Innovation strategies and stock price informativeness

Haina Ding*

Abstract

This paper models the interactions among technological innovation, product market competition and information leakage via the stock market. Both duopoly firms have an opportunity to invest in a risky technology. Information leakage caused by stock price movements provides firms with an option to delay investment as a follower based on better knowledge about the innovation prospect. It may however discourage the leader from investing upfront and lead to a lower efficiency in the product market, when the cost of information leakage overweights the innovation rent to the leader firm. I show that the probability of information leakage increases in the market size of the industry and the profitability of the innovation. Price informativeness mostly improve investment outcomes. I provide the empirical implications on firms' IPO decisions and show that firms are more likely to go public when innovation investments are associated with higher profitability and large market size in an industry with a lower level of competition. In the same circumstance, the investment sensitivity of a firm to the share prices of its competitor increases after it goes public. The model and its results provide new insights on the indirect impact from financial markets on the real economy.

Keywords: Technological innovation, Knowledge spillover, Price efficiency, Feedback

---

*Toulouse University 1 - Capitole, Graduate School of Management, CRM, 2 Rue du Doyen Gabriel Marty 31042 TOULOUSE CEDEX 9, France. I am grateful for helpful comments from Alexander Guembel, Bruno Biais, Sophie Moinas and other participants in the PhD workshop at Toulouse School of Economics. I thank also Guido Friebel, Christian Hellwig, and Augustin Landier for valuable discussions and suggestions. All errors remain mine.

1 Introduction

Innovations are regarded as the mainspring of economic dynamics. While providing firms with advantages in competition, innovations are mostly subject to a large irreversible investment, uncertainty, and potentially asymmetric information. In this regard, the financial market contributes to technological evolution by facilitating resource allocation, by financing and evaluating R&D investments, and by providing channels of risk sharing and diversification (Levine, 2005). It nevertheless exposes listed firms to the risk of information leakage related to their R&D progress, which is one of the main concerns in the IPO decisions of innovation-intensive firms.[1] Information leakage changes the market positions of leaders and the innovation rent they can seize, which thus affects their incentives to invest. It consequently influences the competition in an industry and also social welfare.

The direct and mostly discussed cause of information leakage are regulatory disclosure requirements for public firms. Little attention is paid to an indirect information leakage via stock price movements related to R&D investments. Recent literature, however, argues that prices in financial markets often take a more active role in providing to managers a source of information[2]. Empirical studies also find strong evidence that firms use the information contained in their stock prices when making decisions on corporate disclosure, cash savings, investment and takeovers[3]. In an industry where firms watch closely their rivals' actions while striving to protect their own secrets, it is thus plausible that once stock prices reveal one firm's private knowledge about its innovation progress, this information will be employed by its competitors in their decisions to make similar investments.

Some supporting evidence is uncovered in recent studies. Foucault and Frésard (2012) find a positive relationship between a firm's investment and the market valuation of its peers, the significance of which depends on the stock price informativeness and competition level in the product market. Ozoguz and Rebello (2013) show similar results and relate the link further to economic and operating environment of the industry. Shi and Du (2012) investigate the knowledge spillover among listed firms, and they show that one firm's innovation success may increase the market valuation of its industrial competitors. It is thus plausible that good news about one firm's innovation investment makes its rival more optimistic about their own

[1] Brau and Fawcett (2006) report in a survey of CFOs that "Disclosing information to competitors" and "SEC reproting requirements" are ranked the fourth and fifth factors in firms' decisions to go public.

[2] The origin of the idea goes back to Hayek (1945), Dow and Gorton (1997), and Subrahmanyam and Titman (1999), but it is formalized to the active informational role of prices more recently. See Bond, Edmans and Goldstein (2012) for a survey on this topic.

[3] See for instance Chen, Goldstein and Jiang (2007), Bakke and Whited (2010), Edmans, Goldstein and Jiang (2012), Fresard (2012) among others.

opportunities and thus more incentivized to invest.[4] Empirical evidence combined seems to suggest that stock price informativeness amounts to an indirect information leakage in the context of innovation investment, while a theoretical analysis is still missing.

To this end, I propose a simple model to address this indirect channel of information leakage, and discuss its consequences in innovations and competition. Two firms produce differentiated products and compete in a duopoly market. Both firms have an opportunity to invest in a risky process innovation which may reduce production cost with a positive probability. If a firm makes an investment at the beginning, it learns privately whether the innovation succeeds at the intermediate stage. Meanwhile, the same information can be acquired and traded on by some investors (speculators) in the stock market. Consequently, this information may be partially revealed from share price to the competitor of the firm. The possibility that this leakage may occur is factored in ex-ante decisions on innovation investment of both firms, and it therefore provides an option of waiting that allows a firm to invest when learning more about the innovation prospect from share prices.

The indirect information leakage differs in a fundamental way from the leakage caused by mandatory disclosures. In equilibrium, the amount of information being revealed (defined as the probability of leakage in this paper) depends on firms' innovation strategies and traders' incentives in the stock market. The reason behind is that when share prices feed back to firms' ex ante decisions, speculators' expected trading profit and thus their incentive of acquiring information depend on the characteristics of the industry and the innovation including the product demand, the success possibility and effectiveness of the technology. The probability of information leakage changes accordingly, and so is the option value, which then affects the equilibrium outcome. The two-way causality between product market interactions and information efficiency is little mentioned in the literature. Instead an exogenous probability of information leakage is often imposed, typically in the studies focused on the trade-off between a cheaper capital raised from the equity market and a more intensive competition caused by an increased information disclosure[5]. In addition, the extent of mandatory disclosures in R&D is limited to the related expenses, R&D acquisition and contracting[6], which does not

[4] A good illustration of this effect can be found in Choi (1991), who uses an example of the breakthrough of cold super-conductivity in 1986 by IBM. IBM's intermediate success made other firms more optimistic about this technology and increase their investment intensity. Similary, Austin (1993) observes in the biotech industry that an intermediate success in R&D of one firm leads to an increase in the valuation of its competitors.

[5] See Brander & Lewis, 1986; Maksimovic, 1988; Chemmanur & Fulghieri, 1999; Clementi, 2002; Chod and Lyandres, 2009, among others, for discussions about how different sources of financing, private debt or equity, affect firms' innovation strategies, and the intensity of product market competition.

[6] See Statement of Financial Accounting Standards (SFAS) 2, 68, 141 and 142.

suffice to reveal the actual progress of an innovation.

I show that the option value of waiting increases in the competition level of the industry but decreases in the market size as well as the profitability of the investment. Compared to the case without information leakage, the efficiency in the product market is improved due to either a reduced allocation of resources on unproductive innovation or effective investment by the follower based on a better knowledge about the innovation prospect. The efficiency may also be lowered when the option is too valuable and the innovation rent to the leader becomes insufficient such that it stops investing upfront. The equilibrium arises with no investment in that case. This information leakage may be most beneficial to firms in a young industry where innovation investments are less profitable with a smaller market size and the market competition is less intense, in contrast to industries in the late stage of their life cycles.

The impact of the feedback effect further depends on the information environment when the participation of speculators is endogenized. Speculators have incentive to acquire information only when doing so incurs a cost comparatively smaller than the subsequent trading profit. I show that their trading incentive increases in the success rate and the effectiveness of the innovation. It is also positively correlated with the market size in the industry. When a speculator expects too low a profit from trading one firm, he may then exit the market and this firm's share price is no longer informative. This reduces the overall probability of information spillover. As a result, the innovation rent to the leading firm is raised while the option value of waiting becomes smaller. When speculators expect their profit to be sufficiently low relative to information cost, they no longer acquire information and participate in trading. Share price of both firms, being uninformative, can no longer generate the spillover.

Analogically, the impact of feedback also depends on the number of firms that are publicly traded. I discuss the implications specifically on the situation in which one firm is already listed and the other firm considers going public. Its decision is now complicated by the fact that going public increases the informativeness of share prices at the intermediate stage and the option of waiting to the follower becomes more valuable.[7] Given its competitor is already listed, the follower firm can benefit from going public if the leader can still seize sufficient rent after the probability of leakage increases. We then expect that follower firms more likely go public when the innovation is less costly and has a relatively high success rate and uncertainty, and when the competition is less intense with a strong and inelastic demand in the industry. These predictions, though derived from a different aspect, are consistent with

[7] It is consistent with the general intuition that having more firms listed increases the aggregated information revealed in stock price.

the stylized facts that IPO waves usually occur during economic expansions and in a more profitable industry.[8]

Similar as suggested by Foucault and Frésard (2012), this model predict that followers' investments are more sensitive to the price movements of leading competitors when their own prices are less informative. The theoretical model of those authors gives only one duopolist the opportunity to expand the production capacity and does not allow its competitor to react. The strategic impact of the waiting option on the leader's rent and therefore its ex-ante decision are not considered in their model.[9] Having this feature in this paper allows to make predictions with more characteristics of the technology and the product market. For example, the model suggests that after a private firm's IPO, its investment sensitivity to the share prices of its competitors increases under the aforementioned conditions.[10]

In addition, the model provides a partial explanation for the empirical findings that public firms may invest less and have higher cash holdings than private firms (e.g, Asker, Ferra-Mensa and Ljungqvist (2011), and Ferra-Mensa (2011)). These authors relate the evidence to either the agency problem or the implicit cost caused by mandatory disclosure for seasoned equity offerings. From a different perspective, my model suggests that the problem can occur when leader firms are discouraged from investing upfront if the innovation rent is insufficient due to the information leakage. It can also occur when the follower firms are saved from making wasteful investment when share prices reveal bad news.

