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Jansen, Jos

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Strategic information disclosure and competition for an imperfectly protected innovation

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Jos Jansen

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Max Planck Institute for Research on Collective Goods, Kurt-Schumacher-Str. 10, D-53113 Bonn
http://www.coll.mpg.de

Strategic Information Disclosure and Competition for an Imperfectly Protected Innovation*

Jos Jansen
Max Planck Institute for Research on Collective Goods†

February 2009

Abstract

The imperfect appropriability of revenues from innovation affects the incentives of firms to invest, and to disclose information about their innovative productivity. It creates a free-rider effect in the competition for the innovation that countervails the familiar business-stealing effect. Moreover, it aff

direct cost effect outweighs the indirect competition effect, a more optimistic firm invests more than a pessimistic firm, i.e., $x_R^*(\overline{\theta}) \leq x_R^*(\varnothing) \leq x_R^*(\underline{\theta})$, as stated in part (b) of the lemma. Moreover, the equilibrium investment of firm R with message $\varnothing$ is increasing in posterior probability $P(\varnothing)$, i.e., $\partial x_R^*(\varnothing)/\partial P(\varnothing) > 0$.[14]

Firm S chooses the best response strategy to firm R's investment levels. Analogous to the observation on firm R's investment incentives, firm S with good news has a greater incentive to invest in R&D than firm S with bad news, i.e., $x_S^*(\underline{\theta}; m) > x_S^*(\overline{\theta}; m')$ for any feasible messages m and m'. The effect of disclosure on the investment incentive of firm S depends on the effect of disclosure on firm R's beliefs. Firm R is more pessimistic about the cost of investment after concealment of good news, and invests less, than after disclosure. Consequently, firm S has a greater incentive to invest, i.e., $x_S^*(\underline{\theta}; \varnothing) \geq x_S^*(\underline{\theta}; \underline{\theta})$. Analogous arguments give: $x_S^*(\overline{\theta}; \overline{\theta}) \geq x_S^*(\overline{\theta}; \varnothing)$. A marginal change of the posterior belief $P(\varnothing)$ has similar effects on the investment incentives of a concealing firm S.

Finally, the *ex ante* expected equilibrium investments of firms R and S for disclosure strategy $\boldsymbol{\mu}$ are defined as follows:

$$X_R^*(\boldsymbol{\mu}; \sigma) \equiv E_\theta E_{m(\theta)} \left\{ x_R^*(m(\theta)) \right\}, \text{ and } X_S^*(\boldsymbol{\mu}; \sigma) \equiv E_\theta E_{m(\theta)} \left\{ x_S^*(\theta; m(\theta)) \right\},$$

respectively, with (for $i \in \{R, S\}$)

$$E_{m(\theta)} \left\{ x_i^*(m(\theta)) \right\} \equiv \mu(\theta) x_i^*(\theta) + \left[1 - \mu(\theta) \right] x_i^*(\varnothing).$$

The *ex ante* expected equilibrium investment is independent of the disclosure rule, i.e., $X_i^*(\boldsymbol{\mu}; \sigma) = \widehat{X}(\sigma)$ for any $\boldsymbol{\mu}$ and $i \in \{R, S\}$, with:

$$\widehat{X}(\sigma) \equiv \frac{(1 - \sigma)V - E(\theta)}{\lambda + V/2}. \tag{3.4}$$

This results from the linearity of the equilibrium investments in cost parameter θ.[15]

[14] Combining this fact with the earlier observations that posterior belief $P(\varnothing)$ decreases (increases) in the disclosure probability $\mu(\underline{\theta})$ (respectively, $\mu(\overline{\theta})$), gives part (c) of the lemma.

[15] On the one hand, an increase of $\mu(\theta)$ makes it more likely that firm R invests $x_R^*(\theta)$ instead of $x_R^*(\varnothing)$. On the other hand, an increase in $\mu(\theta)$ changes firm R's investment $x_R^*(\varnothing)$ indirectly through its beliefs. The direct effect exactly offsets the indirect effect. A similar trade-off emerges for firm S. By contrast, in Jansen (2001), where equilibrium investments are non-linear functions of parameter θ, the *ex ante* expected investment under full concealment is smaller than the expected investment under full disclosure.

3.2 Profits

In this subsection I study the firms' equilibrium profits for a given disclosure rule. The *ex ante* expected profit of firm i is defined as follows (for $i \in \{R, S\}$):

$$\Pi_i^*(\boldsymbol{\mu}; \sigma) \equiv E_\theta E_{m(\theta)} \left\{ \pi_i(\mathbf{x}^*(m); \theta, \sigma) \right\}. \tag{3.5}$$

The effect of an increase in the spillover is summarized in the following proposition.

Proposition 1 *For any exogenously given disclosure rule $\boldsymbol{\mu}$ and $i \in \{R, S\}$, the ex ante expected equilibrium profit $\Pi_i^*(\boldsymbol{\mu}; \sigma)$ is single-peaked in spillover σ, and is maximized for spillover $\widehat{\sigma}$, with $0 < \widehat{\sigma} < \frac{1}{2}$.*

The marginal effect of a spillover change on the *ex ante* expected profits can be decomposed in two effects (for $i, j \in \{R, S\}$ and $i \neq j$):

$$\frac{\partial \Pi_i^*(\boldsymbol{\mu}; \sigma)}{\partial \sigma} = E_\theta E_{m(\theta)} \left\{ \frac{\partial \pi_i(\mathbf{x}^*; \theta, \sigma)}{\partial x_j} \cdot \frac{\partial x_j^*}{\partial \sigma} + \frac{\partial \pi_i(\mathbf{x}^*; \theta, \sigma)}{\partial \sigma} \right\}. \tag{3.6}$$

The first term represents an indirect effect. I showed in Lemma 1 (a) that equilibrium investments are decreasing in the spillover, i.e., $\partial x_j^*/\partial \sigma < 0$. The effect of the reduction of the rival's investment on firm i's expected profit depends on the size of the spillover. This effect is as follows:

$$\frac{\partial \pi_i}{\partial x_j} = \left(\sigma - \frac{1}{2} x_i \right) V. \tag{3.7}$$

If the spillover is sufficiently small, then $\partial \pi_i / \partial x_j < 0$. In that case firm i is better off if its rival's investments are reduced, since the business-stealing effect dominates. If the firms share their revenues equally ($\sigma = \frac{1}{2}$), then $\partial \pi_i / \partial x_j > 0$. Hence, for a sufficiently large spillover, and given the own investment, firms would prefer to compete against a rival with high investments, since the free-rider effect is the dominant effect here. The indirect effect is therefore positive for a sufficiently small spillover, and negative for a sufficiently big spillover.

The last term in (3.6) is the direct effect of the spillover on firm i's profits. On the one hand, expected profits are reduced by $VX_i^*(\boldsymbol{\mu}; \sigma)$, since for each unit of a firm's own investment the appropriable revenue is lower. On the other hand, the expected profit is increased by the revenue that spills over from investments of the rival firm, i.e., $VX_j^*(\boldsymbol{\mu}; \sigma)$. These two effects exactly offset each other, since expected equilibrium investments are symmetric (Lemma 1d). The direct effect is therefore zero.

Hence, the overall effect is such that the equilibrium profits are initially increasing, and subsequently decreasing in the spillover. In particular, the spillover $\widehat{\sigma} \in (0, \frac{1}{2})$, which maximizes the firms' *ex ante* expected profits, equals:

$$\widehat{\sigma} = \frac{V - E(\theta)}{2(\lambda + V)}, \tag{3.8}$$

and yields a prize structure strictly between winner-take-all and equal-sharing.

4 Information Disclosure

So far I considered investments and profits for an exogenously given disclosure rule. This section analyzes the incentives to disclose information.

4.1 Precommitment to Disclose Information

The incentive to precommit to an information disclosure rule depends on the effects of disclosure rule changes on the expected profits. The expected profits of firm R and S are, respectively:

$$\Pi_R^*(\boldsymbol{\mu}; \sigma) = \frac{\lambda}{2} E\left\{\mu(\theta) x_R^*(\theta)^2 + [1 - \mu(\theta)]\, x_R^*(\varnothing)^2\right\} + \sigma V X_R^*(\boldsymbol{\mu}; \sigma), \text{ and} \tag{4.1}$$

$$\Pi_S^*(\boldsymbol{\mu}; \sigma) = \frac{\lambda}{2} E\left\{\mu(\theta) x_S^*(\theta; \theta)^2 + [1 - \mu(\theta)]\, x_S^*(\theta; \varnothing)^2\right\} + \sigma V X_S^*(\boldsymbol{\mu}; \sigma). \tag{4.2}$$

An immediate implication of Lemma 1 (d) is that the *ex ante* expected spillover term $\sigma V X_i^*(\boldsymbol{\mu}; \sigma)$ is independent of the disclosure rule for any firm i. Information disclosure has the following effects for the remaining terms of the expected profit functions.

Proposition 2 *For any given spillover σ, firm R prefers precommitment to full disclosure, and firm S prefers precommitment to full concealment. In particular, $\partial \Pi_R^* / \partial \mu(\theta) > 0$ and $\partial \Pi_S^* / \partial \mu(\theta) < 0$ for any $\theta \in \{\underline{\theta}, \overline{\theta}\}$ and any σ.*

First, an increase of the disclosure probability $\mu(\theta)$ increases the likelihood that firm R is able to adjust its investment level to the firm's actual productivity. This increases the average efficiency of firm R's decisions, and increases the firm's expected profit. Second, an increase of the disclosure probability, and subsequent investment adjustments by firm R, increases the correlation between the firms' investments. The increased correlation between investment levels reduces the expected profit of firm S, since investments are strategic substitutes. That is, whereas the expected profit of

firm R increases in the disclosure probability, the expected profit of firm S decreases in disclosure. Consequently, if firm S can precommit to an information-sharing rule before it learns information θ, then it will choose to conceal all information.

The effects of disclosure are independent of the spillover parameter σ for the following reason. Disclosure strategies only affect the variance of the firms' investments, not the mean (Lemma 1d). Conversely, the spillover only affects the average investment level, since it creates a uniform downward shift of investments, and does not affect the variance. Consequently, the effect of disclosure on expected profits does not depend on the size of spillover.

4.2 Strategic Information Disclosure

This subsection studies the incentives of firm S to share information after it received information. Firm S anticipates the effects of its disclosure rule on the beliefs of firm R, and chooses the disclosure rule which maximizes its expected profit. The proposition below shows that for intermediate spillovers firm S discloses its information only partially or not at all. That is, the "unraveling result" of Okuno-Fujiwara *et al.* (1990) breaks down for these spillover values.[16]

Proposition 3 *The values $\underline{\sigma}_k$ and $\overline{\sigma}_k$, and continuous functions $\mu^k : [\underline{\sigma}_k, \overline{\sigma}_k] \to [0,1]$ exist for $k \in \{L, H\}$, where $0 < \underline{\sigma}_L < \overline{\sigma}_L < \widehat{\sigma} < \underline{\sigma}_H < \overline{\sigma}_H < \frac{1}{2}$, μ^L is decreasing, with $\mu^L(\underline{\sigma}_L) = 1$ and $\mu^L(\overline{\sigma}_L) = 0$, and μ^H is increasing, with $\mu^H(\underline{\sigma}_H) = 0$ and $\mu^H(\overline{\sigma}_H) = 1$, such that firm S chooses the following disclosure rule in the unique equilibrium:*[17]
***(a)** if $\sigma \leq \underline{\sigma}_L$, then full disclosure with skeptical beliefs, e.g., $\big(\mu^*(\underline{\theta}), \mu^*(\overline{\theta})\big) = (0,1)$,*
***(b)** if $\underline{\sigma}_L < \sigma < \overline{\sigma}_L$, then partial disclosure, i.e., $\big(\mu^*(\underline{\theta}), \mu^*(\overline{\theta})\big) = (0, \mu^L(\sigma))$,*
***(c)** if $\overline{\sigma}_L \leq \sigma \leq \underline{\sigma}_H$, then full concealment, i.e., $\big(\mu^*(\underline{\theta}), \mu^*(\overline{\theta})\big) = (0,0)$,*
***(d)** if $\underline{\sigma}_H < \sigma < \overline{\sigma}_H$, then partial disclosure, i.e., $\big(\mu^*(\underline{\theta}), \mu^*(\overline{\theta})\big) = (\mu^H(\sigma), 0)$,*
***(e)** if $\sigma \geq \overline{\sigma}_H$, then full disclosure with skeptical beliefs, e.g., $\big(\mu^*(\underline{\theta}), \mu^*(\overline{\theta})\big) = (1,0)$.*

The disclosure probabilities $\mu^L(\sigma)$ and $\mu^H(\sigma)$ are illustrated in Figure 1 below.

