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The Effects of Disclosure Regulation on Innovative Firms

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The Effects of Disclosure Regulation on Innovative Firms*

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Abstract

Firms actively manage rivals' beliefs by disclosing and concealing information on the size of their process innovation. The firms' disclosure strategies affect their product market incentives. We compare equilibria under voluntary disclosure with those under mandatory disclosure in a model where the firms' production costs are identically independently distributed. Under voluntary disclosure firms conceal bad news, and disclose good news only if little knowledge spills over to their rival. Under mandatory disclosure firms expect higher profits.

Keywords: process innovation, strategic substitutes, information disclosure, knowledge spillovers

JEL Codes: D82, D83, L23, O31, O32

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1 Introduction

In many innovative industries firms strategically preannounce their innovations. Pre-announcements are reported in e.g. information technology, biotechnology, the car industry. For example, it is often claimed that Microsoft (MS) is using preannouncements of its products (e.g. operating system upgrades, game console Xbox) to drive competition out of their market.¹ Disclosing good news about your own new product or production process while hiding bad news, may discourage rivals to supply a competing product. Such a disclosure strategy is called a “vaporware” strategy.

At least two attempts have been made to rule against preannouncements in US court cases. First, the potential anti-competitive effects of Microsoft’s product pre-announcements were discussed during the 1994-95 licensing court case against Microsoft (e.g. see *United States v. Microsoft*, Civil Action No. 94-1564). Although the judge recognized that preannouncements may have anti-competitive effects, no restrictions were placed on Microsoft’s announcements. Second, in the period 1987-1991 shareholders of Apple Computer brought securities fraud charges against the company. Apple’s preannouncement of its Lisa computer and Twiggy disk drive and subsequent extensive delay in delivery was alleged to violate Section 10(b) and Rule 10b-5 of the 1934 US Securities Exchange Act (e.g. see Prentice and Langmore, 1994). The case was settled out of court.

Disclosure regulation may be imposed on firms by the courts. Future court cases by an antitrust authority or by investors could yield a ruling against vaporware disclosures. Alternatively, a firm’s disclosure strategy may be restricted to non-strategic disclosures by direct action from consumers. For example, in the 1980s “some computer societies have begun to refuse to allow companies to demonstrate products that are not already being shipped.” (Prentice and Langmore, 1994, p. 14, footnote 88), e.g. the Philadelphia Area Computer Society. This paper studies the effects of disclosure regulation on innovative firms.

In particular, we compare the expected profit of Cournot duopolists under mandatory disclosure with the expected profit under voluntary disclosure. Each firm learns imperfectly about the size of its process innovation, and chooses strategically what information to disclose to its rival.

A firm’s preannouncement need not only have a strategic effect on the expectations in the industry, but can also reveal some valuable information about the innovation’s

¹See e.g. Lopatka and Page (1995), Prentice (1996), Shapiro (1996), and Shapiro and Varian (1999). An anecdotal report on Microsoft’s strategies is presented in Wallace and Erickson (1992).

content to the industry. When knowledge about the contents of the innovation spills over to rival firms after a preannouncement, this enables rival firms to imitate, which lowers a firm’s incentive to preannounce its innovation. This informational catching-up effect is central in most patent design literature (e.g. see Scotchmer, 1991). Therefore a preannouncing firm faces the following trade-off. On the one hand, the firm creates a strategic advantage by revealing it is a strong Cournot competitor. On the other hand, the disadvantage of a preannouncement is that some of the contents of the innovation spills over to the industry, which makes rival firms catch up. While the strategic effect gives firms an incentive to preannounce innovations, the informational catching-up effect encourages concealment of information. This paper illustrates the effect of this trade-off on the firms’ strategic disclosure decisions, and on their production incentives.

Related literature: Anton and Yao (2003, 2004) study information disclosure incentives of competing, innovative firms. These papers focus on separating equilibria where, although firms do not disclose all information, the disclosed information is a perfect signal of the firm’s efficiency. The amount of knowledge that is expected to spill over to the rival determines a firm’s disclosure strategy. The size of the knowledge spillover plays an important role in our analysis too. But in contrast to Anton and Yao’s important results, we obtain equilibria that need not be fully revealing to firms. Furthermore, we perform a profit analysis, which is absent in Anton and Yao (2003, 2004).

“Vaporware”, i.e. strategic preannouncement of good news and concealment of bad news, has been analyzed in some papers. One of the first papers to point to the potential strategic implications of preannouncements is Ordover and Willig (1981). In Farrell and Saloner (1986) the strategic effects of product preannouncements are mainly driven by consumers’ myopia: consumers only anticipate a new product after the preannouncement of it. Both Levy (1997), and Lopatka and Page (1995) note that in a signalling setting preannouncements only have strategic effects when false announcements affect rival’s or consumers’ beliefs. Haan (2003) provides a signalling model of vaporware with intelligent consumers. False preannouncements do not affect consumers’ beliefs and no information is revealed in equilibrium. Our paper assumes partially verifiability of information, and therefore does not obtain cheap talk equilibria. A recent paper by Gerlach (2004) studies the effects of preannouncements on industry entry, and social welfare. The paper differs in several respects from ours. First, it studies a sequential competitive setting. A potential entrant tries to gain

future consumers' demand by preannouncing a new product, while the incumbent can set a preemptive price before entry occurs. Our paper studies a setting in which two firms compete simultaneously in all stages of the game. Moreover, consumers' switching costs play a big role in Gerlach's analysis, but are not needed in our model. Some empirical support for the emergence of vaporware effects in the Digital Versatile Disc (DVD) player industry is given in Dranove and Gandal (2003). In our paper we present the first model that I know of that results in strategic preannouncements among competing firms.