This paper also contributes to the literature of firms' strategies in industries in the face of weak intellectual property protection, and especially to process innovation that attracts relatively less attention compared to product innovation. Often related to cost reduction, process innovation is on average more difficult to be patented compared to product innovation. Good examples include the "no frills" revolution in air travel started by South West Airlines, computerized reservation initiated by IBM and American Airlines, and new business concepts like Groupon. These pioneering firms could hardly prevents their competitors from adopting a similar technology, while the second-mover advantage to the followers may be prominent. The general features of a process innovation are thus contained in the model proposed in this paper.

More importantly, knowledge spillover due to involuntary or strategic disclosures, as dis-

[8] See Pastor and Veronesi (2005) and Jong, Huijgen, Marra, and Roosenboom (2012).

[9] Similarly, in the paper of Spiegel and Tookes (2008) who investigate firms' financing choices for innovation investment in a dynamic duopoly, only one firm can invest in the technology upfront. The impact of the waiting option on the ex-ante financing decision is not considered.

[10] That is, if their products are less similar and have a strong and inelastic demand from consumers, and if the innovative technology is associated with low cost and relatively high success possibility.

cussed in most of the innovation literature[11], may not be suitable in the context of price competition. As shown by Gal-Or (1986), voluntary disclosure is not optimal to the duopolists in price competition when there exists an ex-ante uncertainty in the production cost. As a result, a model of indirect information leakage via share prices captures well the knowledge spillover among firms competing in price, compared to a setup relying on firms' disclosure to shareholders. I thus neglect the discussion of firms' voluntary and strategic disclosures of innovation progress.[12]

The paper proceeds as follows. Section 2 presents the setup of the model. Firms' equilibrium strategies are computed in Section 3, and participation of speculators is discussed in Section 4. Empirical implications are explained in Section 5. An extension is put in Section 6 to discuss the welfare in the product market and the participation of noise traders. Section 7 concludes. Proofs are relegated to the Appendix.

2 The Model

2.1 The timeline

The timing of the model is described in Figure 1. There are four dates in this model. Both firms have an opportunity to invest in a risky innovation at either date 0 or date 1. If one firm invests in this innovation at date 0, it will know privately at the next date whether this innovation succeeds. Once an investment takes place in one firm, speculators can acquire private information about the success of the innovation trade on this information, and trade on this information if that firm is listed. If the other firm decides not to invest at date 0, it can choose either to do so at date 1 or forgo the investment opportunity, given the share prices at date 1. Firms then compete in the product market at both date 2 and date 3, and they liquidate at the end of date 3. Next, I explain in detail the assumptions about the product market and the innovation.

2.2 The product market

The duopoly firm i and j produce differentiated products without capacity constraints. They start at date 0 with the same marginal production cost, c, and they produce and sell

[11] See Jansen (2006 and 2008), Magazzini, Pammolli, Riccaboni and Rossi (2009), among others, who investigate firms' disclosure strategies regarding their innovations given the presence of product market competition.

[12] The interested reader may refer to Gal-Or (1986) for more detail.

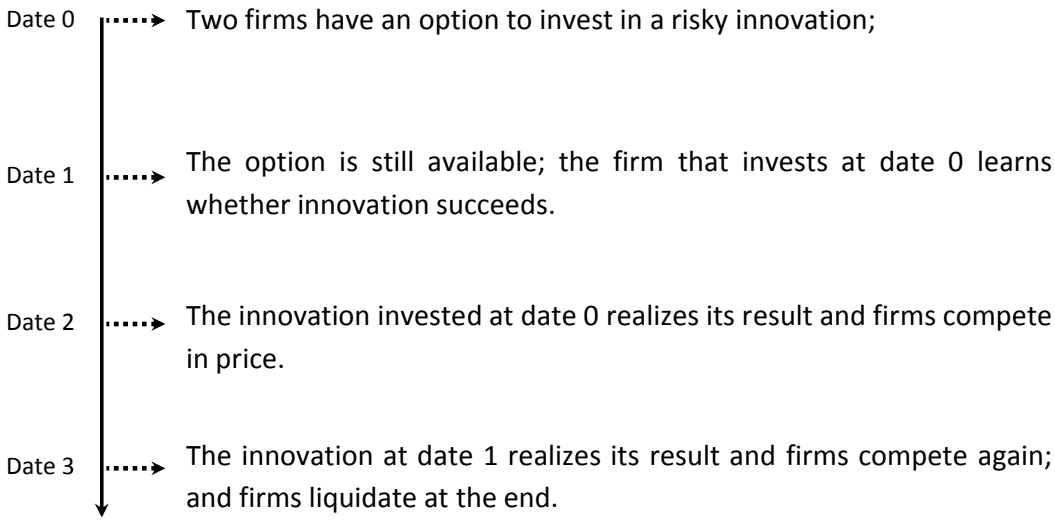

Figure 1: The Timeline

at two dates (2 and 3). To make the computation more tractable, I follow most literature of industrial organization by assuming that the duopolists in this economy share the information about production cost before setting prices.[13]

Following Singh and Vives (1984), I assume that there exists a representative consumer in the economy, who maximizes at both date 2 and 3 his utility function $U(q_i, q_j) - \sum_{i=1}^{2} p_i q_i$, when consuming a quantity q_i and q_j of goods respectively from firm i and j at price p_i and p_j. $U(q_i, q_j)$ is quadratic and strictly concave and symmetric in q_i and q_j for simplicity, formally written as,

$$U(q_i, q_j) = \alpha(q_i + q_j) - \frac{1}{2}\left(q_i^2 + 2\gamma q_i q_j + q_j^2\right), \tag{1}$$

where $\alpha > 0$ and $0 < \gamma < 1$. The parameter γ measures the substitutability between the goods produced by two firms. The higher is γ, the closer substitutes firms' products are and thus the fiercer their competition is. The following demand functions for the goods of firm

[13] More drastic restrictions on the communication about production cost may not only lead to a convolution in results due to the effects from different sources, but also yield additional welfare losses since communication between competing firms enables more efficient decision making in product market (Kuhn and Vives, 1995). By simplifying the information structure that is less relevant to firms' innovation decisions, I can draw clearer inferences about the impact of the feedback effect regarding the innovation progress.

i maximizes the utility of the representative consumer,

$$q_i = \frac{(\alpha - p_i) - \gamma(\alpha - p_j)}{1 - \gamma^2} \tag{2}$$

Consequently, firm i sets price p_i to maximize its profit π_i,

$$\pi_i = (p_i - c_i)\frac{(\alpha - p_i) - \gamma(\alpha - p_j)}{1 - \gamma^2}. \tag{3}$$

At date 0, the firms possess the same production technology and face an innovation decision that requires an investment I. This innovation will either decrease a firm's marginal production cost by δ with probability θ or make no change with probability $1 - \theta$, $\theta \in (0, 1)$ and $0 < \delta < c$. The success of the innovation is assumed to be perfectly correlated across firms regardless of the timing of innovation, and this is common knowledge.[14]

For simplicity, I assume that the investment cost, I, remains unchanged from date 0 to date 1. I also assume that it takes two periods for the invested innovation to exert influence on cost reduction. More specifically, if one firm invests at date 0, and the innovation succeeds, production costs at date 2 and 3 are $c - \delta$. If the firm invests at date 1 instead, its production cost at date 2 stays at c, and if the innovation succeeds, the cost changes to $c - \delta$ at date 3 only. A firm innovating at date 1, i.e., the follower, may thus be disadvantaged in the first-stage product market competition at date 2, if the innovation of the leading firm is found to be effective. This opportunity to invest in this innovation is no longer available after the end of date 1.[15] Firms' decision to invest in innovation is also assumed to be publicly observable.[16]

2.3 The stock market

Three types of agents exist in the stock market. A competitive market maker earns zero profit in expectation by setting share price based on his rational expectation of a firm's profit when observing the submitted orders. There also exists a noise trader who either buys or

[14] This assumption can be relaxed by have an exogenous correlation between the success of the innovation of each firm, which would still make information leakage a problem. It is plausible given that innovation depends on technological feasibility which is fundamental and largely comparable among firms in the same industry. Relaxing the assumption would not change the qualitative result, however.