For low spillovers, a firm's profit is decreasing in the rival's investment level, and consequently firm S has an incentive to disclose only bad news. Firm R anticipates

[16] An important condition for unraveling, which is not satisfied here, is monotonicity of firm S's profit in the rival's strategy. The change in sign of $\partial \pi_S / \partial x_R$ for an intermediate spillover plays an important role for firm S's information disclosure incentives.

[17] Strictly speaking, there are several disclosure rules that may be chosen in parts **(a)** and **(e)**. In particular, $\big(\mu(\underline{\theta}), \mu(\overline{\theta})\big) = (q, 1)$ and $\big(\mu(\underline{\theta}), \mu(\overline{\theta})\big) = (1, q)$ are equilibrium disclosure rules for any $q \in [0,1]$ in **(a)** and **(e)**, respectively. But these disclosure rules transmit the same amount of information with skeptical beliefs, i.e., complete information disclosure.

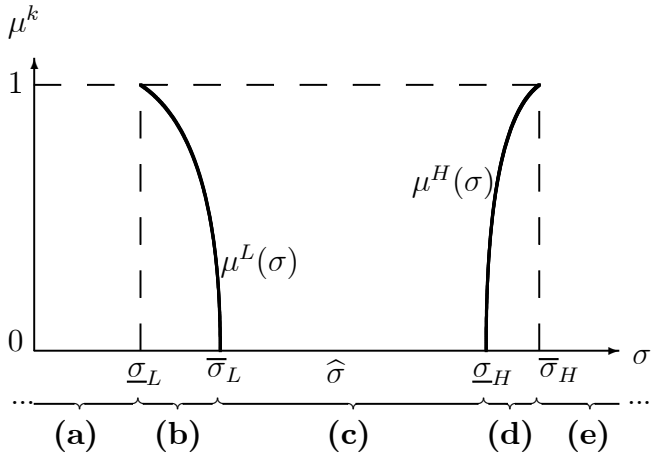

Figure 1: Equilibrium disclosure strategy

this and infers that the concealing firm received low cost information. This eliminates firm S's possibilities to effectively conceal information. For a sufficiently high spillover the reverse holds, i.e., profits are increasing in the rival's investment level, which gives firm S an incentive to disclose only good news. But the disclosure equilibrium is the same as for low spillovers, i.e., full disclosure with skeptical beliefs. This is the unraveling result, as obtained by, e.g., Grossman (1981) and Milgrom (1981).

For intermediate spillovers the intuition is more subtle. As is clear from expression (3.7), the sign of $\partial \pi_S / \partial x_R$ depends not only on the spillover size, but also on firm S's investment x_S. As was observed in lemma 1 (b), a firm with good news invests more than a firm with bad news. Therefore, given beliefs, a region of intermediate spillover values exists where the following holds. On the one hand, firm S's profit is decreasing in firm R's investment, if firm S received good news. But, on the other hand, the firm's profit is increasing in its rival's investment if the firm received bad news. In other words, the firm has countervailing incentives for intermediate spillover values (Lewis and Sappington, 1989). This gives both a firm with good news and a firm with bad news an incentive to conceal information. The firm with good news conceals to discourage investments by its rival (since the firm's profit is decreasing in the rival's investment). But the firm with bad news has an incentive to conceal, because it would like to encourage investments by its rival (since the firm's profit is increasing in its rival's investment). Since both types of firm S have an incentive to conceal its cost information, it can credibly do so. This explains that, for intermediate spillover values, firm S fully conceals the cost in equilibrium.[18]

[18] Hendricks and Kovenock (1989) obtain a related non-disclosure result for a common value model of oil exploration. This result is notably different from those of, e.g., Bhattacharya and Ritter (1983),

Partial disclosure emerges as the equilibrium disclosure rule for the remaining spillover values. These spillover values are such that firm S of one type (e.g., $\underline{\theta}$) prefers to conceal, whereas the other type (e.g., $\overline{\theta}$) is indifferent between disclosure and concealment, given rival's beliefs consistent with such a partial disclosure rule.[19]

The comparison of Propositions 2 and 3 highlights the contrast between the *ex ante* and *ex post* incentives of firms to disclose information. The next section argues that this difference in disclosure incentives has some interesting implications.

5 Implications

After characterizing the equilibrium strategies, I now analyze the consequences for the equilibrium profits, and the probability of innovation.

5.1 Effects on Profits

How does a firm's *ex ante* expected equilibrium profit depend on the spillover? The overall effect of a marginal change in the spillover σ on the expected equilibrium profit is as follows (for Π_R^* and Π_S^* as in (4.1) and (4.2), respectively):

$$\frac{d\Pi_i^*(\boldsymbol{\mu}^*(\sigma);\sigma)}{d\sigma} = \sum_{\theta\in\{\underline{\theta},\overline{\theta}\}} \frac{\partial\Pi_i^*(\boldsymbol{\mu}^*;\sigma)}{\partial\mu(\theta)} \cdot \frac{d\mu^*(\theta)}{d\sigma} + \frac{\partial\Pi_i^*(\boldsymbol{\mu}^*;\sigma)}{\partial\sigma} \tag{5.1}$$

This expression embodies a trade-off between two effects. On the one hand, an increase of the spillover has a direct effect on the expected equilibrium profit (Proposition 1). This direct effect is captured by the second term of (5.1). On the other hand, a marginal increase of the spillover may also have an indirect effect on the expected equilibrium profit, as is captured by the first term of (5.1). An increase of the spillover may change the equilibrium probability of information disclosure (Proposition 3), which in turn changes a firm's expected profit (Proposition 2).

For the spillover values in the intervals $[0, \underline{\sigma}_L]$, $[\overline{\sigma}_L, \underline{\sigma}_H]$, and $[\overline{\sigma}_H, \frac{1}{2}]$, only the direct effect emerges, since for these spillover values the equilibrium disclosure rule does not change with σ as Proposition 3 shows. Therefore, the result of Proposition 1 is directly applicable, and the equilibrium profits reach a local maximum in $\widehat{\sigma}$ on the interval $[\overline{\sigma}_L, \underline{\sigma}_H]$, where firm S conceals all information.

d'Aspremont *et al* (1998, 2000), and Anton and Yao (2003, 2004), who focus on separating equilibria.

[19] Proposition 3 could explain the disclosure of intermediate success by IBM, as reported in Choi (1991). Cold superconductivity is a basic innovation, which can have several applications. Hence, the innovation by one firm may be a source of considerable revenues for rivals. As shown, for sufficiently high spillover values, firm S indeed has an incentive to disclose good news with a positive probability.

For the remaining spillover values, i.e., for spillovers in the intervals $(\underline{\sigma}_L, \overline{\sigma}_L)$ and $(\underline{\sigma}_H, \overline{\sigma}_H)$, both the direct and indirect effects play a role, since for these values the equilibrium disclosure rule changes in the spillover. The trade-off between these two effects is different for the two firms, as the following proposition shows.

Proposition 4 ***(a)*** *Firm S's expected equilibrium profit is single-peaked in σ, and is maximized for spillover $\widehat{\sigma}$;* ***(b)*** *Firm R's expected equilibrium profit has three local maxima: each interval $[\underline{\sigma}_L, \overline{\sigma}_L)$ and $(\underline{\sigma}_H, \overline{\sigma}_H]$, as defined in proposition 3, contains one local maximum, and the third local maximum is reached for $\sigma = \widehat{\sigma}$, with $\widehat{\sigma}$ as defined in (3.8).*

For firm S the direct and indirect effects reinforce each other. The equilibrium profit of firm S is illustrated in Figure 2. The upper (lower) thin line represents

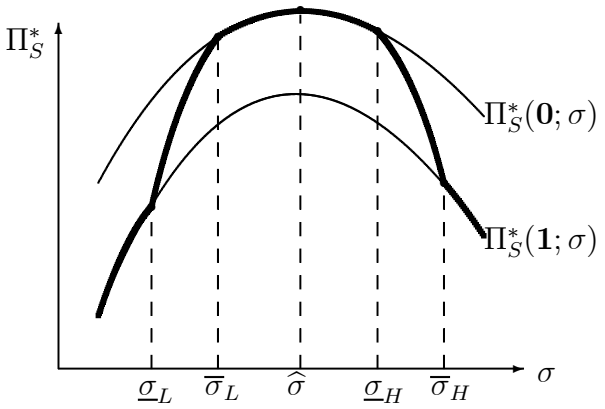

Figure 2: Equilibrium Profit of Firm S

the firm's profit under full concealment (full disclosure). The bold line sketches the expected profit for the equilibrium disclosure rule. Firm S expects the highest profit from full concealment (see Proposition 2). For extreme spillover values (i.e., $\sigma < \overline{\sigma}_L$ or $\sigma > \underline{\sigma}_H$), neither the investment incentives nor the information revelation incentives yield optimal expected profits for firm S. But for intermediate spillover values (i.e., $\overline{\sigma}_L < \sigma < \underline{\sigma}_H$) both R&D incentives (Proposition 1) and disclosure incentives (Proposition 3c) yield the highest expected profits, and expected profits reach a global maximum, as Figure 2 illustrates. Therefore, strategic disclosure has no effect on the choice of the spillover which maximizes the expected profit of firm S. However, strategic disclosure does affect the profit locally. In particular, on the interval $(\underline{\sigma}_L, \overline{\sigma}_L)$ (resp. $(\underline{\sigma}_H, \overline{\sigma}_H)$) the profit increases (decreases) more steeply in the spillover than in the absence of strategic disclosure.

For firm R the direct effect and indirect effects are in conflict. Figure 3 illustrates firm R's expected equilibrium profit. The upper (lower) thin line represents

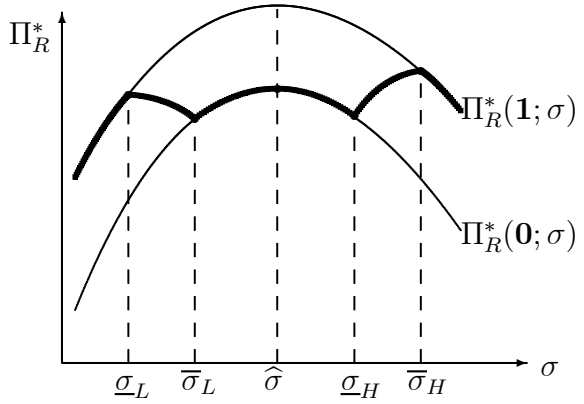

Figure 3: Equilibrium Profit of Firm R

the expected profit under full disclosure (full concealment). The bold line sketches the expected profit for the equilibrium disclosure rule. Firm R would earn the highest expected profits if all information were disclosed (Proposition 2). The firm can obtain this level of expected profit only for extreme spillover values (Proposition 3). However, for these spillover values the firms have sub-optimal investment incentives (Proposition 1). Conversely, for intermediate spillovers the strategic disclosure incentives are such that only sub-optimal expected profit levels can be reached, despite better investment incentives. As a consequence of this trade-off between investment incentives and disclosure incentives, two additional local maxima emerge. One emerges on the interval $[\underline{\sigma}_L, \overline{\sigma}_L]$, while the other emerges on $[\underline{\sigma}_H, \overline{\sigma}_H]$, as Figure 3 illustrates.[20]

5.2 Effects on Innovation Probability

Strategic disclosure may also have an effect on the probability of obtaining an innovation. For a given disclosure rule, $\boldsymbol{\mu}$, the expected probability of innovation in equilibrium equals:

$$I^*(\boldsymbol{\mu};\sigma) \equiv E_\theta E_{m(\theta)} \left\{1 - [1 - x_R^*(m(\theta))]\,[1 - x_S^*(\theta; m(\theta))]\right\}. \tag{5.2}$$

This equilibrium probability has the following properties.