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 Cournot competitors.

The paper is organized as follows. In the next section of this paper we describe the model. The third section discusses the equilibrium outputs and profits when firms are required to disclose their information. Section 4 gives the equilibrium outputs and disclosure choices when firms voluntarily disclose information, and we compare expected profits under mandated disclosure with those under voluntary disclosure. In section 5 we extend the basic analysis by introducing knowledge spillovers. Finally, section 6 concludes the paper. All proofs of the paper's main propositions are relegated to the Appendix.

2 The Model

Two firms produce homogeneous products. Firms do not know their costs of production, θ_i for firm i , with $i = 1, 2$. Firm i has either a low cost, $\theta_i = \underline{\theta}$, or a high cost, $\theta_i = \bar{\theta}$, with $0 \leq \underline{\theta} < \bar{\theta}$ and $i = 1, 2$. The two firms' costs are identically independently distributed. The prior probability for firm i to have a low cost is p , with $0 < p < 1$. Firm i learns about its cost from a signal, Θ_i . With probability r_i firm i learns its true cost, $\Theta_i = \theta_i$. However, with probability $1 - r_i$ firm i receives an uninformative signal, $\Theta_i = \emptyset$, with $0 \leq r_i \leq 1$ and $i = 1, 2$.

After firms receive their private signals they make disclosure choices. Informative signals, $\Theta_i \in \{\underline{\theta}, \bar{\theta}\}$, are verifiable. However, the fact whether or not a firm is informed is not verifiable. If firm i receives information θ_i , it can choose to either disclose or conceal this, i.e. the firm chooses its communication $\delta_i(\theta_i)$ from the set $\{\theta_i, \emptyset\}$. An uninformed firm can only state $\delta_i(\emptyset) = \emptyset$. It therefore suffices to denote firm i 's disclosure rule as $(\delta_i(\underline{\theta}), \delta_i(\bar{\theta}))$. We denote the realization of rule $\delta_i(\cdot)$ as δ_i^* , with $\delta_i^* \in \{\delta_i(\Theta_i) | \Theta_i \in \{\underline{\theta}, \bar{\theta}, \emptyset\}\}$, i.e. δ_i^* is the message from firm i to j , for $i, j = 1, 2$ and $i \neq j$. Firms make their disclosure decision simultaneously.

After signals are received from nature and rivals, firm i chooses quantity $x_i \geq 0$ at cost $C(x_i; \theta_i) = \theta_i x_i$ with $i = 1, 2$ (Cournot competition). The firms produce homogeneous goods, and inverse demand for this good is linear, i.e. $P(X) = A - X$, with $X \equiv x_1 + x_2$.

Firms are risk-neutral. Given cost θ_i , firm i 's expected profit is:

$$\pi_i(\mathbf{x}; \theta_i) = x_i(A - \theta_i - x_i - x_j). \quad (2.1)$$

with $\mathbf{x} \equiv (x_i, x_j)$. We solve the game backwards, and restrict the analysis to symmetric, pure strategy equilibria.

3 Mandatory Disclosure

In this section we study the equilibrium in which firms are required to disclose their information (Θ_i, Θ_j) . Such a disclosure regulation could be implemented by an antitrust authority by the threat of severe penalties after withholding of information is discovered. Alternatively, it can be obtained by *ex ante* commitment to full disclosure by the firms in the industry.

When firms are required to disclose their signals, they base their supply decision

on their relative costs. Firm i 's expected cost, θ_i^E , depends as follows on its signal:

$$\theta^E(\Theta_i) = \begin{cases} \underline{\theta}, & \text{for } \Theta_i = \underline{\theta} \\ E(\theta), & \text{for } \Theta_i = \emptyset \\ \bar{\theta}, & \text{for } \Theta_i = \bar{\theta}. \end{cases} \quad (3.1)$$

Maximization of firm i 's expected profits gives the following first-order condition:

$$x_i = \frac{1}{2}(A - \theta^E(\Theta_i) - x_j). \quad (3.2)$$

Solving for the equilibrium gives the following equilibrium output and profit:

$$\hat{x}_i(\Theta_i, \Theta_j) = \frac{1}{3}(A - 2\theta^E(\Theta_i) + \theta^E(\Theta_j)) \quad \text{and} \quad (3.3)$$

$$\hat{\pi}_i(\Theta_i, \Theta_j) = \hat{x}_i(\Theta_i, \Theta_j)^2, \quad (3.4)$$

respectively, with $i, j = 1, 2, i \neq j$. In equilibrium a more efficient firm i , $\theta^E(\Theta_i) < \theta^E(\Theta_j)$, supplies relatively more in the product market. Moreover, firm i 's equilibrium outputs decrease in its expected costs, $\theta^E(\Theta_i)$, for any given expected rival's costs $\theta^E(\Theta_j)$. And a firm's output increases in its rival's expected cost, given its own expected costs.

4 Voluntary Disclosure

In the previous section firms were required to disclose their information. In this section we characterize firms' equilibrium outputs after firms disclose only good news about their cost, i.e. $(\delta_i(\underline{\theta}), \delta_i(\bar{\theta})) = (\underline{\theta}, \emptyset)$. A firm that discloses good news and conceals bad news discourages its rival to supply in the product market. Disclosure of only low costs makes a firm's rival expect strong competition of the disclosing firms. We call such a disclosure choice vaporware disclosure, and we show that firms actually choose this disclosure rule in equilibrium.