[15] The presumed final liquidation of firms makes it not optimal for firms to invest in innovation later than date 1, even if such an option is still available then.

[16] This may be obligatory for the firms due to disclosure requirement, particularly when the innovation investment is financed by the issuance of equity. This assumption also allows me to focus on the pure equilibrium strategy.

sells 1 unit of each listed firm for liquidity reason.[17] Finally, there are two speculators in the stock market, who can acquire at date 1 the private knowledge regarding firms' innovation progress and trade on this information if profitable. The speculators can only submit market orders.

Share trading is assumed to occur at date 1 after innovating firms acquire their own private knowledge. Order flows in the stock market are publicly observable. When only one firm innovates at date 0, this information can be used by their competitor to decide whether to innovate at date 1. Speculators reap their trading profits at date 2 when the effectiveness of the innovation is observed and firms produce and sell. Note that I assume no other information leakage or spillover in this economy. Consequently no private knowledge about innovation progress will be revealed without informed trading in stock market. Also, if no investment is made at date 0, speculators cannot know whether this innovation will be successful, and hence they will not trade.

3 Firms' Equilibrium Strategies

3.1 A benchmark model with no feedback

I consider first the case in which there is no stock market. As previously specified, firms know their rivals' marginal production cost just before they enter price competition. The representative consumer chooses quantities of goods (q_i, q_j) to maximize the utility function given in (1), and each firm maximizes its profit given in (3). By deriving the first order condition of the profit function with respect to p_i, the best response function of price of firm i can be obtained as below,

$$p_i = \frac{1}{2}\left[\alpha\left(1-\gamma\right) + \gamma p_j + c_i\right]. \tag{4}$$

Solving the system of the response price functions of firm i, we can obtain the optimal price p_i^* for firm i, $i = 1, 2$,

$$p_i^* = \frac{\alpha\left(1-\gamma\right)}{2-\gamma} + \frac{2c_i + \gamma c_j}{4-\gamma^2}. \tag{5}$$

The expression of p_j^* is symmetric to (5). Using the optimal price p_i^* and p_j^*, and the demand function q_i established in (2), I can then state the equilibrium profits of firms as functions

[17] In the Extension, I endogenize the trading incentive of the noise trader.

of c_i and c_j,

$$\pi_{c_i,c_j} = \frac{1}{1-\gamma^2}\left(\frac{1-\gamma}{2-\gamma}\right)^2\left((\alpha - c_i) + \frac{\gamma\,(c_j - c_i)}{(2+\gamma)\,(1-\gamma)}\right)^2 \tag{6}$$

Formula (6) shows that firm i's profit increases in its competitor's cost c_j. If firm i has invested in an innovation that shows effectiveness in reducing its cost, firm i would prefer that its competitor does not invest in the same innovation, i.e., the strategic effect of technology adoption is negative under price competition. The information about the innovation progress will not be revealed before the product market competition.[18] Due to the absence of knowledge spillover in the benchmark case, it is never optimal to invest at date 1 if no firm invests at date 0. This therefore leaves two pure strategies to each firm, either to "invest in innovation at date 0", denoted by L, or not to innovate at all, denoted by N.

Strategy L and N complete firms' action space Ω in the benchmark case, $\Omega = \{L, N\}$. Ω provides four possible combinations of strategies (A_i, A_j) chosen by firm i and its competitor j, and each combination leads to a different expected profit for both firms at either date 2 or 3. Since firms have the same action space and symmetric payoffs, the discussion of mixed strategies does not render additional insights and is therefore skipped. I restrict attention to pure strategy equilibrium in this paper.

To facilitate the illustration hereafter, I first compute and compare firms' profit π_{c_i,c_j} under each realization of their production cost, $c_i, c_j \in \{c, c-\delta\}$.

Lemma 1 *The size of firms' profit π_{c_i,c_j} is ranked as follows: $\pi_{c-\delta,c} > \pi_{c-\delta,c-\delta} > \pi_{c,c} > \pi_{c,c-\delta}$.*

Given the success rate of the innovation θ, we can then compute the expectation of firm i's payoff, denoted by Π_i, under each strategy pair (A_i, A_j) chosen from Ω. $\Pi_i\,(A_i, A_j)$ consists of firm i's profit at both date 2 and 3 as well as the cost of innovation if the investment has taken place. As a result, if both firms choose the same strategy, $\Pi_i\,(L, L) = 2\theta\pi_{c-\delta,c-\delta} + 2\,(1-\theta)\,\pi_{c,c} - I$ and $\Pi_i\,(N, N) = 2\pi_{c,c}$. If, however, only firm i invests in the innovation, $\Pi_i\,(L, N) = 2\theta\pi_{c-\delta,c} + 2\,(1-\theta)\,\pi_{c,c} - I$ and $\Pi_i\,(N, L) = 2\theta\pi_{c,c-\delta} + 2\,(1-\theta)\,\pi_{c,c}$. I derive the Nash equilibria and present the equilibrium conditions in Proposition 1.

Proposition 1 *If $I \geq \theta\bar{I}$, (N, N) is the unique Nash equilibrium; if $I \leq \theta\underline{I}$, (L, L) is the unique Nash equilibrium; and the equilibria are (N, L) & (L, N), if $\theta\bar{I} > I > \theta\underline{I}$, where $\underline{I} = 2\,(\pi_{c-\delta,c-\delta} - \pi_{c,c-\delta})$, and $\bar{I} = 2\,(\pi_{c-\delta,c} - \pi_{c,c})$*

[18] Firm i has no incentive to reveal a good progress of its innovation. Neither would it reveal bad news, since otherwise its competitor could perfectly infer the incidence of a successful innovation.

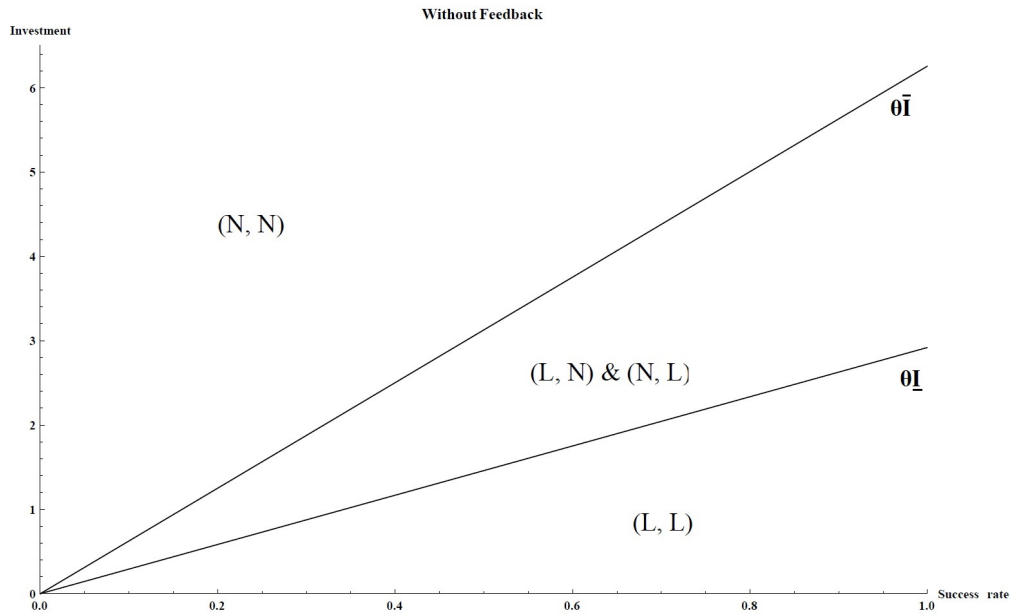

Figure 2: Firms' Equilbrium Strategies - Prop. 1

I plot in Figure 2 the equilibrium strategies for a numerical example, in which $\gamma = \frac{3}{4}$, $c = 3$, $\delta = 2$ and the demand parameter $\alpha = 5$. The parameter values remain unchanged for the illustrations throughout the paper, unless indicated differently. The required investment I for the innovation is scaled on the vertical axis and the success rate θ is on the horizontal axis. The thresholds in the scale of required investment, $\theta\underline{I}$[19] and $\theta\bar{I}$, separate three regions that represent firms' strategies in different equilibria. Notice that both thresholds increase in the success rate (θ) as well as the magnitude of the cost reduction (δ). Intuitively, the investment in an innovation technology is more likely to be taken when the innovation has a high probability to succeed and brings a bigger advantage in product market competition.