Proposition 5 ***(a)*** *For any exogenously given disclosure rule, $\boldsymbol{\mu}$, the ex ante expected probability of innovation $I^*(\boldsymbol{\mu};\sigma)$ is decreasing (and concave) in the spillover σ.*

[20] The indirect effect dominates at least for spillover values sufficiently close to $\overline{\sigma}_L$ and $\underline{\sigma}_H$.

(b) *For any spillover σ the ex ante expected probability of innovation is decreasing in disclosure probability $\mu(\theta)$ for any θ, i.e., $\partial I^*(\boldsymbol{\mu};\sigma)/\partial\mu(\theta) < 0$ for $\theta \in \{\underline{\theta},\overline{\theta}\}$.*

First, the probability of innovation is decreasing in the spillover for any exogenously given disclosure rule, since the equilibrium investments are decreasing in the spillover. Second, disclosure has the following effect on the probability of innovation. The expected probability of innovation under full disclosure is the expected success probability from investments by informed firms, i.e., $E\{1-[1-x_R^*(\theta)]^2\}$. The expected probability under full concealment equals the success probability from expected investments by informed firms, i.e., $1-[1-E\{x_R^*(\theta)\}]^2$. The success probability from expected investments exceeds the expected success probability from informed firms' investments, since the success probability $1-(1-x)^2$ is concave in the investment x.

A marginal change of the spillover has the following overall effect on the probability of innovation in equilibrium:

$$\frac{dI^*(\boldsymbol{\mu}^*(\sigma);\sigma)}{d\sigma} = \sum_{\theta\in\{\underline{\theta},\overline{\theta}\}} \frac{\partial I^*(\boldsymbol{\mu}^*;\sigma)}{\partial\mu(\theta)} \cdot \frac{d\mu^*(\theta)}{d\sigma} + \frac{\partial I^*(\boldsymbol{\mu}^*;\sigma)}{\partial\sigma}. \tag{5.3}$$

As in the profit analysis, a marginal spillover increase yields a trade-off between a direct and an indirect effect. On the one hand, the spillover increase reduces the probability of innovation, as is summarized by the second term of (5.3), which is negative. On the other hand, the spillover increase may affect the equilibrium disclosure rule (Proposition 3), and thereby indirectly change the probability of innovation, since it is decreasing in the disclosure probability. This indirect effect is represented by the first term of (5.3). The trade-off gives the following result.

Proposition 6 *The expected probability of innovation in equilibrium, $I^*(\boldsymbol{\mu}^*(\sigma);\sigma)$, has at most two local maxima. The first local maximum is reached for $\sigma = 0$, it always exists, and it is the unique global maximum. If a second local maximum exists, then it is reached for some spillover σ^o in the interval $(\underline{\sigma}_L,\overline{\sigma}_L]$, as defined in proposition 3. In particular, the critical value λ^o exists such that if $\lambda > \lambda^o$, then the second local maximum exists, and is reached for $\sigma = \overline{\sigma}_L$.*

For all spillovers $\sigma \notin (\underline{\sigma}_L,\overline{\sigma}_L)$ the probability of innovation is decreasing in the spillover, since the direct and indirect effects are not in conflict. Figure 4 illustrates the expected probability of innovation. The upper (lower) thin line represents the expected success probability for full concealment (resp. full disclosure). The thick line sketches the expected success probability for the equilibrium disclosure rule. Strategic

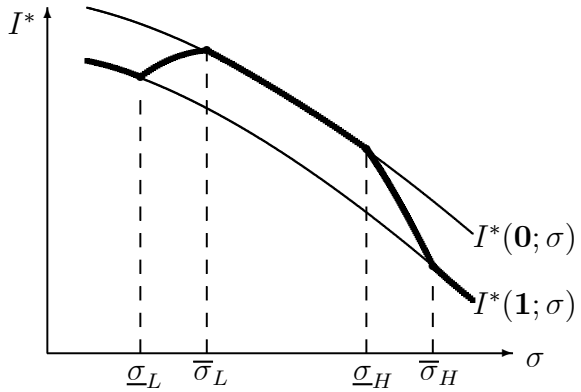

Figure 4: Probability of Innovation

disclosure makes the bold line steeper than any of the thin lines for $\underline{\sigma}_H < \sigma < \overline{\sigma}_H$, since the indirect effect reinforces the direct effect on this interval.

For $\sigma \in (\underline{\sigma}_L, \overline{\sigma}_L)$ the direct and indirect effects are in conflict. On the one hand, the probability of innovation would increase by a spillover reduction for any exogenously given disclosure rule (the second term in 5.3 is always negative). On the other hand, such a spillover reduction increases the disclosure probability μ^L (by Proposition 3), which in turn reduces the probability of innovation (the first term of 5.3 is positive). If the marginal cost of investment is sufficiently steep (i.e., λ is high), then the indirect effect dominates the direct effect. In this case, the probability of innovation increases by reducing the appropriability of revenues from innovation. This is illustrated in Figure 4, where the success probability reaches a local maximum for spillover value $\sigma = \overline{\sigma}_L$.

Although the probability of innovation may reach a local maximum for $\sigma = \overline{\sigma}_L$, the global maximum is unchanged. Perfect appropriability of revenues from innovation ($\sigma = 0$) gives the greatest investments in R&D, and the highest probability of innovation (see the Supplementary Appendix).

6 Discussion

In this section, I discuss the effects of some extensions on the paper's main results.

6.1 Information Structure

The analysis of disclosure incentives in proposition 3 has also implications for the incentives to reveal non-verifiable information. If signals are non-verifiable, then firm

S may misrepresent them. In fact, it is intuitive and easy to show that firm S can never credibly signal the productivity to firm R.

Proposition 7 *If information θ is non-verifiable, then there only exist equilibria in which firm S sends non-informative signals to firm R.*

First, if firm R believes any message it receives, i.e., it has beliefs consistent with truthful revelation, then firm S has an incentive to misrepresent its cost for any spillover value. Firm S with good (bad) news has an incentive to misrepresent its information, and thereby reduce (increase) the investment of a credulous rival, for any $\sigma < \overline{\sigma}_H$ (respectively, $\sigma > \underline{\sigma}_L$). Since $\underline{\sigma}_L < \overline{\sigma}_H$, as shown in Proposition 3, there is always a firm type with an incentive to deviate from truthful revelation. Similar incentives are present for less extreme beliefs. Second, for any spillover there exists an equilibrium in which no information is revealed.[21] This is a standard result for models with non-verifiable signals. Therefore, there only exist equilibria in which firm S sends non-informative signals to firm R. This observation extends the result of Ziv (1993) to a setting with spillovers between firms.

The basic model assumes that firm S receives a perfectly informative signal about the firms' R&D productivity. The introduction of some noise would alter the information and beliefs of firms, since the firms now base their investment decisions on a signal (and the message about the signal), which is positively correlated with θ. But the basic intuition and qualitative results do not change (Jansen, 2004).

Alternatively, the signal of firm S can be imperfect, since the firm may fail to receive information (Dye, 1985, and Farrell, 1986). Uncertainty about the informedness of firm S has the following effects on the R&D incentives, disclosure incentives, and profits. As before, firm S has an incentive to disclose bad (good) news while concealing good (bad) news for sufficiently low (high) spillover values. The crucial difference with the previous analysis is that these disclosure strategies no longer result in unraveling. Now it remains ambiguous whether firm S is informed and conceals the information, or firm S is uninformed (Shin, 1994, and Jansen, 2008). Despite the altered beliefs and failure of full unraveling, the basic trade-offs in the analysis are unchanged.

Finally, the model can be extended by introducing two-sided asymmetric information without changing the qualitative results (Jansen, 2004).

[21] If firm R expects uninformative claims from its rival, it ignores these claims. Consequently, firm S is indifferent between truthful, untruthful, and uninformative claims.

6.2 Policy Conclusions

This paper treats the spillover σ as a parameter, and performs a comparative statics analysis. In practice, however, firms or policy makers may be able to influence the size of the spillover.

Firms may affect the size of the spillover by adjusting their research design (Katsoulacos and Ulph, 1998, and Kamien and Zang, 2000) or location (Gersbach and Schmutzler, 2003, and Fosfuri and Rønde, 2004). First, if the firms do not coordinate, and they can adjust the spillover choice in the short term, then the individual profits are relevant. Section 3 shows that the firms' interests are aligned if information is exogenous (i.e., both firms prefer to move the spillover in the direction of $\widehat{\sigma}$). However, strategic information disclosure may create a conflict of interest between the sender and receiver of information. For spillovers in the intervals $[\underline{\sigma}_L, \overline{\sigma}_L]$ and $[\underline{\sigma}_H, \overline{\sigma}_H]$ the sender prefers to move the spillover towards $\widehat{\sigma}$, whereas the receiver prefers to move the spillover away from $\widehat{\sigma}$, as section 5.1 shows.

Second, if firms coordinate the spillover choice, or if the choice is a long-term commitment, then the industry profits may be more relevant.[22] The analysis of the industry profits in equilibrium is analogous to the profit analysis of the individual firms. The effect of information disclosure on the industry profits depends on the size of cost parameter λ, as Vives (1984) and Kirby (1988) show.

Proposition 8 *Firms jointly prefer precommitment to full concealment (disclosure) if* $\lambda < \lambda^*$ *(respectively,* $\lambda > \lambda^*$*) where* $\lambda^* \equiv (1+\sqrt{2})V/2$*. In particular,* $\partial \sum_i \Pi_i^*/\partial\mu(\theta) \gtreqless 0$ *if* $\lambda \gtreqless \lambda^*$ *for any* $\theta \in \{\underline{\theta}, \overline{\theta}\}$*.*

If λ is sufficiently low (high), then the firms expects the highest profit from a *quid pro quo* agreement to conceal (disclose) all information.[23] Consequently, if λ is low, then the effect of a spillover choice on the expected industry profits corresponds to the effect on the sender's expected profit in section 5.1. Conversely, for high values of λ the industry's incentives to choose a spillover value correspond to the incentives of the receiver in section 5.1.

[22] For example, each firm maximizes industry profits in a model where the identity of the informed firm (S) is determined randomly at the beginning of the game, and the firms choose the spillover before their roles (i.e., receiver or sender) are determined. Alternatively, industry profits are relevant in a symmetric model with two-sided asymmetric information (Jansen, 2004).

[23] Clearly, if firms precommit to a disclosure rule non-cooperatively, then full information concealment is the dominant strategy, as follows from proposition 2.

Proposition 9 *The critical value λ^{**} exists, with $\lambda^{**} > \lambda^{*}$ (and λ^{*} as defined in proposition 2), such that if $\lambda \leq \lambda^{**}$, then the expected industry profits are single-peaked in σ, as in Proposition 4 (a), while if $\lambda > \lambda^{**}$, then the expected equilibrium industry profit has a similar shape as firm R's expected equilibrium profit in Proposition 4 (b).*

A policy maker may affect the size of the spillover by adjusting the strength of intellectual property rights (Denicolò, 1996, and Anton and Yao, 2003, 2004). For a policy maker, the probability of innovation may be important, since it may be related to the economic growth rate, or the consumer surplus. In this case the spillover choice follows from the analysis in section 5.2. A full welfare analysis would have to include the effects of rent dissipation. Unfortunately, such an analysis is less tractable, since equilibrium investments become nonlinear functions of the degree of appropriability. Such an analysis awaits future research.