4.1 Equilibrium Outputs

We derive the outputs under the vaporware disclosure rule, $(\delta_i(\underline{\theta}), \delta_i(\bar{\theta})) = (\underline{\theta}, \emptyset)$ for $i = 1, 2$. Firms' production incentives under vaporware are driven by the strategic effect of information disclosure. First we introduce the following notation: firm i that received signal Θ_i , consequently sends message $\delta_i^* = \delta_i(\Theta_i)$, and received message δ_j^* supplies $\tilde{x}_i(\Theta_i; \delta_i^*, \delta_j^*)$ in equilibrium. We distinguish three different situations

for firms. Either both firms disclose, only one firm discloses, or both firms conceal information. We discuss firms' equilibrium outputs in these situations below.

When both firms learn that they have low costs, they disclose this information. They therefore produce as under mandatory disclosure, i.e. $\tilde{x}_i(\underline{\theta}; \underline{\theta}, \underline{\theta}) = \hat{x}_i(\underline{\theta}, \underline{\theta})$.

The second case is one in which firm i discloses low costs, while firm j discloses no information: $(\delta_i^*, \delta_j^*) = (\underline{\theta}, \emptyset)$. In that case firm j could either be a high-cost firm, or an uninformed firm. Given vaporware disclosure, firm i assigns probability q_j to facing an informed firm j , with

$$q_j \equiv \frac{r_j(1-p)}{1-r_j p}. \quad (4.1)$$

Firm i expects therefore cost $\tilde{E}_j(\theta) \equiv q_j \bar{\theta} + (1-q_j)E(\theta)$ from its competitor. Profit maximization by firm i gives its first-order condition:

$$x_i = \frac{1}{2} (A - \underline{\theta} - [q_j x_j(\bar{\theta}) + (1-q_j)x_j(\emptyset)]). \quad (4.2)$$

Firm j has complete information about its rival's costs, and its outputs are determined by the following first-order conditions:

$$x_j(\Theta_j) = \frac{1}{2} (A - \theta^E(\Theta_j) - x_i), \quad (4.3)$$

for $\Theta_j \in \{\emptyset, \bar{\theta}\}$. After we substitute this in firm i 's first-order condition we easily obtain the following equilibrium outputs (for $\Theta_j \in \{\bar{\theta}, \emptyset\}$):

$$\tilde{x}_i(\underline{\theta}; \underline{\theta}, \emptyset) = \frac{1}{3} (A - 2\underline{\theta} + \tilde{E}_j(\theta)), \text{ and} \quad (4.4)$$

$$\tilde{x}_j(\Theta_j; \emptyset, \underline{\theta}) = \frac{1}{3} (A - 2\theta^E(\Theta_j) + \underline{\theta}) + \frac{1}{6} (\theta^E(\Theta_j) - \tilde{E}_j(\theta)). \quad (4.5)$$

Note that firm j supplies less if it received bad news, and firm j always invests less than firm i in this equilibrium. After information $(\underline{\theta}, \emptyset)$ is disclosed, firms know that firm i has a lower expected marginal cost than firm j . This encourages firm i , and discourages firm j to produce.

Since $\tilde{E}_j(\theta)$ is increasing in r_j , output $\tilde{x}_i(\underline{\theta}; \underline{\theta}, \emptyset)$ is increasing in r_j , while both $\tilde{x}_j(\emptyset; \emptyset, \underline{\theta})$ and $\tilde{x}_j(\bar{\theta}; \emptyset, \underline{\theta})$ are decreasing in r_j . When firm j 's signal precision r_j increases and firm j sends an uninformative signal, firm i puts more weight on competing with a high-cost firm j . This encourages firm i , and discourages firm j in the product market. In particular, when firm j is expected to be uninformed, $r_j = 0$, firms produce their full disclosure quantities $\hat{x}_i(\underline{\theta}, \emptyset)$ and $\hat{x}_j(\emptyset, \underline{\theta})$, respectively. If firm j is

expected to be fully informed, $r_j = 1$, firms supply in equilibrium $\hat{x}_i(\underline{\theta}, \bar{\theta})$ and $\hat{x}_j(\bar{\theta}, \underline{\theta})$, respectively. For signal precisions strictly between zero and one, firm i produce strictly between these mandated disclosure output levels: $\hat{x}_i(\underline{\theta}, \emptyset) < \tilde{x}_i(\underline{\theta}; \underline{\theta}, \emptyset) < \hat{x}_i(\underline{\theta}, \bar{\theta})$ for $0 < r_j < 1$. For $0 < r_j < 1$, informed firm j supplies more under vaporware disclosure, $\tilde{x}_j(\bar{\theta}; \emptyset, \underline{\theta}) > \hat{x}_j(\bar{\theta}, \underline{\theta})$, while uninformed firm j supplies less, $\tilde{x}_j(\emptyset; \emptyset, \underline{\theta}) < \hat{x}_j(\emptyset, \underline{\theta})$. Under vaporware disclosure informed firm j pools with its uninformed counterpart, which discourages firm i 's outputs, and consequently encourages firm j to produce. When firm j is actually uninformed and pools with its high cost counterpart, this encourages its rival and discourages firm j to produce.