3.2 Equilibrium in a model with feedback

I now assume that there exists a stock market in the economy and both firms are publicly listed. All other assumptions regarding the competition in the product market remain as previously stated. Compared to the benchmark case in which the innovation progress is known only to the firm that makes the investment, speculators can also acquire this private information for trading purposes. This additional ingredient introduces an option: a firm can now choose to wait and make the decision at the intermediate stage (date 1) after observing

[19] The lower threshold $\underline{I}$ is zero when the degree of substitution is converges to 1 (i.e., the perfect substitution).

the order flows or share prices in the stock market. If no firm invests in the innovation at date 0, there will be no private information for the speculator to acquire and trade on, and consequently submitted orders will contain no private information. Product market competition still takes place at date 2 and 3.

Each speculator is assumed to trade only one firm's shares, though they may have access to the private information about both firms. This assumption, simplifying the discussion of the trading part of the game, can be justified by the usual limits on exposure that a trader is willing to take. Note that due to the competition between two firms, good news for one firm can be bad news for its competitor if they are taking different investment strategies. That is, even if only firm i invests, to acquire and trade on the information of firm i can be profitable to both speculators. While speculator i trades firm i's shares, speculator j can use that information to trade in firm j. Although speculators are allowed to choose any order size to submit, speculators will follow nevertheless the optimal trading strategy defined by the lemma below.

Lemma 2 *Speculator i submits a buy (sell) order of size 1 of firm i, when he knows that either firm i invests in the innovation and succeeds (fails) or firm j invests and fails (succeeds). Speculator j's optimal strategy is symmetric to the speculator i's.*

Recall that the noise trader buys or sells 1 unit of both firms's shares with equal probability and there is no correlation in their orders across firms. Let x_i and x_j denote the order flow of firm i and of firm j. It is straightforward to see that the trading direction of speculators are hidden if $x_i = x_j = 0$, and their private information is not revealed. Based on Lemma 1, Lemma 2 follows immediately.

Lemma 3 *Stock prices are fully informative with probability $\frac{3}{4}$.*

When prices are not informative, a firm choosing not to invest upfront has to decide whether to invest based on its prior belief. Continuing with the notation "L" and "N" as in the benchmark case, I add two others for the strategies of the follower firm: "F" denoting the strategy "to invest at date 1 only when order flows reveal good news about the innovation", and "$\widetilde{F}$" denoting "to invest at date 1 when order flows reveal good news or no private information". The action space for each firm now consists of four pure strategies, $\Omega = \{L, F, \tilde{F}, N\}$. Given that firm i leads in the innovation investment at date 0, the expected payoff to the other firm with the new strategies F and $\tilde{F}$ are, respectively, $\theta\left(\frac{5}{4}\pi_{c,c-\delta} + \frac{3}{4}\pi_{c-\delta,c-\delta}\right) + 2\left(1-\theta\right)\pi_{c,c} - \frac{3}{4}\theta I$ and $\theta\left(\pi_{c,c-\delta} + \pi_{c-\delta,c-\delta}\right) + 2\left(1-\theta\right)\pi_{c,c} - \left(\frac{1}{4} + \frac{3}{4}\theta\right) I$. As stated in Lemma 4, $\tilde{F}$ cannot be an equilibrium strategy, however.

Lemma 4 *It is a strictly dominated strategy to invest in the innovation at date 1 with no additional information from the stock market.*

The other strategies $\{L, F, N\}$ survive in equilibrium in the product market. For the stock market, given that the profit functions of both firms are publicly known, the market maker is able to anticipate the best response in innovation strategy of the follower firm, and to set the share prices accordingly. The equilibrium is thus defined as follows: (i) A trading strategy by each speculator that maximizes his expected payoff, given the investment strategies of the firms, (ii) the innovation strategies by the firms that maximize expected firm value given all other strategies, (iii) a price-setting strategy by the market maker that allows him to break even in expectation, given the strategies taken by the speculators and firms.

Note that so far speculators are assumed not to bear any information cost and therefore always have incentive to trade as long as there is some private information to acquire. This allows me to focus first on the equilibrium in the product market, which are summarized in the proposition below.[20]

Proposition 2 *The equilibrium conditions remain unchanged as in Proposition 1 either when $\theta > \frac{1}{2}$ or when $I \geq \frac{1}{2}\underline{I}$;*

If $I < \frac{1}{2}\underline{I}$, there is a unique equilibrium (N, N) when $\theta\tilde{I} \leq I < \frac{1}{2}\underline{I}$, for $\theta \in \left(0, \frac{1}{2}\right)$;

$(L,\ L)$ is the unique equilibrium if $0 < I < \min\left\{\frac{5\theta}{2(4-3\theta)}\underline{I}, \frac{1}{2}\underline{I}\right\}$;

$(L,\ F)$ & $(F,\ L)$ are the equilibria if $\frac{5\theta}{2(4-3\theta)}\underline{I} \leq I < \min\left\{\theta\tilde{I}, \frac{1}{2}\underline{I}\right\}$.

$\bar{I}$ and $\underline{I}$ are defined as in Proposition 1, and $\tilde{I} = \frac{5}{4}\pi_{c-\delta,c} + \frac{3}{4}\pi_{c-\delta,c-\delta} - 2\pi_{c,c}$.

I plot in Figure 3 the thresholds of equilibrium strategies in Proposition 2 in solid lines in contrast to the dotted ones from Proposition 1. We observe the the same thresholds when the investment cost is greater than $\frac{1}{2}\underline{I}$ that is the condition for the follower firm not to invest at date 1 even if share prices reveal good news. Proposition 2 also shows that when the success probability θ is above $\frac{1}{2}$, choosing F is no longer optimal for the non-leading firm. The intuition is that strategy F is preferable to the follower only if the wasteful investment avoided by using the option of waiting overweights the expected competition disadvantage, that is, $(1-\theta)\,I > \frac{\theta}{2}\underline{I}$. When $\theta > \frac{1}{2}$, this condition contradicts the threshold for investing upon good news at date 1 (i.e., $I < \frac{1}{2}\underline{I}$).

[20] To assure the existence of a pure-stretegy equilibrium, I assume that the parameter α is not too large such that $\tilde{I} > \frac{5\theta}{2(4-3\theta)}\underline{I}$ when $\theta = \frac{1}{2}$, i.e., $\alpha < c + \delta\frac{20+(3-10\gamma)\gamma}{6(2-\gamma-\gamma^2)}$.

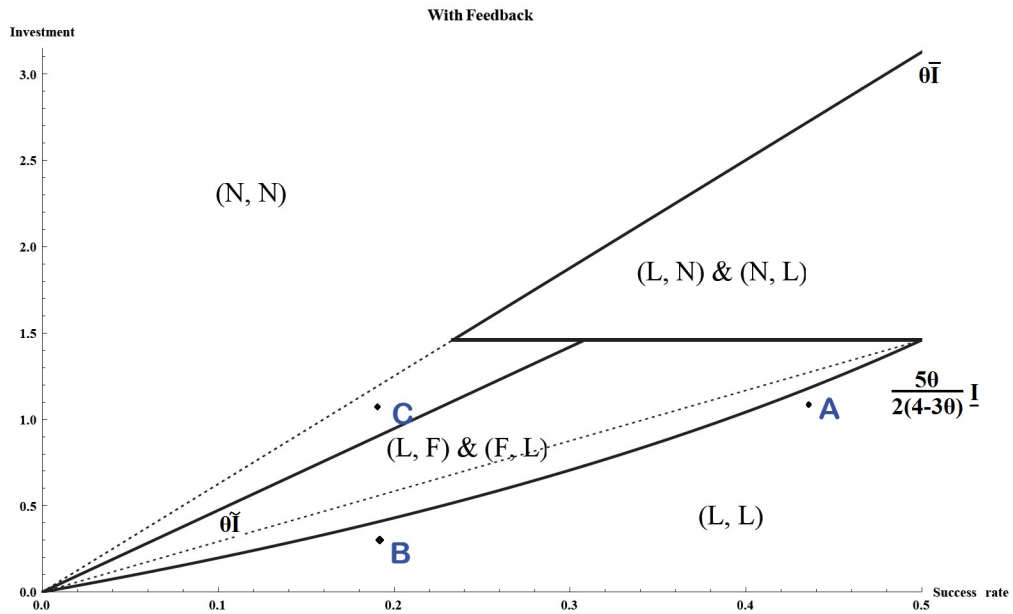

Figure 3: Firms' Equilbrium Strategies - Prop. 2

Moreover, the new strategy F and thus the option of waiting lead to fundamental changes in Proposition 2 compared to the benchmark case. I first define the option value of waiting.

Corollary 1 *The option value of waiting is the benefit to a firm from choosing the strategy F over L given its competitor chooses L, that is,* $\Pi(F, L) - \Pi(L, L)$.