A Appendix

In this Appendix I prove Lemma 1, and Propositions 1-9.

Proof of Lemma 1

The first-order conditions (3.2) and (3.3) yield the following equilibrium R&D investments of firm R and S, respectively (for $m \in \{\theta, \varnothing\}$ and $\theta \in \{\underline{\theta}, \overline{\theta}\}$):

$$x_R^*(m) = \frac{(1-\sigma)V - E(\theta|m)}{\lambda + V/2}, \tag{A.1}$$

$$x_S^*(\theta; m) = x_R^*(\theta) + \frac{[E(\theta|m) - \theta]\, V/2}{\lambda(\lambda + V/2)} \tag{A.2}$$

(a) Equilibrium investments are decreasing in σ, since $\partial x_R^*(m)/\partial\sigma < 0$ for any m.
(b) From (A.1) and (A.2) it is immediate that, respectively (for $\theta \in \{\underline{\theta}, \overline{\theta}\}$):

$$x_R^*(\theta) - x_R^*(\varnothing) = \frac{E(\theta|\varnothing) - \theta}{\lambda + V/2}, \text{ and} \tag{A.3}$$

$$x_S^*(\theta;\theta) - x_S^*(\theta;\varnothing) = \frac{-[E(\theta|\varnothing) - \theta]\, V/2}{\lambda(\lambda + V/2)}. \tag{A.4}$$

The inequalities then follow immediately from the inequality $\underline{\theta} \leq E(\theta|\varnothing) \leq \overline{\theta}$.
(c) It is easy to verify that (for $\theta \in \{\underline{\theta}, \overline{\theta}\}$):

$$\frac{\partial P(\varnothing)}{\partial \mu(\theta)} = \frac{\Pr(\theta)}{1 - E\{\mu(\theta)\}} \cdot \frac{\theta - E\{\theta|\varnothing\}}{\overline{\theta} - \underline{\theta}}. \tag{A.5}$$

Moreover, it follows immediately from (A.1) and (A.2) that, respectively:

$$\frac{\partial x_R^*(\varnothing)}{\partial P(\varnothing)} = \frac{\overline{\theta} - \underline{\theta}}{\lambda + V/2} > 0, \text{ and } \frac{\partial x_S^*(\theta;\varnothing)}{\partial P(\varnothing)} = \frac{-(\overline{\theta} - \underline{\theta})V/2}{\lambda(\lambda + V/2)} < 0. \tag{A.6}$$

Combining (A.5) with (A.6) yields (for $\theta, \theta' \in \{\underline{\theta}, \overline{\theta}\}$):

$$\frac{\partial x_R^*(\varnothing)}{\partial \mu(\theta)} = \frac{\partial x_R^*(\varnothing)}{\partial P(\varnothing)} \cdot \frac{\partial P(\varnothing)}{\partial \mu(\theta)} = \frac{\Pr(\theta)}{1 - E\{\mu(\theta)\}} \cdot \frac{\theta - E\{\theta|\varnothing\}}{\lambda + V/2}, \text{ and} \tag{A.7}$$

$$\frac{\partial x_S^*(\theta';\varnothing)}{\partial \mu(\theta)} = \frac{\partial x_S^*(\theta';\varnothing)}{\partial P(\varnothing)} \cdot \frac{\partial P(\varnothing)}{\partial \mu(\theta)} = \frac{-\Pr(\theta)}{1 - E\{\mu(\theta)\}} \cdot \frac{[\theta - E\{\theta|\varnothing\}]\, V/2}{\lambda(\lambda + V/2)}. \tag{A.8}$$

The signs of these expressions then follow immediately from $\underline{\theta} \leq E(\theta|\varnothing) \leq \overline{\theta}$.

(d) The *ex ante* expected equilibrium investments of firms R and S equal:

$$X_R^*(\boldsymbol{\mu};\sigma) = E\left\{\mu(\theta) x_R^*(\theta)\right\} + \left[1 - E\{\mu(\theta)\}\right] x_R^*(\varnothing), \tag{A.9}$$

$$X_S^*(\boldsymbol{\mu};\sigma) = E\left\{\mu(\theta) x_S^*(\theta;\theta) + \left[1 - \mu(\theta)\right] x_S^*(\theta;\varnothing)\right\}. \tag{A.10}$$

Substituting (A.1) in (A.9), and (A.2) in (A.10), gives $X_i^*(\boldsymbol{\mu};\sigma) = \widehat{X}(\sigma)$ for all i. □

Proof of Proposition 1

Lemma 1 (d) implies that $E_\theta E_{m(\theta)} \left\{ \frac{\partial \pi_i(\mathbf{x}^*;\theta,\sigma)}{\partial \sigma} \right\} = 0$ for all i and σ. Expressions (A.1) and (A.2) imply that $\partial x_j^*/\partial \sigma = -V/(\lambda + V/2)$ for all θ, m, and $j \in \{R, S\}$. Using these facts, together with (3.7), reduces (3.6) for $i \in \{R, S\}$ to:

$$\begin{aligned} \frac{\partial \Pi_i^*(\boldsymbol{\mu};\sigma)}{\partial \sigma} &= -\left(\sigma - \frac{1}{2}\widehat{X}(\sigma)\right) \cdot \frac{V^2}{\lambda + V/2} \\ &= -\left(\sigma(\lambda + V) - \frac{1}{2}(V - E(\theta))\right) \cdot \left(\frac{V}{\lambda + V/2}\right)^2. \end{aligned} \tag{A.11}$$

Clearly, $\partial \Pi_i^*/\partial \sigma$ is linear in σ, with $\partial \Pi_i^*(\boldsymbol{\mu};0)/\partial \sigma > 0 > \partial \Pi_i^*(\boldsymbol{\mu};\frac{1}{2})/\partial \sigma$, and it is independent of i. Hence, Π_i^* is single-peaked in σ, and the unique spillover $\widehat{\sigma} \in (0, \frac{1}{2})$ exists with $\partial \Pi_i^*(\boldsymbol{\mu};\widehat{\sigma})/\partial \sigma = 0$ for any given $\boldsymbol{\mu}$ and σ, and $i \in \{R, S\}$. □

Proof of Proposition 2

First, differentiating the *ex ante* expected profit of firm R in (4.1) with respect to $\mu(\theta)$ gives (for some $\theta \in \{\underline{\theta}, \overline{\theta}\}$):

$$\frac{\partial \Pi_R^*(\boldsymbol{\mu};\sigma)}{\partial \mu(\theta)} = \frac{\lambda}{2} \Pr(\theta) \left(x_R^*(\theta)^2 - x_R^*(\varnothing)^2\right) + \lambda \left[1 - E\{\mu(\theta)\}\right] x_R^*(\varnothing) \frac{\partial x_R^*(\varnothing)}{\partial \mu(\theta)}. \tag{A.12}$$

Using (A.3) to simplify the first term, and (A.7) for the second term, gives:

$$\begin{aligned}\frac{\partial \Pi_R^*(\boldsymbol{\mu};\sigma)}{\partial \mu(\theta)} &= \frac{\lambda}{2}\Pr(\theta)\frac{E\{\theta|\varnothing\}-\theta}{\lambda+V/2}\left(x_R^*(\theta)+x_R^*(\varnothing)\right)-\lambda\Pr(\theta)\frac{E\{\theta|\varnothing\}-\theta}{\lambda+V/2}x_R^*(\varnothing)\\ &= \frac{\lambda}{2}\Pr(\theta)\frac{E\{\theta|\varnothing\}-\theta}{\lambda+V/2}\left(x_R^*(\theta)-x_R^*(\varnothing)\right)\\ &= \frac{\lambda}{2}\Pr(\theta)\left(\frac{E\{\theta|\varnothing\}-\theta}{\lambda+V/2}\right)^2>0. \end{aligned} \tag{A.13}$$

Second, differentiating firm S's expected profit (4.2) with respect to $\mu(\theta')$ gives:

$$\frac{\partial \Pi_S^*(\boldsymbol{\mu};\sigma)}{\partial \mu(\theta')}=\frac{\lambda}{2}\Pr(\theta')\left(x_S^*(\theta';\theta')^2-x_S^*(\theta';\varnothing)^2\right)+\lambda E\left\{\left[1-\mu(\theta)\right]x_S^*(\theta;\varnothing)\frac{\partial x_S^*(\theta;\varnothing)}{\partial \mu(\theta')}\right\} \tag{A.14}$$

for $\theta'\in\{\underline{\theta},\overline{\theta}\}$. Using (A.4) for the first term, and (A.8) for the second term yields:

$$\begin{aligned}\frac{\partial \Pi_S^*(\boldsymbol{\mu};\sigma)}{\partial \mu(\theta')} &= -\frac{\lambda}{2}\Pr(\theta')\frac{\left[E(\theta|\varnothing)-\theta'\right]V/2}{\lambda(\lambda+V/2)}\left(x_S^*(\theta';\theta')+x_S^*(\theta';\varnothing)\right)\\ &\quad +\lambda\frac{\Pr(\theta')}{1-E\{\mu(\theta)\}}\cdot\frac{\left[E\{\theta|\varnothing\}-\theta'\right]V/2}{\lambda(\lambda+V/2)}E\left\{\left[1-\mu(\theta)\right]x_S^*(\theta;\varnothing)\right\}\\ &= -\frac{\lambda}{2}\Pr(\theta')\frac{\left[E(\theta|\varnothing)-\theta'\right]V/2}{\lambda(\lambda+V/2)}\left(x_S^*(\theta';\theta')+x_S^*(\theta';\varnothing)-2x_R^*(\varnothing)\right)\\ &= -\frac{\lambda}{2}\Pr(\theta')\left(\frac{E(\theta|\varnothing)-\theta'}{\lambda+V/2}\right)^2\frac{(2\lambda+V/2)V/2}{\lambda^2}<0. \end{aligned} \tag{A.15}$$

This completes the proof. □

Proof of Proposition 3

Firm S with information θ expects to earn the following profit from sending message m (for $m\in\{\theta,\varnothing\}$ and $\theta\in\{\underline{\theta},\overline{\theta}\}$):

$$\pi(m|\theta)=\frac{\lambda}{2}x_S^*(\theta;m)^2+\sigma V x_R^*(m). \tag{A.16}$$

Hence, using (A.3) and (A.4), the expected profit difference between disclosure and concealment of θ can be written as follows (for $\theta\in\{\underline{\theta},\overline{\theta}\}$):

$$\begin{aligned}\pi(\theta|\theta)-\pi(\varnothing|\theta) &= \frac{\lambda}{2}\left(x_S^*(\theta;\theta)^2-x_S^*(\theta;\varnothing)^2\right)+\sigma V\left(x_R^*(\theta)-x_R^*(\varnothing)\right)\\ &= \frac{\lambda}{2}\cdot\frac{-\left[E(\theta|\varnothing)-\theta\right]V/2}{\lambda(\lambda+V/2)}\left(x_S^*(\theta;\theta)+x_S^*(\theta;\varnothing)\right)+\sigma V\frac{E(\theta|\varnothing)-\theta}{\lambda+V/2}\\ &= \frac{\left[E(\theta|\varnothing)-\theta\right]V/2}{\lambda+V/2}\left(2\sigma-\frac{1}{2}\left(x_S^*(\theta;\theta)+x_S^*(\theta;\varnothing)\right)\right)\\ &= \frac{\left[E(\theta|\varnothing)-\theta\right]V/2}{(\lambda+V/2)^2}\left(2(\lambda+V)\sigma-\left[V-\theta+\frac{\left[E(\theta|\varnothing)-\theta\right]V/2}{2\lambda}\right]\right)\end{aligned}$$