Finally we consider the case in which both firms disclose no information: $(\delta_i^*, \delta_j^*) = (\emptyset, \emptyset)$. This gives the following first-order conditions (for $\Theta_i \in \{\bar{\theta}, \emptyset\}$ and $i, j = 1, 2$, with $i \neq j$):

$$x_i(\Theta_i) = \frac{1}{2} (A - \theta^E(\Theta_i) - [q_j x_j(\bar{\theta}) + (1 - q_j) x_j(\emptyset)]). \quad (4.6)$$

This gives equilibrium outputs (for $\Theta_i \in \{\bar{\theta}, \emptyset\}$ and $i = 1, 2$, and $i \neq j$):

$$\tilde{x}_i(\Theta_i; \emptyset, \emptyset) = \frac{1}{3} (A - 2\theta^E(\Theta_i) + \tilde{E}_j(\theta)) + \frac{1}{6} (\theta^E(\Theta_i) - \tilde{E}_i(\theta)). \quad (4.7)$$

Note that $\tilde{x}_i(\bar{\theta}; \emptyset, \emptyset) < \tilde{x}_i(\emptyset; \emptyset, \emptyset)$. An uninformed firm is more optimistic about its costs, and therefore produces more in equilibrium.

When firm j 's signal precision r_j increases, it becomes more likely that concealing firm j actually received bad news. This encourages firm i to produce. Therefore, firm i 's investments are increasing in r_j . Conversely, firm j 's output decreases in response to firm i 's increased output. If firms are equally likely to be informed, i.e. $r_i = r$ for $i = 1, 2$, and likelihood r increases, the direct positive effect dominates the negative effect, and consequently outputs increase. It is intuitive that: $\hat{x}_i(\Theta_i, \emptyset) \leq \tilde{x}_i(\Theta_i; \emptyset, \emptyset) \leq \hat{x}_i(\Theta_i, \bar{\theta})$ for $\Theta_i \in \{\emptyset, \bar{\theta}\}$, with $\tilde{x}_i(\emptyset; \emptyset, \emptyset) = \hat{x}_i(\emptyset, \emptyset)$ for $r_i = r_j = 0$, and $\tilde{x}_i(\bar{\theta}; \emptyset, \emptyset) = \hat{x}_i(\bar{\theta}, \bar{\theta})$ for $r_i = r_j = 1$.

Firm i 's expected equilibrium profits, given disclosed information $(\delta_i(\Theta_i), \delta_j^*)$ and equilibrium beliefs, are:

$$\tilde{\pi}_i(\Theta_i; \delta_i(\Theta_i), \delta_j^*) = \tilde{x}_i(\Theta_i; \delta_i(\Theta_i), \delta_j^*)^2, \quad (4.8)$$

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

We summarize the findings of this subsection in the following lemma:

Lemma 1 Take $(\delta_i(\underline{\theta}), \delta_i(\bar{\theta})) = (\underline{\theta}, \emptyset)$, $r_i = r_j = r$ and $i = 1, 2$, $i \neq j$.

(i) For $0 < r < 1$, equilibrium outputs have the following properties:

(i.a) $\tilde{x}_i(\bar{\theta}; \emptyset, \underline{\theta}) < \tilde{x}_i(\emptyset; \emptyset, \underline{\theta}) < \tilde{x}_i(\underline{\theta}; \underline{\theta}, \underline{\theta}) < \tilde{x}_i(\underline{\theta}; \underline{\theta}, \emptyset)$, and
 $\tilde{x}_i(\bar{\theta}; \emptyset, \underline{\theta}) < \tilde{x}_i(\bar{\theta}; \emptyset, \emptyset) < \tilde{x}_i(\emptyset; \emptyset, \emptyset) < \tilde{x}_i(\underline{\theta}; \underline{\theta}, \emptyset)$;

(i.b) $\partial \tilde{x}_i(\Theta_i; \delta_i(\Theta_i), \underline{\theta}) / \partial r < 0$ for $\Theta_i \in \{\emptyset, \bar{\theta}\}$, and
 $\partial \tilde{x}_i(\Theta_i; \delta_i(\Theta_i), \emptyset) / \partial r > 0$ for $\Theta_i \in \{\underline{\theta}, \emptyset, \bar{\theta}\}$;

(ii) Outputs under mandatory and vaporware disclosure compare as follows:

(ii.a) $\hat{x}_i(\Theta_i, \emptyset) \leq \tilde{x}_i(\Theta_i; \tilde{\delta}_i(\Theta_i), \emptyset) \leq \hat{x}_i(\Theta_i, \bar{\theta})$, for $\Theta_i \in \{\underline{\theta}, \emptyset, \bar{\theta}\}$,
 $\hat{x}_i(\underline{\theta}; \underline{\theta}, \underline{\theta}) = \hat{x}_i(\underline{\theta}, \underline{\theta})$, $\hat{x}_i(\emptyset; \emptyset, \underline{\theta}) \leq \hat{x}_i(\emptyset, \underline{\theta})$, and $\tilde{x}_i(\bar{\theta}; \emptyset, \underline{\theta}) \geq \hat{x}_i(\bar{\theta}, \underline{\theta})$;

(ii.b) For $r = 0$: $\tilde{x}_i(\emptyset; \emptyset, \emptyset) = \hat{x}_i(\emptyset, \emptyset)$

for $r = 1$: $\tilde{x}_i(\Theta_i; \delta_i(\Theta_i), \delta_j(\Theta_j)) = \hat{x}_i(\Theta_i, \Theta_j)$ with $\Theta_i, \Theta_j \in \{\underline{\theta}, \bar{\theta}\}$,
 $\tilde{x}_i(\emptyset; \emptyset, \delta_j(\Theta_j)) = \frac{\bar{\theta}}{E(\bar{\theta})} \hat{x}_i(\bar{\theta}, \Theta_j)$ with $\Theta_j \in \{\underline{\theta}, \bar{\theta}\}$.

