^{(i)}, 1)$. Take $R = \widetilde{R}(\rho)$, and note that $\widetilde{\rho}(\widetilde{R}(\rho)) = \rho$. This implies that $\widehat{\Pi}_i(\widehat{R}(\rho)) > \widetilde{\Pi}_i(\widetilde{R}(\rho))$ holds for all $\rho < \widehat{\rho}$, where $\widehat{\rho} \equiv \widetilde{\rho}(R^{(i)})$, as is stated in part (i) of the proposition.
(ii) It is easily verified that $\widehat{\Pi}_i\left(\widehat{R}(\widetilde{\rho}(0))\right) = \widetilde{\Pi}_i(0)$. Furthermore it is straightforward to show that:

$$\frac{d\widehat{\Pi}_i\left(\widehat{R}(\widetilde{\rho}(0))\right)}{dR} - \frac{d\widetilde{\Pi}_i(0)}{dR} = \frac{3\widehat{\Psi}^2}{2\widetilde{\Psi}(0)} + \frac{d\widetilde{\Psi}(0)}{dR} - \frac{1}{2}\widetilde{\Psi}(0) - p\underline{\theta}\widetilde{D}_i(\underline{\theta};0)\frac{\partial \widetilde{D}_i(\underline{\theta};0)}{\partial r}, \quad \text{(A.39)}$$

Therefore $d\left(\widehat{\Pi}_i(\widehat{R}(\widetilde{\rho}(0))) - \widetilde{\Pi}_i(0)\right)/dR > 0$ if $C_0 > 0$, and the reverse holds if $C_0 < 0$. Continuity of $\widehat{\Pi}_i(\widehat{R}(\widetilde{\rho}(R))) - \widetilde{\Pi}_i(R)$ in R, implies that there is an $R^{(ii)} > 0$ such that for all $0 < R < R^{(ii)}$: $\widehat{\Pi}_i(\widehat{R}(\widetilde{\rho}(R))) > \widetilde{\Pi}_i(R)$ if $C_0 > 0$, and $\widehat{\Pi}_i(\widehat{R}(\widetilde{\rho}(R))) < \widetilde{\Pi}_i(R)$ if $C_0 < 0$. Define $\widetilde{\rho} \equiv \widetilde{\rho}(R^{(ii)})$. Note that $\widetilde{\rho}(\widetilde{R}(\rho)) = \rho$, and therefore $\widehat{\Pi}_i\left(\widehat{R}(\widetilde{\rho}(\widetilde{R}(\rho)))\right) \equiv \widehat{\Pi}_i\left(\widehat{R}(\rho)\right)$. Hence we obtain the existence of a $\widetilde{\rho} < \infty$, such that for all $\rho > \widetilde{\rho}$: $\widehat{\Pi}_i(\widehat{R}(\rho)) > \widetilde{\Pi}_i(\widetilde{R}(\rho))$ if $C_0 > 0$, and $\widehat{\Pi}_i(\widehat{R}(\rho)) < \widetilde{\Pi}_i(\widetilde{R}(\rho))$ if $C_0 < 0$, which is stated in part (ii) of the proposition. This completes the proof of proposition 6.□

A.4 Conditions for Partial Disclosure, Proposition 7

Suppose $\widetilde{\delta}$ is the equilibrium disclosure rule. This disclosure rule gives equilibrium R&D investments $\widetilde{D}_i(\underline{\theta})$, $\widetilde{D}_i(\varnothing)$ and $\widetilde{D}_i(\overline{\theta})$ for firm i. Consider the two possible deviations from the equilibrium disclosure rule. First, a firm with a low cost signal, $\Theta_i = \underline{\theta}$, can choose to disclose its information. Disclosing low R&D costs, results in investment $\widehat{D}_i(\underline{\theta})$ and profit $\frac{1}{2}\underline{\theta}\widehat{D}_i(\underline{\theta})^2$ for firm i. Concealment of low costs gives expected equilibrium profits $\frac{1}{2}\underline{\theta}\widetilde{D}_i(\underline{\theta})^2$. Therefore deviation from the equilibrium disclosure rule is not profitable whenever $\widehat{D}_i(\underline{\theta}) \leq \widetilde{D}_i(\underline{\theta})$. After solving for the equilibrium investment from (A.5) we obtain:

$$\widetilde{D}_i(\underline{\theta}) - \widehat{D}_i(\underline{\theta}) = \frac{W(1-p)(\overline{\theta}-\underline{\theta})(1-r_i)(1-r_j)\Delta Z_D^L}{(\underline{\theta}+\Delta)Z_N}, \quad \text{(A.40)}$$

with

$$
\begin{aligned}
Z_N &= \left[p(1-p)\left(r_i(1-r_j)+(1-r_i)r_j\right)\overline{\theta}+p^2(r_i+r_j-r_ir_j)\underline{\theta}\right]\underline{\theta}(\underline{\theta}^2-\Delta^2)+ \\
&\quad +(1-r_i)(1-r_j)\left[\underline{\theta}^2\left(E(\theta)^2-\Delta^2\right)-(1-p)^2r_ir_j\Delta^2(\overline{\theta}^2-\Delta^2)\right] \qquad \text{(A.41)} \\
&\geq (1-r_i)(1-r_j)\left[\underline{\theta}^2\left(E(\theta)^2-\Delta^2\right)-(1-p)^2r_ir_j\Delta^2(\overline{\theta}^2-\Delta^2)\right] \\
&= (1-r_i)(1-r_j)\left[\underline{\theta}^2\left(p^2(\underline{\theta}^2-\Delta^2)+2p(1-p)(\underline{\theta}\overline{\theta}-\Delta^2)\right)+\right. \\
&\quad \left.+(1-p)^2(\overline{\theta}^2-\Delta^2)\left(\underline{\theta}^2-r_ir_j\Delta^2\right)\right],
\end{aligned}
$$

which is clearly non-negative, and

$$
Z_D^L=(1-p)(\overline{\theta}-\Delta)\left((1-r_i)\underline{\theta}-r_i(1-r_j)\Delta\right)+p\underline{\theta}(\underline{\theta}-\Delta). \qquad \text{(A.42)}
$$

Note that $Z_D^L \geq 0$ under condition (C.3).

Second, a firm with a high cost signal, $\Theta_i=\overline{\theta}$, can choose to conceal its information. After disclosing high costs, firm i receives profit $\frac{1}{2}\overline{\theta}\widetilde{D}_i(\overline{\theta})^2$. After stating $\delta_i^*=\varnothing$, high-cost firm i only changes firm j's R&D investments when $\Theta_j=\varnothing$. In that case firm j's investment changes from $\widetilde{D}_j(\overline{\theta})$ to $\widetilde{D}_j(\varnothing)$. Consequently firm i's deviation investment and profits are respectively:

$$
\overline{\theta}D_i^{\varnothing}=W-\left(r_j\widetilde{D}_j(\overline{\theta})+(1-r_j)\widetilde{D}_j(\varnothing)\right)\Delta \text{ and } \pi_i^{\varnothing}(\varnothing|\overline{\theta})=\frac{1}{2}\overline{\theta}(D_i^{\varnothing})^2. \qquad \text{(A.43)}
$$

Therefore, when $r_j<1$ deviation from $\widetilde{\delta}_i(\overline{\theta})$ is not profitable whenever $D_i^{\varnothing}\leq\widetilde{D}_i(\overline{\theta})$, or $\widetilde{D}_j(\varnothing)\geq\widetilde{D}_j(\overline{\theta})$. After deriving equilibrium investment $\widetilde{D}_j(\varnothing)$ from (A.7) we rewrite the inequality to:

$$
\widetilde{D}_j(\varnothing)-\widehat{D}_j(\overline{\theta})=\frac{Wp\underline{\theta}(\overline{\theta}-\underline{\theta})Z_D^H}{(\overline{\theta}+\Delta)Z_N}\geq 0, \qquad \text{(A.44)}
$$

where

$$
Z_D^H=p\underline{\theta}(\underline{\theta}-\Delta)+(1-p)[(1-r_j)\left(\underline{\theta}-r_i\Delta\right)\overline{\theta}-(1-r_i)(\underline{\theta}-r_j\Delta)\Delta], \qquad \text{(A.45)}
$$

and $Z_D^H\geq 0$ gives condition (C.4). This completes the proof.□

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