Firm S is indifferent between disclosure and concealment of θ, given rival's beliefs consistent with $\boldsymbol{\mu}$, if $\pi(\theta|\theta) = \pi(\varnothing|\theta)$, which reduces to: $\sigma = s(\boldsymbol{\mu};\theta)$, where

$$s(\boldsymbol{\mu};\theta) \equiv \frac{1}{2(\lambda+V)}\left(V - \theta + \frac{[E(\theta|\varnothing) - \theta]\,V/2}{2\lambda}\right). \tag{A.17}$$

The spillover $s(\boldsymbol{\mu};\theta)$ is monotonic in $\mu(\theta')$ for any $\theta, \theta' \in \{\underline{\theta}, \overline{\theta}\}$, since differentiating (A.17), and substitution of (A.5) gives:

$$\frac{\partial s(\boldsymbol{\mu};\theta)}{\partial \mu(\theta')} = \frac{\partial s(\boldsymbol{\mu};\theta)}{\partial P(\varnothing)} \cdot \frac{\partial P(\varnothing)}{\partial \mu(\theta')} = \frac{-\Pr(\theta')}{1 - E\{\mu(\theta)\}} \cdot \frac{(\theta' - E\{\theta|\varnothing\})\,V/2}{4\lambda(\lambda+V)}. \tag{A.18}$$

Further, one can show (using the regularity condition 2.1) that for any $\boldsymbol{\mu}$:

$$0 < s(\boldsymbol{\mu};\overline{\theta}) < s(\boldsymbol{\mu};\underline{\theta}) < \frac{1}{2}. \tag{A.19}$$

Consequently, there does not exist an equilibrium where firm S randomizes the disclosure of both cost levels. Define: $\underline{\sigma}_L \equiv s(0,1;\overline{\theta})$, $\overline{\sigma}_L \equiv s(0,0;\overline{\theta})$, $\underline{\sigma}_H \equiv s(0,0;\underline{\theta})$, and $\overline{\sigma}_H \equiv s(1,0;\underline{\theta})$.

(a) Suppose that firm R has beliefs consistent with $(\mu(\underline{\theta}), \mu(\overline{\theta})) = (q,1)$ for $0 \leq q \leq 1$, i.e., $P(\varnothing) = 1$. Then firm S has an incentive to disclose bad news, i.e. $\pi(\overline{\theta}|\overline{\theta}) \geq \pi(\varnothing|\overline{\theta})$, if $\sigma \leq s(q,1;\overline{\theta})$, or $\sigma \leq \underline{\sigma}_L$, since $s(q,1;\overline{\theta}) = \underline{\sigma}_L$ for any q.

(b) Now suppose that firm R has beliefs consistent with $(\mu(\underline{\theta}), \mu(\overline{\theta})) = (0,q)$. Then firm S has an incentive to conceal good news, if $\pi(\underline{\theta}|\underline{\theta}) < \pi(\varnothing|\underline{\theta})$, or $\sigma < s(0,q;\underline{\theta})$. The firm is indifferent between disclosing and concealing bad news, if $\sigma = s(0,q;\overline{\theta})$. Inequality (A.19) implies that $(0,q)$ is an equilibrium disclosure rule for $\sigma = s(0,q;\overline{\theta})$. Define $\mu^L(\sigma)$ as the inverse of $s(0,q;\overline{\theta})$, and notice that μ^L is continuous and decreasing for $\underline{\sigma}_L \leq \sigma \leq \overline{\sigma}_L$ (see A.18).

(c) Firm S conceals all information in equilibrium, if $\pi(\theta|\theta) < \pi(\varnothing|\theta)$ for all $\theta \in \{\underline{\theta}, \overline{\theta}\}$ and $P(\varnothing) = p$. The firm prefers to conceal good news, if $\sigma \leq \underline{\sigma}_H$, and it prefers to conceal bad news, if $\sigma \geq \overline{\sigma}_L$. Hence, full concealment is chosen in equilibrium for all spillovers $\overline{\sigma}_L \leq \sigma \leq \underline{\sigma}_H$.

(d) Analogous to part **(b)**, suppose that firm R has beliefs consistent with $(\mu(\underline{\theta}), \mu(\overline{\theta})) = (q,0)$ for some $0 \leq q \leq 1$. In that case $\pi(\underline{\theta}|\underline{\theta}) = \pi(\varnothing|\underline{\theta})$ gives $\sigma = s(q,0;\underline{\theta})$, and $\pi(\overline{\theta}|\overline{\theta}) < \pi(\varnothing|\overline{\theta})$ gives $\sigma > s(q,0;\overline{\theta})$. Hence, inequality (A.19) implies that disclosure rule $(q,0)$ is chosen in equilibrium for $\sigma = s(q,0;\underline{\theta})$. Define $\mu^H(\sigma)$ as the inverse of $s(q,0;\underline{\theta})$ for any $0 \leq q \leq 1$ and $\underline{\sigma}_H \leq \sigma \leq \overline{\sigma}_H$, and notice that μ^H is continuous and increasing (see A.18).

(e) Analogous to part **(a)**, suppose that firm S chooses $(\mu(\underline{\theta}), \mu(\overline{\theta})) = (1, q)$ for $0 \leq q \leq 1$. Given consistent beliefs (i.e., $P(\varnothing) = 0$) firm S has an incentive to disclose good news, if $\sigma \geq \overline{\sigma}_H$, since $s(1, q; \underline{\theta}) = \overline{\sigma}_H$ for any q.

Finally, uniqueness of the disclosure equilibrium follows from the monotonicity of μ^L and μ^H, and the non-existence of equilibria in which both types choose mixed disclosure strategies. This completes the proof. □

Proof of Proposition 4

For spillover values in $[0, \underline{\sigma}_L]$, $[\overline{\sigma}_L, \underline{\sigma}_H]$, and $[\overline{\sigma}_H, \frac{1}{2}]$ the analysis of (5.1) coincides with proposition 1, since disclosure rules are constant on these intervals (see proposition 3 a, c, and e). The analysis for $(\underline{\sigma}_L, \overline{\sigma}_L)$ and $(\underline{\sigma}_H, \overline{\sigma}_H)$ follows. First, define the type that adopts a mixed disclosure strategy on interval $(\underline{\sigma}_k, \overline{\sigma}_k)$ as θ_k for $k \in \{L, H\}$, i.e.:

$$\theta_k \equiv \begin{cases} \overline{\theta}, \text{ if } k = L, \\ \underline{\theta}, \text{ if } k = H. \end{cases} \tag{A.20}$$

Second, define the spillover level $\sigma_L \equiv s(0, q; \overline{\theta})$ for some $0 < q < 1$, and $s(.)$ as in (A.17), i.e., $\underline{\sigma}_L < \sigma_L < \overline{\sigma}_L$ (see proposition 3b). The equilibrium disclosure rule for $\sigma = \sigma_L$ is $(\mu^*(\underline{\theta}), \mu^*(\overline{\theta})) = (0, \mu^L(\sigma_L)) = (0, q)$, since μ^L is the inverse of $s(0, \mu^L; \overline{\theta})$. Similarly, define $\sigma_H \equiv s(q, 0; \underline{\theta})$ for some $0 < q < 1$ (i.e., $\underline{\sigma}_H < \sigma_H < \overline{\sigma}_H$ and $\boldsymbol{\mu}^*(\sigma_H) = (q, 0)$). Applying the implicit function theorem yields (for $k \in \{L, H\}$):

$$\frac{d\mu^k(\sigma_k)}{d\sigma} = \frac{1}{\frac{\partial s(\boldsymbol{\mu}^*(\sigma_k); \theta_k)}{\partial \mu(\theta_k)}} \tag{A.21}$$

Hence, evaluating (5.1) at $\sigma = \sigma_k$ (for $i \in \{R, S\}$ and $k \in \{L, H\}$) reduces to:

$$\frac{d\Pi_i^*(\boldsymbol{\mu}^*(\sigma_k); \sigma_k)}{d\sigma} = \frac{\partial \Pi_i^*(\boldsymbol{\mu}^*(\sigma_k); \sigma_k)}{\partial \mu(\theta_k)} \cdot \frac{1}{\left(\frac{\partial s(\boldsymbol{\mu}^*(\sigma_k); \theta_k)}{\partial \mu(\theta_k)}\right)} + \frac{\partial \Pi_i^*(\boldsymbol{\mu}^*(\sigma_k); \sigma_k)}{\partial \sigma}. \tag{A.22}$$

The proof proceeds by evaluating the signs of (A.22) for $k \in \{L, H\}$ and $i \in \{R, S\}$.
(a) The analysis of (5.1) for $i = S$ gives immediately that both terms are positive (negative) if $\sigma = \sigma_L$ (resp. $\sigma = \sigma_H$) for any $q \in (0, 1)$.
(b) Dividing (A.12) by (A.18) yields:

$$\begin{aligned} \frac{\partial \Pi_R^*(\boldsymbol{\mu}; \sigma)}{\partial \mu(\theta)} \cdot \frac{1}{\left(\frac{\partial s(\boldsymbol{\mu}; \theta)}{\partial \mu(\theta)}\right)} &= \frac{\lambda}{2} \Pr(\theta) \left(\frac{E\{\theta|\varnothing\} - \theta}{\lambda + V/2}\right)^2 \frac{1}{\frac{-\Pr(\theta)}{1 - E\{\mu(\theta)\}} \cdot \frac{(\theta - E\{\theta|\varnothing\})V/2}{4\lambda(\lambda+V)}} \\ &= \frac{E\{\theta|\varnothing\} - \theta}{(\lambda + V/2)^2} 2\left[1 - E\{\mu(\theta)\}\right] \frac{\lambda + V}{V/2} \lambda^2. \end{aligned} \tag{A.23}$$

Second, evaluating (A.11) at $\sigma = \sigma_k$, and using the definition $\sigma_k = s(\boldsymbol{\mu}^*(\sigma_k); \theta_k)$, with $s(.)$ as defined in (A.17), gives (for $i \in \{R, S\}$):

$$\begin{aligned}\frac{\partial \Pi_i^*(\boldsymbol{\mu}^*(\sigma_k);\sigma_k)}{\partial \sigma} &= -\frac{1}{2}\left(\frac{[E\{\theta|\varnothing\} - \theta_k]\, V/2}{2\lambda} + E(\theta) - \theta_k\right)\left(\frac{V}{\lambda + V/2}\right)^2 \\ &= \frac{-[E\{\theta|\varnothing\} - \theta_k]}{(\lambda + V/2)^2}\left(\frac{V/2}{\lambda} + 2\left[1 - E\{\mu^*(\theta)\}\right]\right)(V/2)^2 \quad \text{(A.24)}\end{aligned}$$

since $E(\theta) - \theta_k = [1 - E\{\mu^*(\theta)\}]\,[E\{\theta|\varnothing\} - \theta_k]$ if $\sigma = \sigma_k$ for $k \in \{L, H\}$. Substitution of (A.23), evaluated at $\boldsymbol{\mu}^*(\sigma_k)$, σ_k and θ_k, and (A.24) in (A.22) for $i = R$ gives:

$$\begin{aligned}\frac{d\Pi_R^*(\boldsymbol{\mu}^*(\sigma_k);\sigma_k)}{d\sigma} &= \frac{E\{\theta|\varnothing\} - \theta_k}{(\lambda + V/2)^2} 2\left[1 - E\{\mu^*(\theta)\}\right]\frac{\lambda + V}{V/2}\lambda^2 \\ &\quad - \frac{E\{\theta|\varnothing\} - \theta_k}{(\lambda + V/2)^2}\left(\frac{V/2}{\lambda} + 2\left[1 - E\{\mu^*(\theta)\}\right]\right)(V/2)^2 \\ &= \frac{E\{\theta|\varnothing\} - \theta_k}{V/2(\lambda + V/2)^2} h(\lambda, q). \quad \text{(A.25)}\end{aligned}$$

where

$$h(\lambda, q) \equiv 2\left[1 - \Pr(\theta_k) q\right]\left((\lambda + V)\lambda^2 - (V/2)^3\right) - \frac{(V/2)^4}{\lambda}. \quad \text{(A.26)}$$