4.2 Disclosure Equilibrium

In the previous subsection we characterized equilibrium outputs under the vaporware disclosure rule. This section shows that the vaporware rule is indeed chosen in equilibrium.

First we show that other pure-strategy disclosure rules are not chosen by both firms in equilibrium (see Appendix).

Lemma 2 Under voluntary disclosure equilibria do not exist in which:

(a) Both firms disclose all information: $(\delta_i(\underline{\theta}), \delta_i(\bar{\theta})) = (\underline{\theta}, \bar{\theta})$, for $i = 1, 2$;

(b) Both firms conceal all information: $(\delta_i(\underline{\theta}), \delta_i(\bar{\theta})) = (\emptyset, \emptyset)$, for $i = 1, 2$;

There is no equilibrium in which both firms completely disclose their information. If a firm's rival expects that all information is disclosed, the firm can discourage its rival to produce by unilaterally concealing high cost information. There is no equilibrium in which both firms fully conceal their information. An informed efficient firm creates a strategic advantage in the product market by unilaterally disclosing its cost. Given these disclosure incentives it is intuitive that the following proposition holds.

Proposition 1 In any symmetric pure-strategy equilibrium with voluntary disclosure firms disclose low cost information, while they conceal high costs: $(\tilde{\delta}_i(\underline{\theta}), \tilde{\delta}_i(\bar{\theta})) = (\underline{\theta}, \emptyset)$, for $i = 1, 2$.

By preannouncing good news about your costs, you disclose yourself as an “aggressive” competitor in the product market. This discourages your rival, since strategies

are strategic substitutes. And since there is only one effect that drives this result, it holds for all parameter values.

4.3 Overall Profit Comparison

In this section we compare expected profits under mandatory disclosure with those under voluntary disclosure. Firm i 's expected profit under mandatory disclosure is as follows:

$$\widehat{\Pi}_i(r_i, r_j) \equiv E_{\Theta_i} \left\{ pr_j \widehat{\pi}_i(\Theta_i, \underline{\theta}) + (1 - pr_j) [q_j \widehat{\pi}_i(\Theta_i, \bar{\theta}) + (1 - q_j) \widehat{\pi}_i(\Theta_i, \emptyset)] \right\}. \quad (4.9)$$

Under mandatory disclosure firms evaluate the expected profit of disclosed costs. Conversely under vaporware disclosure firms evaluate the profit of expected costs. In particular firm i 's expected profit under vaporware disclosure is as follows:

$$\widetilde{\Pi}_i(r_i, r_j) \equiv E_{\Theta_i} \left\{ pr_j \widetilde{\pi}_i(\Theta_i; \widetilde{\delta}_i(\Theta_i), \underline{\theta}) + (1 - pr_j) \widetilde{\pi}_i(\Theta_i; \widetilde{\delta}_i(\Theta_i), \emptyset) \right\}. \quad (4.10)$$

Since the firms' profit functions are convex in their cost signals, they prefer the expected profit of disclosed signals over the profit of expected signals. We state this formally in the following proposition.

Proposition 2 *Firms that fully disclose their information expect higher profits than firms that choose vaporware disclosure strategies: $\widehat{\Pi}_i(r_i, r_j) \geq \widetilde{\Pi}_i(r_i, r_j)$ for all (r_i, r_j) .*

Although firms have interim incentives to conceal bad news, *ex ante* they have an incentive to commit to full information disclosure. Disclosure regulation would help the firms to achieve higher *ex ante* expected profits.

5 Knowledge Spillovers

In this section we study the effects of knowledge spillovers on disclosure incentives and profits. Not only information about the rival's production cost is relevant for a firm, but also the *contents* of the rival's technology becomes valuable. When firm i discovers that it has low costs while firm j has high costs, firm j would like to imitate its rival's technology. To model this effect we assume that an exogenous fraction $\kappa \in [0, 1]$ of an efficient firm's knowledge spills over to the rival after disclosure. When a firm's rival discloses low costs, the firm can benefit from the knowledge spillover.

Naturally, whenever firm i does not disclose a low cost signal, no knowledge spills over to firm j . Firm i 's expected marginal cost after observing signals (Θ_i, δ_j^*) is therefore:

$$\theta^\kappa(\Theta_i, \delta_j^*) = \begin{cases} \kappa\underline{\theta} + (1 - \kappa)\theta^E(\Theta_i), & \text{for } \delta_j^* = \underline{\theta}, \\ \theta^E(\Theta_i), & \text{otherwise.} \end{cases} \quad (5.1)$$

Note that the case of no spillover, $\kappa = 0$, corresponds to the study of previous sections. The case of full spillover, $\kappa = 1$, under mandatory disclosure effectively gives perfect positive correlation with $\Pr[\theta_i = \theta_j = \underline{\theta}] = 1 - (1 - p)^2$, and $\Pr[\theta_i = \theta_j = \bar{\theta}] = (1 - p)^2$.

5.1 Production with Knowledge Spillovers

First we study the effects that knowledge spillovers have on the output strategies of the previous sections. That is, we take the disclosure rules of previous sections as given, and focus on production. In the next subsection we find conditions under which these disclosure strategies are still employed in equilibrium, and what other disclosure equilibrium may emerge.

The equilibrium outputs under mandatory disclosure are similar to those without knowledge spillovers, with $\theta^E(\Theta_i)$ and $\theta^E(\Theta_j)$ replaced by $\theta^\kappa(\Theta_i, \Theta_j)$ and $\theta^\kappa(\Theta_j, \Theta_i)$, respectively.