The option value equals zero at the lower threshold of (L, F) & (F, L) in investment cost, $\frac{5\theta}{2(4-3\theta)}\underline{I}$, above which (L, L) is replaced by (L, F) & (F, L), since it is optimal for one firm to take advantage of the option and act as the follower. The option value is even higher in the parameter region where a firm switches its strategy from N to F and invest upon good news at date 1. The efficiency is improved in (L, F) & (F, L) due to either a more effective investment at the intermediate stage or a reduced unproductive investment, since the option allows firms to invest with a better knowledge about the innovation prospect.

On the other hand, (L, N) & (N, L) are replaced by (N, N) in the region where strategy F reduces the leader's innovation rent to the extent that it no longer profits from investing at date 0. We thus observe a new threshold $\theta\tilde{I}$ between (N, N) and (L, F) & (F, L). In this scenario, informative leakage deters the investment upfront and lead to a lower efficiency in the industry.

We now take a careful look at how the option value varies with stock price informativeness as well as the characteristics of the innovation and the product market.

Corollary 2 *The option value of waiting decreases in the success rate θ and the demand parameter α, and increases in the degree of product substitution γ and the investment cost I.*

To illustrate the intuition of Corollary 2, let us look at point A, B and C in Figure 3. For a given size of I, when the success rate is very small, for example at point C, the option is very valuable since it prevents the follower from making a wasteful investment with a high probability. Meanwhile the profitability of the investment at point C is not sufficiently high, this deters the investment that would be made by leader without feedback. When θ approaches $\frac{1}{2}$, the option value becomes too small such that the region of $(L,\ F)$ & $(F,\ L)$ shrinks and firms find it more profitable to both invest up-front, such as at point A. The analogy can be seen from the comparison between point A and B regarding the required investment I.

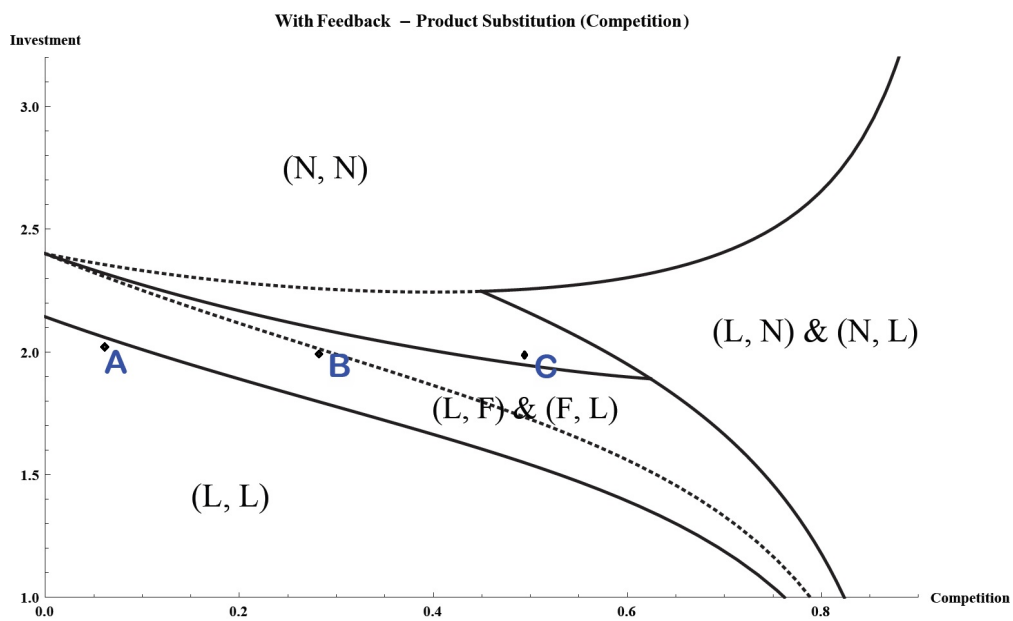

Figure 4: Firms' Equilbrium Strategies - Competition Level γ

Figure 4 shows the impact of γ on equilibrium strategies, where θ takes a value 0.4 and the other parameter value remain unchanged. When γ increases, products of firm i and j become closer substitutes, and the competition level in the industry increases. Expecting its competitor to lead, a firm has a lower incentive to invest at the same time, since the profit function π_{c_i,c_j} decreases in γ if $c_i = c_j$. Naturally, the option value increases in γ. For example, at point A in Figure 4 the option of delay has a low value such that both firms

invest upfront. When γ increases to point B, one firm takes the waiting option. While at point C, the innovation rent to the leading firm becomes too low, and the equilibrium (N, N) emerges. Note that the information spillover does not affect the equilibrium outcome when γ is approaching 1, i.e., products become perfect substitutes.

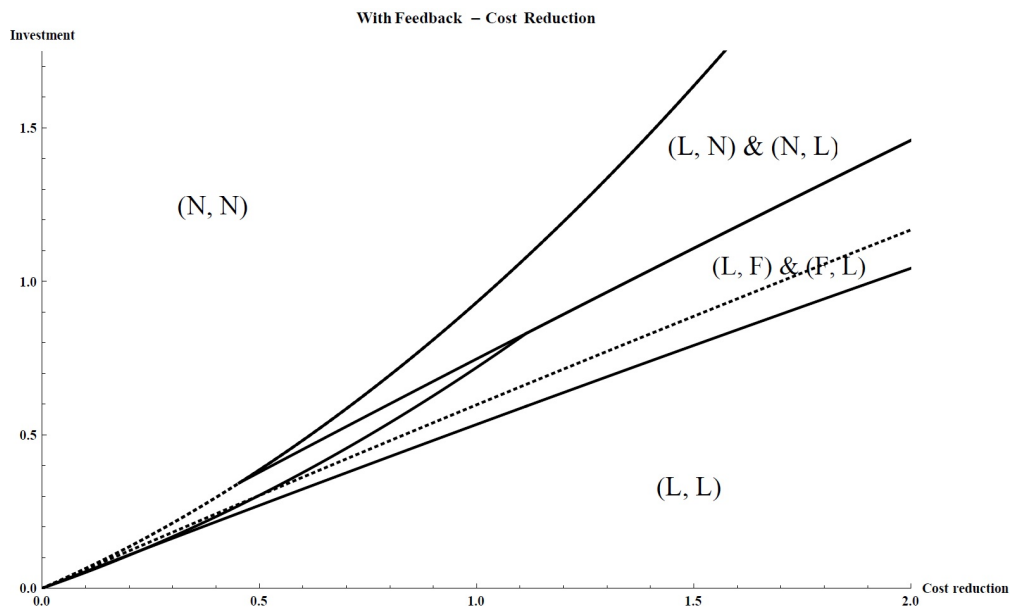

Figure 5: Firms' Equilbrium Strategies - Cost Reduction δ

The market size in the industry also matters. Using the demand function in (2) and the equilibrium price in (5), we can compute the intercept of the demand function and the price elasticity of demand[21]. It is then easy to prove that a higher value of α is associated with a larger intercept of demand and a lower price elasticity, and therefore a larger market size in the industry. When the market size increases, competition advantage brought by the innovation becomes more significant and firms are more inclined to invest upfront. The option value of delay drops as a consequence.

Finally, the cost reduction δ also matters to the impact of information leakage, as shown by Figure 5 below in which δ varies from 0 to 2, $\theta = 0.4$, $\gamma = 0.75$ and $\alpha = 5$. When δ is small the upper boundary of $(L,\ F)$ & $(F,\ L)$, $\theta\tilde{I}$, decreases in δ more significantly than the lower boundary, and thus the main change brought by information leakage is to replace $(L,\ N)$ & $(N,\ L)$ by (N, N). A small δ makes the innovation investment less profitable particularly to the leader firm and thus L becomes much less desirable. When δ becomes

[21] The intercept of the demand function $p_i(q_i = 0)$ equals $\alpha\,(1-\gamma)+\gamma p_j$, and the price elasticity of demand E_{di} equals $-\frac{\gamma}{1-\gamma^2}\frac{p_i}{q_i}$.

sufficiently large (i.e., $\delta > 1$ in the example shown by Figure 5), the efficiency in the product market is improved by and large.

It is clear so far that an industry benefits from the indirect information leakage when facing innovations associated with a moderate investment, high effectiveness and uncertainty, and when the competition level is relatively high. Informative share prices encourage innovations and improve the efficiency of innovation investment. This may fit an industry at the growth stage of its life cycle, in which incremental innovations are frequently needed and often effective, required investment are lower than the introduction stage while uncertainty is still high. The opposite can be said for industries at stages of maturity or decline, when the prevailing technology is very mature and hence innovations carry little risk with small impact on production and require lower investment.