Evaluating this expression for $q \to 0$ (i.e. $\sigma_L \to \overline{\sigma}_L$, and $\sigma_H \to \underline{\sigma}_H$) yields:

$$\lim_{\sigma \uparrow \overline{\sigma}_L} \frac{d\Pi_R^*(\boldsymbol{\mu}^*(\sigma);\sigma)}{d\sigma} < 0, \text{ and } \lim_{\sigma \downarrow \underline{\sigma}_H} \frac{d\Pi_R^*(\boldsymbol{\mu}^*(\sigma);\sigma)}{d\sigma} > 0,$$

respectively. Moreover, $h(\lambda, q)$ in (A.26) is monotonic in q, and therefore it changes sign at most once on the interval $(\underline{\sigma}_k, \overline{\sigma}_k)$ for $k \in \{L, H\}$. Hence, one local maximum is reached on the interval $[\underline{\sigma}_k, \overline{\sigma}_k]$ for $k \in \{L, H\}$. □

Proof of Proposition 5

This proof is similar to the proofs of Propositions 1 and 2. Therefore, I only report the results of derivations. First, the effect of the spillover on the probability of innovation equals:

$$\begin{aligned}\frac{\partial I^*(\boldsymbol{\mu};\sigma)}{\partial \sigma} &= E_\theta E_{m(\theta)}\left\{\frac{\partial x_R^*(m)}{\partial \sigma}\left[1 - x_S^*(\theta; m)\right] + \left[1 - x_R^*(m)\right]\frac{\partial x_S^*(\theta; m)}{\partial \sigma}\right\} \\ &= \frac{-2V}{\lambda + V/2}\left(1 - \widehat{X}(\sigma)\right) < 0. \quad \text{(A.27)}\end{aligned}$$

Second, the effect of the disclosure probability on the probability of innovation equals:

$$\begin{aligned}\frac{\partial I^*(\boldsymbol{\mu};\sigma)}{\partial \mu(\theta')} &= \Pr(\theta')\left([1-x_R^*(\varnothing)]\,[1-x_S^*(\theta';\varnothing)]-[1-x_R^*(\theta')]\,[1-x_S^*(\theta';\theta')]\right)\\ &\quad +E\left\{[1-\mu(\theta)]\left(\frac{\partial x_R^*(\varnothing)}{\partial \mu(\theta')}\,[1-x_S^*(\theta;\varnothing)]+[1-x_R^*(\varnothing)]\,\frac{\partial x_S^*(\theta;\varnothing)}{\partial \mu(\theta')}\right)\right\}\\ &= -\Pr(\theta')\left(\frac{E\{\theta|\varnothing\}-\theta'}{\lambda+V/2}\right)^2<0 \qquad \text{(A.28)}\end{aligned}$$

for any $\theta' \in \{\underline{\theta},\overline{\theta}\}$. This completes the proof. □

Proof of Proposition 6

This proof is similar to the proof of proposition 4. The existence of the first local maximum at $\sigma=0$, and the absence of further local maxima on the interval $(0,\underline{\sigma}_L]\cup(\overline{\sigma}_L,\frac{1}{2}]$ follows immediately from monotonicity of $I^*(\boldsymbol{\mu}^*(\sigma);\sigma)$ on the interval, as implied by propositions 3 and 5, and (5.3). First, I show that there exists at most one local maximum on the remaining interval $(\underline{\sigma}_L,\overline{\sigma}_L]$. As in the proof of proposition 4, take $\sigma_L \equiv s(0,q;\overline{\theta})$ for some $0<q\leq 1$, with s as in (A.17), and evaluate (5.3) at $\sigma=\sigma_L$:

$$\frac{dI^*(\boldsymbol{\mu}^*(\sigma_L);\sigma_L)}{d\sigma}=\frac{\partial I^*(0,q;\sigma_L)}{\partial \mu(\overline{\theta})}\cdot\frac{1}{\partial s(0,q;\overline{\theta})/\partial \mu(\overline{\theta})}+\frac{\partial I^*(0,q;\sigma_L)}{\partial \sigma} \qquad \text{(A.29)}$$

Using (A.28) and (A.18), the first term of (A.29) reduces to:

$$\frac{\partial I^*(0,q;\sigma_L)}{\partial \mu(\overline{\theta})}\cdot\frac{1}{\partial s(0,q;\overline{\theta})/\partial \mu(\overline{\theta})}=\frac{4}{(\lambda+V/2)^2}\cdot\frac{p(\overline{\theta}-\underline{\theta})\lambda(\lambda+V)}{V/2}$$

Evaluating (A.27) at $\sigma=\sigma_L$ reduces the second term of (A.29) to:

$$\frac{\partial I^*(0,q;\sigma_L)}{\partial \sigma}=\frac{-4}{(\lambda+V/2)^2}\cdot\frac{V/2}{\lambda+V}\left[(\lambda+V/2)(\lambda+E(\theta))-(\overline{\theta}-\underline{\theta})V/2\left(p+P(\varnothing)\frac{V/2}{2\lambda}\right)\right]$$

with $P(\varnothing)=p/[1-q(1-p)]$. Clearly, $dI^*(\boldsymbol{\mu}^*(\sigma_L);\sigma_L)/d\sigma$ is increasing in q, since the first term is constant in q, and the second term is increasing in q. This implies that $I^*(\boldsymbol{\mu}^*(\sigma);\sigma)$ is concave in σ for $\sigma\in(\underline{\sigma}_L,\overline{\sigma}_L]$, since σ_L is decreasing in q. Concavity implies in turn that a local maximum on the interval is unique, if it exists.

Second, if (A.29) is positive for any feasible σ_L (or q), then a local maximum exists at $\sigma=\overline{\sigma}_L$. The derivations above imply that for any $\sigma\in(\underline{\sigma}_L,\overline{\sigma}_L]$:

$$\begin{aligned}\frac{dI^*(\boldsymbol{\mu}^*(\sigma);\sigma)}{d\sigma} &> \frac{4}{(\lambda+V/2)^2}\left(\frac{p(\overline{\theta}-\underline{\theta})\lambda(\lambda+V)}{V/2}-\frac{(\lambda+V/2)(\lambda+E(\theta))V/2}{\lambda+V}\right)\\ &= \frac{4}{(\lambda+V/2)^2}\cdot\frac{F(\lambda)}{(\lambda+V)V/2}\end{aligned}$$

with

$$F(\lambda) \equiv p(\overline{\theta} - \underline{\theta})\lambda(\lambda + V)^2 - (\lambda + V/2)(\lambda + E(\theta))(V/2)^2$$

Clearly, F is convex and increasing in λ for sufficiently high values of λ. Therefore, there exists a critical value for λ beyond which F is positive. □

Proof of Proposition 7

Suppose the statement is not true. In other words, suppose there is an equilibrium in which firm S sends informative messages, e.g. $m \in \{L, H\}$ and w.l.o.g. $E\{\theta|L\} < E\{\theta|H\}$. The expected profit of firm S with information θ for sending message m is $\pi(m|\theta)$ as defined in (A.16). Similar steps as in the proof of proposition 3 give:

$$\begin{aligned}\pi(L|\theta) - \pi(H|\theta) &= \frac{[E(\theta|H) - E(\theta|L)]\,V/2}{(\lambda + V/2)^2} \cdot \\ &\quad \cdot \left[2\sigma(\lambda + V) - \left(V - \theta + \frac{[E(\theta|L) + E(\theta|H) - 2\theta]\,V/2}{2\lambda}\right)\right]\end{aligned}$$

Since $E\{\theta|L\} < E\{\theta|H\}$, firm S with cost θ prefers message L, iff $\sigma > s^o(\theta)$, with

$$s^o(\theta) \equiv \frac{1}{2(\lambda + V)}\left(V - \theta + \frac{[E(\theta|L) + E(\theta|H) - 2\theta]\,V/2}{2\lambda}\right)$$

Monotonicity of $s^o(\theta)$ in θ gives the following optimal message strategy for firm S:

$$(m(\underline{\theta}), m(\overline{\theta})) = \begin{cases} (H, H), \text{ if } \sigma \leq s^o(\overline{\theta}) \\ (H, L), \text{ if } s^o(\overline{\theta}) \leq \sigma \leq s^o(\underline{\theta}) \\ (L, L), \text{ if } \sigma \geq s^o(\underline{\theta}) \end{cases}$$

This message strategy is always inconsistent with firm R's beliefs, i.e. the assumption $E\{\theta|L\} < E\{\theta|H\}$. This contradiction completes the proof. □

Proof of Proposition 8

Taking the sum of (A.13) and (A.15), immediately yields the following:

$$\begin{aligned}\frac{\partial \sum_i \Pi_i^*(\boldsymbol{\mu}; \sigma)}{\partial \mu(\theta')} &= \frac{\partial \Pi_R^*(\boldsymbol{\mu}; \sigma)}{\partial \mu(\theta')} + \frac{\partial \Pi_S^*(\boldsymbol{\mu}; \sigma)}{\partial \mu(\theta')} \\ &= \frac{\lambda}{2}\Pr(\theta')\left(\frac{E\{\theta|\varnothing\} - \theta'}{\lambda + V/2}\right)^2 \frac{\lambda^2 - 2\lambda V/2 - (V/2)^2}{\lambda^2}, \quad \text{(A.30)}\end{aligned}$$

which is positive (negative) iff $\lambda > \lambda^*$ (resp. $\lambda < \lambda^*$), as stated in the proposition. □

Proof of Proposition 9

Comparison of (A.13) and (A.30) gives:

$$\frac{\partial \sum_i \Pi_i^*(\boldsymbol{\mu};\sigma)}{\partial \mu(\theta)} \cdot \frac{1}{\frac{\partial s(\boldsymbol{\mu};\theta)}{\partial \mu(\theta)}} = \left(\frac{\partial \Pi_R^*(\boldsymbol{\mu};\sigma)}{\partial \mu(\theta)} \cdot \frac{1}{\frac{\partial s(\boldsymbol{\mu};\theta)}{\partial \mu(\theta)}} \right) \frac{\lambda^2 - 2\lambda V/2 - (V/2)^2}{\lambda^2}. \tag{A.31}$$

Substitution of (A.23) in (A.31), and adding $\sum_i \partial \Pi_i^*(\boldsymbol{\mu}^*(\sigma_k);\sigma_k)/\partial\sigma$ from (A.24) yields:

$$\begin{aligned} &\frac{d \sum_i \Pi_i^*(\boldsymbol{\mu}^*(\sigma_k);\sigma_k)}{d\sigma} = 2\frac{E\{\theta|\varnothing\} - \theta_k}{V/2(\lambda + V/2)^2} \cdot \\ &\cdot \left(\left[1 - E\{\mu^*(\theta)\}\right] \left[(\lambda + V)\left(\lambda^2 - 2\lambda V/2 - (V/2)^2\right) - 2(V/2)^3\right] - \frac{(V/2)^4}{\lambda} \right) \\ = \;& 2\frac{E\{\theta|\varnothing\} - \theta_k}{\lambda V/2(\lambda + V/2)^2} H(\lambda, q), \end{aligned} \tag{A.32}$$

with

$$H(\lambda, q) \equiv \left[1 - \Pr(\theta_k) q\right] \lambda(\lambda + V/2)\left(\lambda^2 - \lambda V/2 - 4\,(V/2)^2\right) - (V/2)^4. \tag{A.33}$$