The equilibrium outputs under vaporware disclosure only differ from those in the previous section after firms send message combination $(\delta_i^*, \delta_j^*) = (\underline{\theta}, \emptyset)$. In that case the equilibrium investments $\tilde{x}_i^\kappa(\underline{\theta}; \underline{\theta}, \emptyset)$ and $\tilde{x}_j^\kappa(\Theta_j; \emptyset, \underline{\theta})$ are as in expressions (4.4) and (4.5), with $E(\theta)$, $\bar{\theta}$, and $\tilde{E}_j(\theta)$ replaced by $\theta^\kappa(\emptyset, \underline{\theta})$, $\theta^\kappa(\bar{\theta}, \underline{\theta})$, and $\tilde{E}_j(\theta^\kappa)$, respectively, where $\tilde{E}_j(\theta^\kappa) \equiv \kappa\underline{\theta} + (1 - \kappa)\tilde{E}_j(\theta)$.

The more knowledge spills over from an efficient firm to its rival, the more “aggressive” the efficient firm’s rival becomes, and therefore the lower its incentive to produce. The firm that receives the knowledge increases its productivity, and has therefore a bigger incentive to produce. The more the receiving firm’s productivity increases, the bigger this firm’s production incentives.

Given the effects of an increase in spillover on the outputs, we can study the overall effect of an increase in spillover on expected equilibrium profits. On the one hand, the more knowledge spills over to firm i from its rival, the higher firm i 's expected profit. It is therefore immediate that if firm i is always uninformed ($r_i = 0$), then its expected equilibrium profit increases in the knowledge spillover. On the other hand, if the amount of knowledge that spills over from firm i to its rival increases, this decreases firm i 's expected profit. It is therefore immediate that if firm i 's rival is uninformed

($r_j = 0$), i.e. information can only spill over from firm i to its rival, then firm i 's expected equilibrium profit decreases in the knowledge spillover. For symmetric distributions of information among firms ($r_i = r_j$) the firms face a more subtle trade-off between these two opposing spillover effects. We show in the proposition below that in this case the positive effect on expected profits outweighs the negative effect.

Proposition 3 (i) For $\Theta \neq (\underline{\theta}, \underline{\theta})$, and given disclosure rules of the previous sections, equilibrium outputs of an efficient (respectively, inefficient or uninformed) firm decrease (respectively, increase) in the size of spillover κ :

$$\partial \hat{x}_i^\kappa(\underline{\theta}, \Theta_j) / \partial \kappa < 0 \text{ and } \partial \tilde{x}_i^\kappa(\underline{\theta}; \underline{\theta}, \emptyset) / \partial \kappa < 0 \text{ for } \Theta_j \in \{\bar{\theta}, \emptyset\}, \text{ and}$$

$$\partial \hat{x}_i^\kappa(\Theta_i, \underline{\theta}) / \partial \kappa > 0 \text{ and } \partial \tilde{x}_i^\kappa(\Theta_i; \emptyset, \underline{\theta}) / \partial \kappa > 0, \text{ for } \Theta_i \in \{\bar{\theta}, \emptyset\}.$$

(ii) If $r_i = r_j = r$, then expected equilibrium profits increase in knowledge spillover κ : $\partial \hat{\Pi}_i^\kappa(r, r) / \partial \kappa > 0$, and $\partial \tilde{\Pi}_i^\kappa(r, r) / \partial \kappa > 0$.

It follows from part (ii) of the proposition that under mandatory disclosure firms expect to benefit if they commit *ex ante* to share information on the contents of their technology. Under voluntary disclosure firms have similar incentives, provided that firms choose vaporware disclosure rules. However the firms' incentives to disclose low costs decreases in the knowledge spillover. In the next subsection we study how equilibrium information disclosure rules depend on knowledge spillovers.

5.2 Disclosure with Knowledge Spillovers

The previous subsection took vaporware disclosure strategies as given. Now we study when firms do employ such strategies, and we find what other equilibrium may emerge.

Concerning the effect of knowledge spillovers on the firms' incentives to disclose information, we make two observations. First, an informed inefficient firm never has an incentive to disclose that it is inefficient. After the firm discloses bad news its rival only updates his beliefs on the disclosing firm, while his own cost expectation remains unchanged. Second, the disclosure incentives of an informed efficient firm depends on the size of the knowledge spillover κ . If only little knowledge spills over after disclosure, efficient firms disclose their low costs in equilibrium. The positive strategic effect of disclosure outweighs the negative spillover effect in this case. An informed efficient firm typically has an incentive to conceal its information, if too much knowledge spills over to its rival. For high enough κ the strategic effect of disclosure is outweighed by the spillover effect in most cases. Before we prove this in

a proposition, we define the following parameter:

$$\alpha_i \equiv r_i p E(\theta) \bar{\theta} + r_i (1-p) \underline{\theta} E(\theta) + (1-r_i) \underline{\theta} \bar{\theta}, \quad (5.2)$$

and we introduce the following condition:

$$\alpha_i > \alpha_j - (E(\theta) \bar{\theta} - \alpha_j) (\underline{\theta} E(\theta) \bar{\theta} - \alpha_j \Delta) / \alpha_j \Delta. \quad (C.1)$$

Proposition 4 (i) *There is a critical spillover $\kappa^* \in (0, 1)$ such that an equilibrium exists in which both firms preannounce iff $\kappa \leq \kappa^*$.*