4 Participation of Speculators

4.1 Speculator's profit

To understand the trading incentive of speculators, I compute speculators' expected profit and show how the profitability of their information acquisition can be affected. Recall that if no firm innovates at date 0, no informed trading will occur at the next date since no private information is there for acquiring. On the other hand, if both firms invest at date 0, speculators still profit from trading, even though the revealed private information is no longer used for firms' decision making.

Assuming firm i innovates at date 0, trading is profitable to speculators only if $x_i = x_j = 0$, in which case firm j will not invest in the innovation at date 1. Given that the profit functions of both firms are publicly known, the market maker is able to anticipate the optimal strategy of firm j and quotes the price P_i and P_j as exactly the expected payoff of firm i and j, respectively,

$$\begin{aligned} P_i &= \Pi_i(L, N) = 2\theta\pi_{c-\delta,c} + 2(1-\theta)\pi_{c,c} - I \\ P_j &= \Pi_j(N, L) = 2\theta\pi_{c,c-\delta} + 2(1-\theta)\pi_{c,c}. \end{aligned} \tag{7}$$

Speculators' trading profit is not related to the investment cost I due to the assumption that firms' investment actions can be observed by all agents. It however depends on other parameters including the success rate of the innovation, the cost reduction and the parameter α that characterizes the consumer demand. Using the demand function in (2) and the best

response of price in (4) and the equilibrium price in (5), we can compute the intercept of the demand function, and also the price elasticity of demand[22]. Substituting the equilibrium price p_i and q_i, we know that the intercept of the demand increases in α while the price elasticity decreases in α.

The next proposition summarizes how speculators' profit depends on θ, δ and α.

Proposition 3 *The expected trading profit of the speculators decreases in the success rate of innovation, θ, when $\theta > \frac{1}{2}$, but increases in θ when $\theta < \frac{1}{2}$. It monotonically increases in both the scale of cost reduction, δ, and the demand parameter α.*

Relating to the equilibrium conditions in Proposition 2 and the option value of waiting in Corollary 2, we know that when the required investment is very low, the option value is low and thus both firms are inclined to innovate at date 0. The information produced by the speculators is thus less useful to firms in the product market. When only one firm innovates at date 0 and the innovation has a larger impact on the production cost (a higher δ), all the thresholds in the equilibrium conditions stated in Proposition 2 increase. This then yields a higher incentive for speculative trading since it becomes less likely that no firm invests. Also, a higher δ makes the leading firm more advantaged in competition if the innovation succeeds, and the speculative trading becomes more profitable as a result. Proposition 3 also says that if the investment in the innovation is more risky, i.e., θ closer to $\frac{1}{2}$, speculators have a higher incentive to acquire and trade on the privation information, which enable firms to ride on better information set and thus improve investment decision.

4.2 Endogenized information leakage

Let us now assume that it costs ϵ for each speculator to acquire information related to the innovation progress. Speculators will participate only when ϵ is lower than the expected trading profit, i.e., their net expected payoff is positive.

As a result, three possible outcomes can arise corresponding to the size of ϵ relative to other parameters: both speculators exit the market and the equilibrium goes back to the one in the benchmark (Proposition 1); both are active and we obtain the equilibrium as in Section 3 (Proposition 2); one speculator quits and the other remains active when their expected trading profits are different. In equilibrium, firms' ex ante innovation strategies correspond to the number of active speculators in expectation. Since the trading incentive of

[22] The intercept of the demand function $p_i(q_i = 0)$ equals $\alpha(1-\gamma)+\gamma p_j$, and the price elasticity of demand E_{di} equals $-\frac{\gamma}{1-\gamma^2}\frac{p_i}{q_i}$.

speculators is determined by the parameters characterizing the innovation and the industry, as shown by Proposition 3, Lemma 5 follows immediately.

Lemma 5 *The probability of information leakage is endogenized by the fundamentals in the industry.*

We already know the equilibrium strategies of firms are defined by Proposition 1 when both speculators quit the market. We next have a careful look at what may happen in equilibrium with only one active speculator. Assuming only firm i invests at date 0, speculators i and j then earn $\Pi_i^S|L,N$ and $\Pi_j^S|N,L$, respectively, and it is easy to see $\Pi_i^S|L,N > \Pi_j^S|N,L$. When other parameters remain unchanged, an increasing ϵ will first drive speculator j out of the market, since trading the follower firm's shares yields a lower profit. This leaves speculator i the only informed trader in the stock market, thereafter called the monopoly speculator. That may as well take place, according to Proposition 3, if the cost reduction (a lower δ) is not sufficient, product demand is too low or too elastic (a low α), or the innovation technology is less risky (θ further away from $\frac{1}{2}$).

A direct consequence of having a monopoly speculator is that share prices are less informative than having both speculators active in the stock market. It is rather intuitive since the market maker can no longer update his belief based on the total order flows of both firms. See the Appendix for a complete proof for the following lemma.

Lemma 6 *With a monopoly speculator, the probability of having information spillover is reduced to $\frac{1}{2}$.*

Note the logic of Lemma 2 always holds that the non-leading firm will not invest at date 1 if the share price does not reveal any private information. It is then straightforward to compute the expected profit of the monopoly speculator, $\Pi_i^S|L,N = 2\theta(1-\theta)(\pi_{c-\delta,c} - \pi_{c,c})$, twice as much as with two active speculators. Anticipating a monopoly speculator in the stock market, firms choose optimal innovation strategies as summarized in the proposition below.

Proposition 4 *The equilibrium conditions remain unchanged as in Proposition 1 either when $\theta > \frac{1}{2}$ or when $I \geq \frac{1}{2}\underline{I}$;*

If $I < \frac{1}{2}\underline{I}$, there is a unique equilibrium (N,N) when $\theta\tilde{I}' \leq I < \frac{1}{2}\underline{I}$, for $\theta \in \left(0, \frac{1}{2}\right)$; (L, L) is the unique equilibrium if $0 < I < \min\left\{\frac{3\theta}{2(2-\theta)}\underline{I}, \frac{1}{2}\underline{I}\right\}$; and the equilibria are (L, F) & (F, L) if $\frac{3\theta}{2(2-\theta)}\underline{I} \leq I < \min\left\{\theta\tilde{I}', \frac{1}{2}\underline{I}\right\}$, while (N, L) & (L, N) cannot be equilibria.

$\bar{I}$ and $\underline{I}$ are defined as in Proposition 1, and $\tilde{I}' = \frac{3}{2}\pi_{c-\delta,c} + \frac{1}{2}\pi_{c-\delta,c-\delta} - 2\pi_{c,c}$.

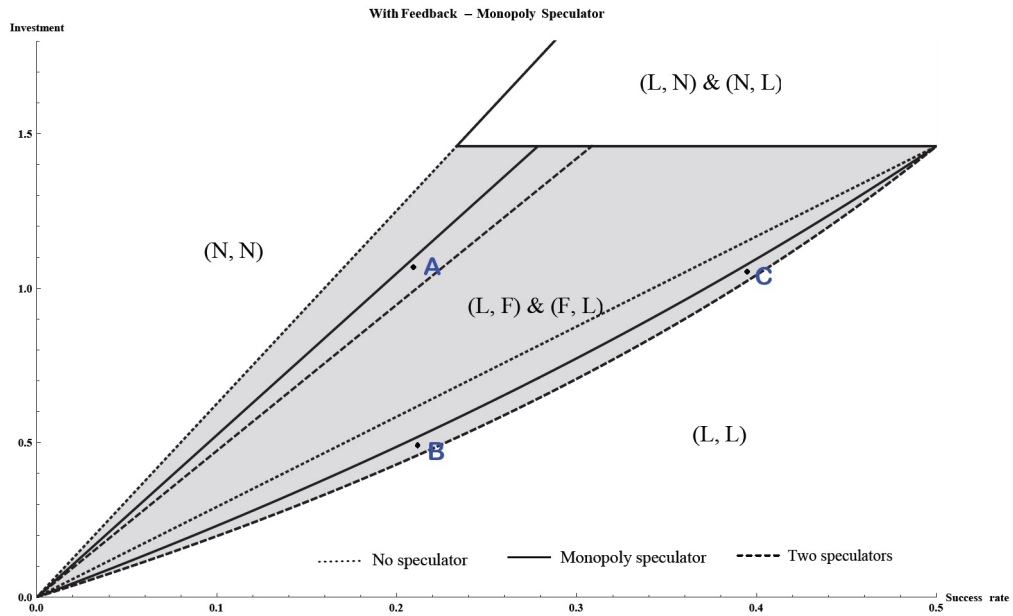

Figure 6: Firms' Equilbrium Strategies - With a Monopoly Speculator

Using both Lemma 5 and Prop. 4, we can easily deduce Corollary 2.