Clearly, $\lambda^2 - \lambda V/2 - 4\,(V/2)^2$ is increasing in λ, and has the root $\lambda' \equiv (1 + \sqrt{17})V/4$, i.e. $\lambda' > \lambda^*$. Consequently, if $\lambda \leq \lambda'$, then $H(\lambda, q) < 0$ for any q. If $\lambda > \lambda'$, then $H(\lambda, q)$ is decreasing in q, and increasing in λ. Define λ^{**} such that $H(\lambda^{**}, 0) = 0$, i.e., $\lambda^{**} > \lambda'$. First, if $\lambda' < \lambda < \lambda^{**}$, then $H(\lambda, 0) < 0$, and therefore $H(\lambda, q) < 0$ for any q, i.e., equilibrium industry profits are single-peaked, as in Proposition 4 (a). Second, if $\lambda > \lambda^{**}$, then $H(\lambda, 0) > 0$, which implies that $\lim_{\sigma \uparrow \overline{\sigma}_L} d \sum_i \Pi_i^*(\boldsymbol{\mu}^*(\sigma);\sigma)/d\sigma < 0$ and $\lim_{\sigma \downarrow \underline{\sigma}_H} d \sum_i \Pi_i^*(\boldsymbol{\mu}^*(\sigma);\sigma)/d\sigma > 0$. Moreover, $d \sum_i \Pi_i^*(\boldsymbol{\mu}^*(\sigma);\sigma)/d\sigma$ changes sign at most once on the interval $(\underline{\sigma}_k, \overline{\sigma}_k)$ for $k \in \{L, H\}$, since H is monotonic in q. Hence, one local maximum is reached on the interval $[\underline{\sigma}_k, \overline{\sigma}_k]$ for $k \in \{L, H\}$ as in Proposition 4 (b). $\square$

B Supplementary Appendix

Here I prove Propositions 10 and 11, which are related to the maximization of profits and innovation probability, respectively.

Proposition 10 *The critical cost parameter λ^{***} exists, with $\lambda^{***} > \lambda^{**}$, such that for all $\lambda \geq \lambda^{***}$ neither firm R's expected equilibrium profit nor the expected equilibrium industry profit reach a global maximum in $\sigma = \widehat{\sigma}$, i.e., the spillovers σ' and σ'' exist such that $\Pi_R^*(\boldsymbol{\mu}^*(\sigma');\sigma') > \Pi_R^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma})$, and $\sum_i \Pi_i^*(\boldsymbol{\mu}^*(\sigma'');\sigma'') > \sum_i \Pi_i^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma})$.*

Proof: (a) First, for $\boldsymbol{\mu}^*$ and $\sigma = \widehat{\sigma}$ the expected equilibrium profit of firm R in (4.1) equals:

$$\Pi_R^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma}) = \Pi_R^*(\mathbf{0};\widehat{\sigma}) = \left(\frac{\lambda}{2}\widehat{X}(\widehat{\sigma}) + \widehat{\sigma}V\right)\widehat{X}(\widehat{\sigma}), \tag{B.1}$$

since $x_R^*(\varnothing) = \widehat{X}(\sigma)$ for $\boldsymbol{\mu} = \mathbf{0}$. Second, evaluate firm R's expected equilibrium profit at spillover value $\widetilde{\sigma} \in \{\underline{\sigma}_L, \overline{\sigma}_H\}$, i.e., $\boldsymbol{\mu}^*(\widetilde{\sigma}) \in \{(0,1),(1,0)\}$ implying full disclosure in equilibrium (using definitions A.1 and 3.4):

$$\begin{aligned}
\Pi_R^*(\boldsymbol{\mu}^*(\widetilde{\sigma});\widetilde{\sigma}) &= \frac{\lambda}{2}E\left\{x_R^*(\theta)^2\right\} + \widetilde{\sigma}V\widehat{X}(\widetilde{\sigma}) \\
&= \frac{\lambda}{2}E\left\{\left(\frac{(1-\widetilde{\sigma})V - E(\theta) - [\theta - E(\theta)]}{\lambda + V/2}\right)^2\right\} + \widetilde{\sigma}V\widehat{X}(\widetilde{\sigma}) \\
&= \left(\frac{\lambda}{2}\widehat{X}(\widetilde{\sigma}) + \widetilde{\sigma}V\right)\widehat{X}(\widetilde{\sigma}) + \frac{\lambda}{2}\cdot\frac{Var(\theta)}{(\lambda+V/2)^2} \\
&= \left(\frac{\lambda}{2}\widehat{X}(\widehat{\sigma}) + \widehat{\sigma}V - \frac{1}{2}(\lambda+V)\frac{(\widehat{\sigma}-\widetilde{\sigma})V}{\lambda+V/2}\right)\left[\widehat{X}(\widehat{\sigma}) + \frac{(\widehat{\sigma}-\widetilde{\sigma})V}{\lambda+V/2}\right] \\
&\quad + \frac{\lambda}{2}\cdot\frac{Var(\theta)}{(\lambda+V/2)^2} \\
&= \left(\frac{\lambda}{2}\widehat{X}(\widehat{\sigma}) + \widehat{\sigma}V\right)\widehat{X}(\widehat{\sigma}) - \frac{1}{2}(\lambda+V)\left(\frac{(\widehat{\sigma}-\widetilde{\sigma})V}{\lambda+V/2}\right)^2 + \frac{\lambda\cdot Var(\theta)}{2(\lambda+V/2)^2} \\
&\quad + \left(\frac{\lambda}{2}\widehat{X}(\widehat{\sigma}) + \widehat{\sigma}V - \frac{1}{2}(\lambda+V)\widehat{X}(\widehat{\sigma})\right)\frac{(\widehat{\sigma}-\widetilde{\sigma})V}{\lambda+V/2} \\
&= \Pi_R^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma}) - \frac{1}{2}(\lambda+V)\left(\frac{(\widehat{\sigma}-\widetilde{\sigma})V}{\lambda+V/2}\right)^2 + \frac{\lambda\cdot Var(\theta)}{2(\lambda+V/2)^2},
\end{aligned} \tag{B.2}$$

since $\frac{\lambda}{2}\widehat{X}(\widehat{\sigma}) + \widehat{\sigma}V = \frac{1}{2}\left(V - E(\theta)\right)$, and $\widehat{X}(\widehat{\sigma}) = \left(V - E(\theta)\right)/(\lambda+V)$, as follows from (3.4) and (3.8). Recall that: $\underline{\sigma}_L = s(0,1;\overline{\theta})$ and $\overline{\sigma}_H = s(1,0;\underline{\theta})$, with $s(\boldsymbol{\mu};\theta)$, as in

(A.17). The spillover $\underline{\sigma}_L$ can be rewritten as follows (using definition 3.8):

$$\begin{aligned}\underline{\sigma}_L &= s(0,1;\overline{\theta}) = \frac{1}{2(\lambda+V)}\left(V-\overline{\theta}-\frac{(\overline{\theta}-\underline{\theta})V/2}{2\lambda}\right)\\ &= \frac{1}{2(\lambda+V)}\left(V-E(\theta)-\frac{p2\lambda+V/2}{2\lambda}(\overline{\theta}-\underline{\theta})\right) = \widehat{\sigma}-\frac{p2\lambda+V/2}{4\lambda(\lambda+V)}(\overline{\theta}-\underline{\theta}).\end{aligned}$$

Similarly, $\overline{\sigma}_H = s(1,0;\underline{\theta}) = \widehat{\sigma} + [(1-p)2\lambda + V/2](\overline{\theta}-\underline{\theta})/[4\lambda(\lambda+V)]$. Moreover, $Var(\theta) = p(1-p)(\overline{\theta}-\underline{\theta})^2$. Hence, $\Pi_R^*(\boldsymbol{\mu}^*(\widetilde{\sigma});\widetilde{\sigma})$ in (B.2) can be written as follows (for $\theta \in \{\underline{\theta},\overline{\theta}\}$):

$$\Pi_R^*(\boldsymbol{\mu}^*(\widetilde{\sigma});\widetilde{\sigma}) = \Pi_R^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma}) + \frac{(\overline{\theta}-\underline{\theta})^2}{2(\lambda+V/2)^2}g(\lambda;P(\theta)), \tag{B.3}$$

with

$$g(\lambda;P) \equiv \lambda P[1-P] - \frac{[P2\lambda+V/2]^2\,V^2}{16\lambda^2(\lambda+V)}, \tag{B.4}$$

and $\theta = \underline{\theta}$ if $\widetilde{\sigma} = \underline{\sigma}_L$, while $\theta = \overline{\theta}$ if $\widetilde{\sigma} = \overline{\sigma}_H$. Clearly, the function g is increasing and unbounded in λ for any given P, with $0 < P < 1$. Hence, there exists a critical cost parameter $\widehat{\lambda}_1$ such that $g(\lambda;P) > 0$ for all $\lambda > \widehat{\lambda}_1$.

(b) First, for $\boldsymbol{\mu}^*$ and $\sigma = \widehat{\sigma}$ the expected equilibrium profit of firm S in (4.2) equals (using A.1, A.2 and B.1):

$$\begin{aligned}\Pi_S^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma}) &= \Pi_S^*(\mathbf{0};\widehat{\sigma}) = \frac{\lambda}{2}E\left\{x_S^*(\theta;\varnothing)^2\right\} + \widehat{\sigma}V\widehat{X}(\widehat{\sigma})\\ &= \frac{\lambda}{2}E\left\{\left(x_R^*(\theta)+\frac{[E(\theta)-\theta]V/2}{\lambda(\lambda+V/2)}\right)^2 - x_R^*(\varnothing)^2\right\} + \Pi_R^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma})\\ &= \frac{\lambda}{2}E\left\{\left(x_R^*(\varnothing)+\frac{E(\theta)-\theta}{\lambda}\right)^2 - x_R^*(\varnothing)^2\right\} + \Pi_R^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma})\\ &= \Pi_R^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma}) + \frac{\lambda\cdot Var(\theta)}{2\lambda^2}.\end{aligned} \tag{B.5}$$

Second, evaluating firm S's expected equilibrium profit at spillover level $\widetilde{\sigma} \in \{\underline{\sigma}_L, \overline{\sigma}_H\}$, i.e., full disclosure in equilibrium (using $x_S^*(\theta;\theta) = x_R^*(\theta)$, as follows from A.2, and Lemma 1 d) yields immediately: $\Pi_S^*(\boldsymbol{\mu}^*(\widetilde{\sigma});\widetilde{\sigma}) = \Pi_R^*(\boldsymbol{\mu}^*(\widetilde{\sigma});\widetilde{\sigma})$. Combining this ob-

servation with (B.3) for some θ and (B.5) yields:

$$\begin{aligned}\sum_{i\in\{R,S\}}\Pi_i^*(\boldsymbol{\mu}^*(\widetilde{\sigma});\widetilde{\sigma}) &= 2\Pi_R^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma})+2g(P(\theta))\frac{(\overline{\theta}-\underline{\theta})^2}{2(\lambda+V/2)^2}\\ &= \sum_{i\in\{R,S\}}\Pi_i^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma})+g(P(\theta))\left(\frac{\overline{\theta}-\underline{\theta}}{\lambda+V/2}\right)^2-\frac{\lambda\cdot Var(\theta)}{2\lambda^2}\\ &= \sum_{i\in\{R,S\}}\Pi_i^*(\boldsymbol{\mu}^*(\widehat{\sigma});\widehat{\sigma})+G(\lambda;P(\theta))\frac{(\overline{\theta}-\underline{\theta})^2}{2(\lambda+V/2)^2},\end{aligned}$$

with

$$G(\lambda;P)\equiv P(1-P)\lambda\frac{\lambda^2-2\lambda V/2-(V/2)^2}{\lambda^2}-\frac{[P2\lambda+V/2]^2V^2}{16\lambda^2(\lambda+V)}, \tag{B.6}$$

and $\theta=\underline{\theta}$ if $\widetilde{\sigma}=\underline{\sigma}_L$, while $\theta=\overline{\theta}$ if $\widetilde{\sigma}=\overline{\sigma}_H$. As in part (a), function G is clearly increasing and unbounded in λ for all $\lambda>\lambda^*$. Hence, there exists a critical cost parameter $\widehat{\lambda}_2>0$ such that $G(\lambda;P)>0$ for all $\lambda>\widehat{\lambda}_2$. Proposition 9 implies that $\widehat{\lambda}_2>\lambda^{**}$. Finally, define $\lambda^{***}\equiv\max\{\widehat{\lambda}_1,\widehat{\lambda}_2\}$, and the proof is complete. □