(ii) *If for all $i, j = 1, 2$ ($i \neq j$) condition C.1 holds, then there is a critical spillover $\kappa^o \in (0, 1)$ such that an equilibrium exists in which both firms fully conceal iff $\kappa > \kappa^o$.*

Notice that condition C.1 is satisfied for both firms if firms receive information with equal probability, i.e. $r_i = r_j$. For sufficiently asymmetric precisions of information, one of the firms has an incentive to unilaterally disclose low costs. In particular, if $r_i = \varepsilon$, $r_j = 1 - \varepsilon$, and $p = 1 - \varepsilon$ with $\varepsilon > 0$ sufficiently small, firm i may have an incentive to disclose its low cost even if all knowledge spills over to its rival after disclosure ($\kappa = 1$). If r_j and p are high, firm i expects to face an informed rival with low costs. Therefore the knowledge that spills over from firm i 's disclosure of low cost is expected to have little effect on firm j 's efficiency. But firm i 's low-cost disclosure has a substantial effect on its rival's beliefs. If r_i is low, firm j expects that firm i is uninformed, and therefore (if $\bar{\theta} - \underline{\theta}$ is sufficiently big) a relatively weak supplier. By disclosing its marginal cost, firm i surprises its rival, and makes him realize that firm i will be an "aggressive" supplier in the product market.

From propositions 3 (ii) and 4 we conclude that the expected profits under voluntary disclosure initially increase in the knowledge spillover (for $\kappa \leq \kappa^*$), and subsequently remains constant (for $\kappa > \kappa^o$). Under mandatory disclosure expected profits increase in the knowledge spillover for all κ . We state this formally in the following corollary.

Corollary 1 *If $r_i = r_j = r$, and disclosure is voluntary, then expected profits increase in spillover κ for all $\kappa \leq \kappa^*$, and remains constant for all $\kappa \leq \kappa^o$.*

6 Conclusion

In this paper we analyzed the effects of strategic information disclosure and knowledge spillovers on product market competition. We have seen that disclosure regulation substantially affects firms' outputs and profits.

We have given a model in which preannouncements emerge in equilibrium. We have seen that Microsoft's and Apple's alleged strategic preannouncements can be explained in a strategic setting of incomplete information. Furthermore, we have explained how firm's outputs and profits are affected in the different regimes. In particular, firms expect higher profits under mandatory disclosure. This result holds in industries with independently distributed technologies, where Cournot duopolists make announcements about their process innovations.

A Appendix

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

A.1 Equilibrium Outputs

The proof of lemma 1 is straightforward.

A.2 Voluntary Disclosure

We prove lemma 2 and propositions 1 and 2, respectively.

A.2.1 Proof of Lemma 2

(a) Suppose full disclosure *is* chosen in equilibrium. Then firm j 's outputs are $\hat{x}_j(\Theta_j, \delta_i^*)$ for $\delta_i^*, \Theta_j \in \{\underline{\theta}, \bar{\theta}, \emptyset\}$. Given that firm j fully discloses its information Θ_j and holds beliefs consistent with full disclosure, an informed and inefficient firm i expects the profit $E_{\Theta_j} \{\hat{x}_i(\bar{\theta}, \Theta_j)^2\}$ from disclosure. If firm i conceals $\bar{\theta}$, its rival supplies $\hat{x}_j(\Theta_j, \emptyset)$, and firm i 's best response to this output is as follows:

$$x_i = \frac{1}{2} (A - \bar{\theta} - \hat{x}_j(\Theta_j, \emptyset)) \Leftrightarrow x_i(\Theta_j) = \hat{x}_i(\bar{\theta}, \Theta_j) + \frac{1}{6} (\bar{\theta} - E(\theta)). \quad (\text{A.1})$$

Concealment of high costs gives firm i a profit of $E_{\Theta_j} \{x_i(\Theta_j)^2\}$. This profit exceeds the full disclosure profit, since $x_i(\Theta_j) > \hat{x}_i(\bar{\theta}, \Theta_j)$ for any $\Theta_j \in \{\underline{\theta}, \bar{\theta}, \emptyset\}$.

(b) Suppose full concealment *is* an equilibrium strategy for firms. Under full concealment the firms' equilibrium outputs $x^o(\cdot)$ are determined by the following first-order conditions (for $\Theta_i \in \{\underline{\theta}, \bar{\theta}, \emptyset\}$):

$$x_i^o(\Theta_i) = \frac{1}{2} [A - \theta^E(\Theta_i) - (r_j p x_j^o(\underline{\theta}) + r_j(1-p)x_j^o(\bar{\theta}) + (1-r_j)x_j^o(\emptyset))]. \quad (\text{A.2})$$

This results in the following equilibrium outputs:

$$x_i^o(\Theta_i) = \frac{1}{3} (A - 2\theta^E(\Theta_i) + E(\theta)) + \frac{1}{6} (\theta^E(\Theta_i) - E(\theta)). \quad (\text{A.3})$$

Firm i 's equilibrium profit under full concealment equals:

$$E_{\Theta_i} \{\pi_i^o(\Theta_i; \emptyset, \emptyset)\} = x_i^o(\Theta_i)^2. \quad (\text{A.4})$$