Corollary 3 *Having a monopoly speculator leads to a lower option value of waiting.*

To understand the consequence of Corollary 3, I draw the thresholds of equilibrium strategies conditioning on having a monopoly speculator (Prop.5) in Figure 6 by using the solid lines, in contrast to the dashed lines that represent the thresholds of having two active speculators (Prop. 3). We can observe that the upper bound for the required investment is pushed up for the strategy profile (L, L). The intuition is that when share prices are less informative with one active speculator and thus the option of waiting becomes less valuable, it is less optimal for firms to choose F. Typically when the required investment is relatively small, it becomes optimal for both firms to invest early in the innovation. On the other hand, a lower probability of information leakage increases the expected payoff to the leader when expecting its competitor to follow, such that the leader is less likely to be deterred. As a result, the lower bound for (N, N) is raised, and the region with low efficiency becomes smaller.

Observe that the shaded area in Figure 6 represents the case in which that firms' equilibrium strategies are affected by the numbers of active speculators. Assume the values of all other parameters are fixed except the information cost ϵ. At point A, when ϵ is significant such that none of the speculators find it profitable to acquire information, it is optimal to

have only one firm invest at date 0. If ϵ decreases to the point that the net payoff is expected to be positive to the speculator of the leader firm but not to the other one, the strategy profiles change to (L, F) & (F, L). If ϵ is sufficiently low such that both speculators find it profitable to trade, firms nevertheless choose (N, N) since the leader firm is now deterred by the lower rent. Similarly, the follower firm's strategy at the point B and C is switched from F to L when the speculator assigned to this firm cannot earn sufficient trading profit to cover its information cost.

The same reasoning applies to the case in which speculators' trading incentive varies with θ, δ or α as in Proposition 4. Therefore, firms' ex-ante innovation decisions have a two-way causality with traders' incentive and thus the probability of knowledge spillover, both determined by the values taken by the variables in this economy (i.e., the success rate of the innovation, the required investment, the magnitude of cost reduction and the information environment).

5 Empirical Implications

5.1 Listing decisions

An analogy can be seen between the number of active speculators and the number of publicly listed firms. Naturally, speculators cannot trade on their private information when both firms are private, which is less often seen than having some firms private and other public. I therefore discuss the implications specifically on the situation in which one firm is already listed and the other firm considers going public.

To simplify the illustration, assume that the information cost is not large enough to prevent speculators' participation. When firm i is already listed and expected to be the leader, firm j has to decide whether to go public at the beginning of the game[23]. For example, at point A in Figure 6, where the profitability of the innovation investment is small due to a high investment and a smaller success rate (also a lower risk $\forall\theta < \frac{1}{2}$), firm j going public ex ante changes the threshold between (L, F) and (N, N) from the solid line to the dashed line. That is, the leader now has little incentive to invest up front, and the equilibrium (N, N) arises. Going public is apparently not desirable to firm j in this case. In contrast to point A, the profitability of the investment is higher at point B (a lower I) and

[23] The choice in IPO timing is out of the scope of this paper. While the issue is far more complex, it is evident in a static setting that under the conditions opposit to the ones in Implication 1-3, the follower firms would strategically delay their IPO.

point C (a higher θ). By being listed, firm j can switch its strategy from L to F thanks to a higher probability of information leakage. The testable implication then follows.

IMPLICATION 1: *The follower firms are more likely to go public if the innovation is associated with a lower investment and a higher success rate, and if there is a higher uncertainty about the innovation.*

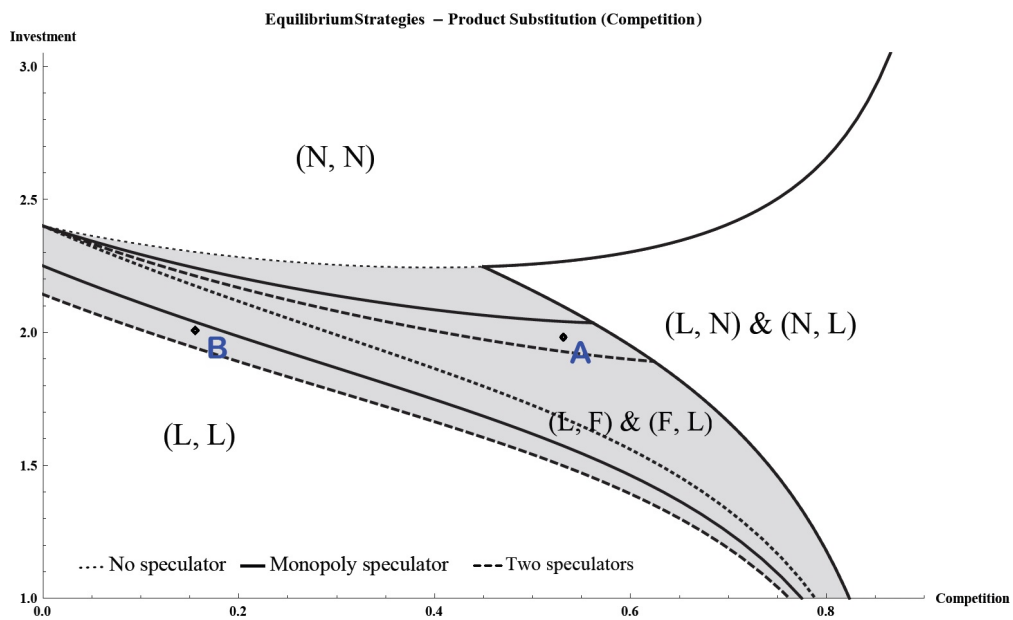

Figure 7: Impact of Listing - Competition Level γ

Similarly, the listing decision of the follower also depends on the level of competition in the industry, which is characterized here by product substitution γ. As discussed previously, the option value of waiting increases in γ. Therefore, given a low competition level (at Point B in Figure 7), the follower firm being listed pushes down the threshold of (L, L) such that it can now benefit from information leakage. When the competition is intense (at Point A), having both firms listed switch the equilibrium to the unfavorable (N, N). We therefore have the second implication.

IMPLICATION 2: *The follower firms are more likely to go public if the similarity of products in an industry is lower.*

It is also interesting to see how firms' listing decision may be changed from the perspective of the product market. Using Proposition 4, we know that speculators' expected trading profit increases also in the demand parameter α. Similarly, I show firms' equilibrium strategies in Figure 8. The shaded area again represents the region where informed trading in the stock market has an impact on firms' strategies in equilibrium. The boundaries of

the scenarios with different probabilities of information spillover (0, $\frac{1}{2}$ and $\frac{3}{4}$) are shown, respectively, by the dotted, solid and dashed lines. A similar pattern as in Figure 6 and 7 can be observed. For example, getting listed is appealing to the follower at point B (of a higher value of α), but not at point A. The intuition behind is that when the consumption expands given a higher α, firms can obtain sufficient innovation rent to cover investment cost since they can demand a higher price for their goods. If however the consumption shrinks and demands are more elastic with a lower α, the rent to the leading firm is reduced. Have the second firm been listed, the equilibrium (N, N) arises. Consequently, it is optimal for the follower to remain private. Implication 3 then follows.

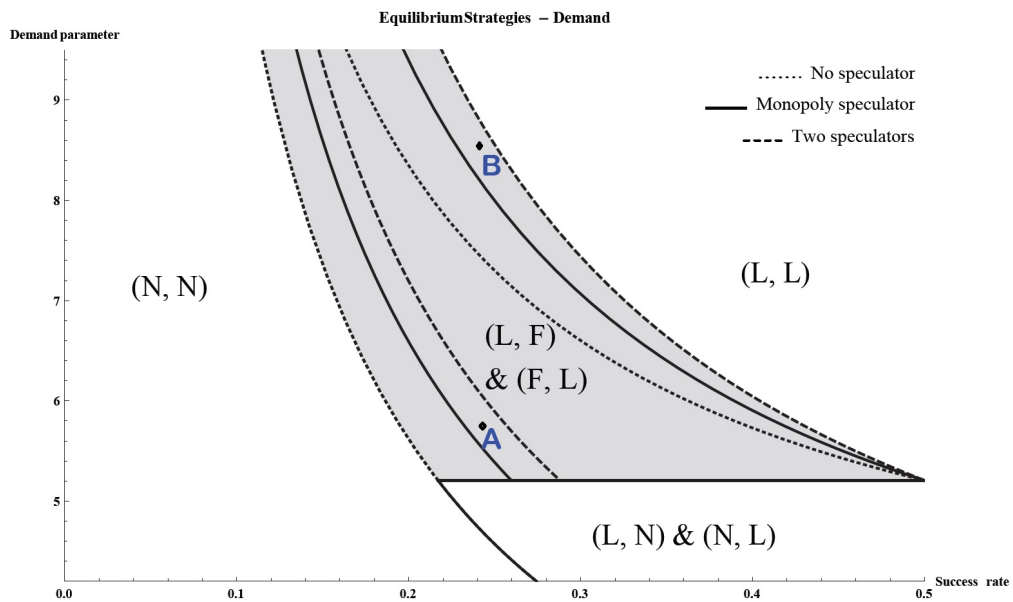

Figure 8: Impact of Listing - Demand Parameter α

IMPLICATION 3: *The follower firms are more likely to go public if the demand of products are less elastic to the prices and if there exists large demand from consumers.*

5.2 Investment activities

An important observation is that the industry incurs a lower investment at both point A and B after going public. It happens either due to the deterred investment of leader at date 0 in the equilibrium (N, N) (e.g., point A) in which case neither of the firms invest, or due to a delayed investment taken by the follower conditioning on good news (e.g., point B). The model thus provides a partial explanation to the empirical evidence that public firms invest

less and also hoard more cash than private firms. For instance, Asker et al. (2011) find that compared to private firms, public firms take fewer investments and they are also less responsive to investment opportunities. These authors associate their findings with agency costs. Farre-Mensa (2011) shows a higher cash holdings in public firms, and relates it to the financing need for future projects without incurring disclosure costs from raising equity capital. Nevertheless, observing from Figure 6-8, we see that when the parameters take the values not too high or too low, the increased information leakage does not have an impact on the investment strategies. Implication 4 summarizes.