Proposition 11 *The expected probability of innovation in equilibrium, $I^*(\boldsymbol{\mu}^*(\sigma);\sigma)$, reaches the unique global maximum for $\sigma=0$.*

Proof: The existence of the first local maximum at $\sigma=0$, and the absence of further local maxima on the interval $(0,\underline{\sigma}_L]\cup(\overline{\sigma}_L,\frac{1}{2}]$ follows immediately from monotonicity of $I^*(\boldsymbol{\mu}^*(\sigma);\sigma)$ on the interval, as implied by propositions 3 and 5, and (5.3). Therefore, it suffices to show that $I^*(\mathbf{1};0)>I^*(\mathbf{0};\underline{\sigma}_L)$, with $\underline{\sigma}_L\equiv s(0,1;\overline{\theta})$ and s as in (A.17), to establish the global maximum can only be reached for $\sigma=0$. It is straightforward to show that:

$$\begin{aligned}I^*(\mathbf{1};0) &= \widehat{X}(0)\left(2-\widehat{X}(0)\right)-\frac{Var(\theta)}{(\lambda+V/2)^2}\\ I^*(\mathbf{0};\sigma) &= \widehat{X}(\sigma)\left(2-\widehat{X}(\sigma)\right)\\ &= \widehat{X}(0)\left(2-\widehat{X}(0)\right)-\sigma\frac{V}{\lambda+V/2}\left[2\left(1-\widehat{X}(0)\right)+\sigma\frac{V}{\lambda+V/2}\right]\end{aligned}$$

with $Var(\theta)=p(1-p)(\overline{\theta}-\underline{\theta})^2$. Since $I^*(\mathbf{0};\sigma)$ is quadratic in σ, it is easy to find the spillover σ_0 such that $I^*(\mathbf{0};\sigma_0)=I^*(\mathbf{1};0)$:

$$\sigma_0\equiv\frac{1}{V}\left(\sqrt{(\lambda+V/2)^2\left(1-\widehat{X}(0)\right)^2+Var(\theta)}-(\lambda+V/2)\left(1-\widehat{X}(0)\right)\right)$$

It is easy to verify that σ_0 is concave in p, and is maximized for $p = p_0$, with:

$$p_0 \equiv \frac{4\lambda - 2V + 3\overline{\theta} + \underline{\theta}}{4\left(2\lambda - V + \overline{\theta} + \underline{\theta}\right)}$$

Evaluating σ_0 at $p = p_0$ gives an upper bound for σ_0:

$$\sigma_0 \leq \frac{(\overline{\theta} - \underline{\theta})^2}{4V\left(2\lambda - V + \overline{\theta} + \underline{\theta}\right)}$$

Using this upper bound and regularity condition (2.1) yields the following inequalities:

$$\begin{aligned}
\underline{\sigma}_L - \sigma_0 &\geq \frac{1}{2(\lambda + V)}\left(V - \overline{\theta} - \frac{(\overline{\theta} - \underline{\theta})V/2}{2\lambda}\right) - \frac{(\overline{\theta} - \underline{\theta})^2}{4V\left(2\lambda - V + \overline{\theta} + \underline{\theta}\right)} \\
&> \frac{1}{2(\lambda + V)}\left(V/2 - \frac{(V/2 - \underline{\theta})V/2}{2\lambda}\right) - \frac{(V/2 - \underline{\theta})^2}{4V\left(2\lambda - V/2 + \underline{\theta}\right)} \\
&\geq \frac{1}{2(\lambda + V)}\left(V/2 - \frac{(V/2)^2}{2\lambda}\right) - \frac{V/2}{8\left(2\lambda - V/2\right)} = \frac{\left[14\lambda^2 - 10\lambda V + V^2\right]V/2}{16\lambda(\lambda + V)\left(2\lambda - V/2\right)} > 0
\end{aligned}$$

Monotonicity of $I^*(\mathbf{0}; \sigma)$ in σ (i.e. $\partial I^*(\mathbf{0}; \sigma)/\partial\sigma < 0$ as Proposition 5 shows) yields immediately: $I^*(\mathbf{1}; 0) = I^*(\mathbf{0}; \sigma_0) > I^*(\mathbf{0}; \underline{\sigma}_L) \geq I^*(\mathbf{0}; \sigma)$ for any $\sigma \in [\underline{\sigma}_L, \overline{\sigma}_L]$. Moreover, monotonicity of $I^*(\mu; \sigma)$ in $\mu(\overline{\theta})$ (i.e. $\partial I^*(\boldsymbol{\mu}; \sigma)/\partial\mu(\overline{\theta}) < 0$ as proposition 5 shows) implies that $I^*(\mathbf{0}; \sigma) \geq I^*(0, \mu^L(\sigma); \sigma) = I^*(\boldsymbol{\mu}^*(\sigma); \sigma)$ for any $\sigma \in [\underline{\sigma}_L, \overline{\sigma}_L]$. $\square$

References

Anton, J.J. and Yao, D.A., 2003, 'Patents, Invalidity, and the Strategic Transmission of Enabling Information,' *Journal of Economics and Management Strategy* 12, pp. 151-178.

Anton, J.J. and Yao, D.A., 2004, 'Little Patents and Big Secrets: Managing Intellectual Property,' *RAND Journal of Economics* 35, pp. 1-22.

d'Aspremont, C.; Bhattacharya, S. and Gérard-Varet, L-A., 1998, 'Knowledge as a Public Good: Efficient Sharing and Incentives for Development Effort,' *Journal of Mathematical of Economics 30,* pp. 389-404.

d'Aspremont, C.; Bhattacharya, S. and Gérard-Varet, L-A., 2000, 'Bargaining and Sharing Innovative Knowledge,' *Review of Economic Studies* 67, pp. 255-271.

Austen, D.H., 1993, 'An Event-Study Approach to Measuring Innovative Output: The Case of Biotechnology,' *American Economic Review (Papers and Proceedings)* 83, pp. 253-258.

Bhattacharya, S.; Glazer, J. and Sappington, D.E.M., 1990, 'Sharing Productive Knowledge in Internally Finance R&D Contests,' *Journal of Industrial Economics* 39, pp. 187-208.

Bhattacharya, S.; Glazer, J. and Sappington, D.E.M., 1992, 'Licensing and the Sharing of Knowledge in Research Joint Ventures,' *Journal of Economic Theory* 56, pp. 43-69.

Bhattacharya, S. and Guriev, S., 2006, 'Patents vs. Trade Secrets: Knowledge Licensing and Spillover,' *Journal of the European Economic Association* 4, pp. 1112-1147.

Bhattacharya, S. and Ritter, J.R., 1983, 'Innovation and Communication: Signalling with Partial Disclosure,' *Review of Economic Studies* 50, pp. 331-346.

Choi, J.P., 1991 'Dynamic R&D Competition under 'Hazard Rate' Uncertainty,' *RAND Journal of Economics* 22, pp. 596-610.

De Fraja, G., 1993, 'Strategic Spillovers in Patent Races,' *International Journal of Industrial Organization* 11, pp. 139-146.

Denicolò V., 1996, 'Patent Races and Optimal Patent Breadth and Length,' *Journal of Industrial Economics* 44, pp. 249-265.

Dye, R.A., 1985, 'Disclosure of Nonproprietary Information,' *Journal of Accounting Research* 23, pp. 123-145.

Farrell, J., 1986, 'Voluntary Disclosure: Robustness of the Unraveling Result, and Comments on Its Importance,' in Grieson, R. (ed.), *Antitrust and Regulation* (Lexington Books, Lexington).

Fosfuri, A. and Rønde, T., (2004) 'High-Tech Clusters, Technology Spillovers, and Trade Secret Laws,' *International Journal of Industrial Organization* 22, pp. 45-65.

Gersbach, H. and Schmutzler, A., 2003, 'Endogenous Technological Spillovers: Causes and Consequences,' *Journal of Economics and Management Strategy* 12, pp. 197-205.

Gill, D., 2008 'Strategic Disclosure of Intermediate Research Results,' *Journal of Economics and Management Strategy*, 17, pp. 733-758.

Grossman, S.J., 1981, 'The Informational Role of Warranties and Private Disclosure about Product Quality,' *Journal of Law and Economics* 24, pp. 461-483.

Hendricks, K. and Kovenock, D., 1989, 'Asymmetric Information, Information Externalities, and Efficiency: The Case of Oil Exploration,' *RAND Journal of Economics* 20, pp. 164-182.

Jansen, J., 2001, 'Strategic Information Revelation and Revenue Sharing in an R&D Race,' *Discussion Paper* FS IV 01-06, Social Science Research Center Berlin (WZB).

Jansen, J., 2004, 'Strategic Information Revelation in an R&D Race with Spillovers,' *mimeo*, Social Science Research Center Berlin (WZB), http://ssrn.com/abstract=517982.

Jansen, J., 2008, 'Information Acquisition and Strategic Disclosure in Oligopoly,' *Journal of Economics and Management Strategy* 17, pp. 113-148.

Kamien, M.I. and Zang, I., 2000, 'Meet Me Halfway: Research Joint Ventures and Absorptive Capacity,' *International Journal of Industrial Organization* 18, pp. 995-1012.

Katsoulacos, Y. and Ulph, D., 1998, 'Endogenous Spillovers and the Performance of Research Joint Ventures,' *Journal of Industrial Economics* 46, pp. 333-357.

Kirby, A.J., 1988, 'Trade Associations as Information Exchange Mechanisms,' *RAND Journal of Economics* 19, pp. 138-146.

Lewis, T.R. and Sappington, D.E.M., 1989, 'Countervailing Incentives in Agency Problems,' *Journal of Economic Theory* 49, pp. 294-313.

Milgrom, P.R., 1981, 'Good News and Bad News: Representation Theorems and Applications,' *Bell Journal of Economics* 12, pp. 380-391.

Moldovanu, B. and Sela, A., 2001, 'The Optimal Allocation of Prizes in Contests,' *American Economic Review* 91, pp. 542-558.

Okuno-Fujiwara, M.; Postlewaite, A. and Suzumura, K., 1990, 'Strategic Information Revelation,' *Review of Economic Studies* 57, pp. 25-47.

Raith, M., 1996 'A General Model of Information Sharing in Oligopoly,' *Journal of Economic Theory* 71, pp. 260-288.

Rosenkranz, S., 2001, 'To Reveal or Not to Reveal: Know-How Disclosure and Joint Ventures in Procurement Auctions,' *Journal of Institutional and Theoretical Economics* 157, pp. 555-567.

Shin, H.S., 1994, 'News Management and the Value of Firms,' *RAND Journal of Economics* 25, pp. 58-71.

Vives, X., 1984, 'Duopoly Information Equilibrium: Cournot and Bertrand", *Journal of Economic Theory* 34, pp. 71-94.

Vives, X., 1999, *Oligopoly Pricing: Old Ideas and New Tools*, (MIT Press, Cambridge).

Ziv, A., 1993, 'Information Sharing in Oligopoly: The Truth-telling Problem,' *RAND Journal of Economics* 24, pp. 455-465.