Consider firm i 's incentive to unilaterally disclose a low marginal cost. After firm i 's disclosure the firms' outputs are determined by the following first-order conditions:

$$x_i' = \frac{1}{2} [A - \underline{\theta} - (r_j p x_j(\underline{\theta}) + r_j(1-p)x_j(\bar{\theta}) + (1-r_j)x_j(\emptyset))], \quad (\text{A.5})$$

$$\text{and } x_j(\Theta_j) = \frac{1}{2} (A - \theta^E(\Theta_j) - x_i'), \text{ for } \Theta_j \in \{\underline{\theta}, \bar{\theta}, \emptyset\}. \quad (\text{A.6})$$

which results in the following equilibrium output and profit for firm i :

$$x'_i = \hat{x}_i(\underline{\theta}, \emptyset), \text{ and } \pi_i = \hat{x}_i(\underline{\theta}, \emptyset)^2, \text{ respectively.} \quad (\text{A.7})$$

Clearly unilateral disclosure of low costs is profitable, since $\hat{x}_i(\underline{\theta}, \emptyset) > x_i^o(\underline{\theta})$. This completes the proof. \square

A.2.2 Proof of Proposition 1

Firm i 's expected profits under vaporware disclosure are as follows:

$$E_{\delta_j^*} \left\{ \tilde{\pi}_i(\Theta_i; \tilde{\delta}_i(\Theta_i), \delta_j^*) \right\} = pr_j \tilde{\pi}_i(\Theta_i; \tilde{\delta}_i(\Theta_i), \underline{\theta}) + (1 - pr_j) \tilde{\pi}_i(\Theta_i; \tilde{\delta}_i(\Theta_i), \emptyset), \quad (\text{A.8})$$

for $\Theta_i \in \{\underline{\theta}, \bar{\theta}, \emptyset\}$ and $i = 1, 2$. Distinguish two unilateral deviations from the vaporware disclosure equilibrium.

First, consider firm i with $\Theta_i = \bar{\theta}$. If it unilaterally chooses to disclose its cost, it receives expected profit:

$$E_{\delta_j^*} \left\{ \pi_i(\bar{\theta}; \bar{\theta}, \delta_j^*) \right\} = pr_j \hat{x}_i(\bar{\theta}, \underline{\theta})^2 + (1 - pr_j) x_i^h(\bar{\theta}; \bar{\theta}, \emptyset)^2, \quad (\text{A.9})$$

where $x_i^h(\bar{\theta}; \bar{\theta}, \emptyset) \equiv \frac{1}{3} \left(A - 2\bar{\theta} + \tilde{E}_j(\theta) \right)$ solves:

$$x_i^h = \frac{1}{2} \left(A - \bar{\theta} - [q_j x_j(\bar{\theta}) + (1 - q_j) x_j(\emptyset)] \right), \quad (\text{A.10})$$

$$x_j(\Theta_j) = \frac{1}{2} \left(A - \theta^E(\Theta_j) - x_i^h \right), \text{ for } \Theta_j \in \{\bar{\theta}, \emptyset\}. \quad (\text{A.11})$$

It is straightforward to verify that $\tilde{x}_i(\bar{\theta}; \emptyset, \underline{\theta}) > \hat{x}_i(\bar{\theta}, \underline{\theta})$ and $\tilde{x}_i(\bar{\theta}; \emptyset, \emptyset) > x_i^h(\bar{\theta}; \bar{\theta}, \emptyset)$. And, therefore, $E_{\delta_j^*} \left\{ \tilde{\pi}_i(\bar{\theta}; \emptyset, \delta_j^*) \right\} > E_{\delta_j^*} \left\{ \pi_i(\bar{\theta}; \bar{\theta}, \delta_j^*) \right\}$.

Second, if firm i knows it has a low cost, it should not have an incentive to unilaterally conceal this. Firm i 's profit-maximizing outputs after concealment of $\underline{\theta}$ are such that:

$$\begin{aligned} x_i(\underline{\theta}; \emptyset, \underline{\theta}) &= \frac{1}{2} \left(A - \underline{\theta} - \tilde{x}_j(\underline{\theta}; \underline{\theta}, \emptyset) \right), \text{ and} \\ x_i(\underline{\theta}; \emptyset, \emptyset) &= \frac{1}{2} \left(A - \underline{\theta} - [q_j \tilde{x}_i(\bar{\theta}; \emptyset, \emptyset) + (1 - q_j) \tilde{x}_j(\emptyset; \emptyset, \emptyset)] \right). \end{aligned}$$

This yields: $x_i(\underline{\theta}; \emptyset, \delta_j^*) = \tilde{x}_i(\underline{\theta}; \underline{\theta}, \delta_j^*) - \frac{1}{6} (\tilde{E}_i(\theta) - \underline{\theta})$, for $\delta_j^* \in \{\underline{\theta}, \emptyset\}$. Clearly, the expected profit from unilateral deviation profit, which equals

$$E_{\delta_j^*} \left\{ \pi_i(\underline{\theta}; \emptyset, \delta_j^*) \right\} = pr_j x_i(\underline{\theta}; \emptyset, \underline{\theta})^2 + (1 - pr_j) x_i(\underline{\theta}; \emptyset, \emptyset)^2, \quad (\text{A.12})$$

is lower than the expected profit from disclosure, since $x_i(\underline{\theta}; \emptyset, \delta_j^*) < \tilde{x}_i(\underline{\theta}; \underline{\theta}, \delta_j^*)$ for $\delta_j^* \in \{\underline{\theta}, \emptyset\}$. This completes the proof. \square

A.2.3 Proof of Proposition 2

[To be completed...]

A.3 Knowledge Spillovers

In this part of the Appendix we prove propositions 3 and 4, respectively.

A.3.1 Proof of Proposition 3

[To be completed...]

A.3.2 Proof of Proposition 4

[To be completed...]

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