IMPLICATION 4: *The amount of investment taken in an industry may be reduced when more firms are listed due to an enhanced information leakage. The impact is less significant when the characteristics of an industry and the technology in question are moderate.*

When managers can learn from the stock prices of other firms in the same industry, they share the aggregated belief about the prospect of a certain technology and possibly behave in a similar way. This indirect information leakage may thus contribute to explain why public firms may rationally herd in their investment decisions (See for example Scharfstein and Stein (1990)). Comparing the thresholds of the equilibria stated by Proposition 1 and 2 in Figure 3, we can observe that public firms have more correlated investment in the region where only one firm would invest given that both firms are private, i.e., the region of (L, N) in the benchmark case.

IMPLICATION 5: *R&D investments among publicly-listed competing firms are more correlated, when the technology is associated with a relatively low cost and uncertainty, and when their products are close substitutes with a high demand from the market.*

This model also provides implications for the sensitivity of R&D investment to share prices. Foucault and Frésard (2012) find that the investment of private firms, after they go public, are less correlated to their peers' prices, while my results suggest cross-sectional differences in the impact of one firm going public on its investment sensitivity to share prices of its competitors. As stated in the previous analysis, when the option of waiting is taken into account in ex-ante investment decisions, the size of the option value relative to the innovation rent determines whether firms invest in the same (a similar) innovation after the IPO of their rivals. From the perspective of investment sensitivity, a different interpretation of Implication 1 to 3 is as follows.

IMPLICATION 6: *After a private firm is listed in the stock market, its investment sensitivity to the share prices of its publicly-listed competitors increases if their products are less similar and if the innovative technology is associated with lower cost, higher success*

probability as well as a strong demand from consumers. The sensitivity decreases otherwise.

It is worth mentioning that one technology can be adopted at different timings and brings different benefits across industries, depending on the characteristics of each industry and the functionality of the technology itself.[24] It is hence subject to different investment costs and implementation risks. Consequently, the link between investments and share prices should show cross-sectional differences for a given technology, which gives another interpretation of Implication 5 and 6.

Last not the least, it is shown by a couple of empirical studies that a firm's investment is less sensitive to its own share price when the share prices of its peers are more informative (see Foucault & Frésard (2012), Ozoguz & Rebello (2013)). A similar implication can be read from Section 4 in this paper from the perspective of follower firms. Since the speculator of the follower firm earns a lower trading profit and thus has a lower incentive to participate, share prices of followers are expected to be less informative, even more so when a firm is illiquid and less transparent, having less attention from financial analysts.

IMPLICATION 7: *The investment of followers are more sensitive to the price movements of leading competitors when their own prices are less informative.*

Finally, information cost depends on the complexity of the innovation investment in question as well as the cost of acquiring information. Cost to speculators can also come from low transparency of firms' disclosure policy and restrictions on short selling, both subject to regulatory constraints. The regulatory concerns are particularly relevant to young and innovation-intensive industries, which can benefit largely from investment efficiency promoted by price informativeness. They also rely heavily on equity financing due to uncertain and volatile returns, inherent riskiness of investment, and limited collateral value of intangible assets.[25] Even though this paper does not consider financial constraints, the results nevertheless show from another perspective that a better functioning financial market helps to encourage innovations in a those industries.

[24] For example, as a long-existed technology, the adoption timing of radio frequency identification (RFID) system varies largely from the early 1990s in factory automation to the mid-late 2000s in asset tracking in the retail and banking industry. Another example is the launch of e-commerce across industries.

[25] See Stiglitz (1985), Stiglitz and Weiss (1981), Hall (2002), and Brown, Fazzari and Petersen (2009).

6 Extension

6.1 Surplus in the product market

Regulators pay much attention to innovation investment at firm level due to its vital impact on technological development in the economy. I therefore discuss briefly the changes in welfare due to the presence of the feedback from the stock market. First, let us denote the consumer surplus by CS. Using the formula $CS = U(q_i, q_j) - p_i q_i - p_j q_j$, with $U(q_1, q_2)$ as the utility given in formula (1), it is straightforward to compute the expectation of consumer surplus for each strategy profile (A_i, A_j), $A_i, A_j \in \{L, F, N\}$. By comparing the ex-ante expectation of consumer surplus in different equilibria, I obtain the proposition below.

Proposition 5 *The expected consumer surplus increases in the expected amount of innovation investment.*

In other words, the expected consumer surplus descends by the order of (L, L), (L, F), (L, N), and finally (N, N). The information spillover thanks to the informative share prices is beneficial to the consumer when the non-leading firm choosing the strategy F instead of N compared to the benchmark case. It, however, has a negative impact either when firms' strategies change from (L, N) to (N, N) or when firms choose (L, F) over (L, L). As a result, whether consumers benefit from having more information revealed from the stock market depends on the values taken by model parameters.

Combining the consumer surplus and the expected firm profits, we can obtain the expected total surplus (TS) in the product market. Using Proposition 2 and Proposition 3, we know that the total surplus increases when the non-leading firm choose the strategy F over N, and it is reduced when firms' strategies changes from (L, N) to (N, N).

Corollary 4 *The expected total surplus in the product market is higher with a leader and a follower firm than with only one firm investing. Given a small success rate, it also increases when the strategy (L, L) is replaced by (L, F) & (F, L). The total surplus is reduced when the up-front investment is deterred such that firms' strategy change from (L, N) & (N, L) to (N, N).*

Corollary 3 again shows that the impact from stock price informativeness on total surplus in the product market has a similar pattern as on consumer welfare, except that it is inclusive for the case in which the strategy (L, L) is replaced by (L, F) and (F, L).

6.2 Noise traders' private benefit

In this subsection, I extend the analysis by endogenizing the participation of noise traders and explore the impact on the equilibrium outcome. The assumption that noise traders are completely disconcerned about their trading profit is more convenient rather than realistic. To relax this assumption, I assume that there exists for each firm a continuum of noise traders with measure 1, who trade for exogenous needs of liquidity. Noise traders are indexed by k_i for firm i (ergo k_j for firm j), which distinguishes the magnitude of their private benefit of having a position in the stock. I denote this benefit by b, $b_{k_i} = (1 - k_i)\,\tau$, where τ signifies the common nature of the trading motive shared by noise traders, $\tau > 0$. Noise traders are thus heterogenous only in the size of private benefit. I define the utility of noise trader k_i as

$$u_{k_i} = \begin{cases} b_{k_i}, & \text{if } X_{k_i} = z_i \\ 0, & \text{otherwise} \end{cases}, \; z_i \in \{-1, 1\}, \tag{8}$$

where z_i denotes the state of world and X_{k_i} is the trading order of the kth noise trader of firm i. Noise traders of each firm have the same preference for the size and sign of the orders to submit. For instance, if $z_i = -1$, the spectrum of noise traders of firm i are in need of liquidity and X_{k_i} equals -1. The realizations of z are uncorrelated across firms, and noise traders' preference between cash and share is decided by nature with equal probability.[26] The realization of z is private information to noise traders.

Each noise trader plays strategically and thus participates only when the net expected payoff is non-negative. As a result, there exists a $k_i^{*\text{th}}$ noise trader of firm i who is indifferent between trading and otherwise, and all the others with $k_i > k_i^*$ will quit the market. Based on the same argument as in Section 3, the threshold k_i^* determines the optimal trading size of speculator i. By comparing speculator i's expected profit to the kth noise trader's private benefit, we can find the threshold k_i^* for the indifferent noise trader. We can express k_i^* as

$$k_i^* = \begin{cases} \max\left(1 - \frac{\Pi_i^S}{\tau}, 0\right), \text{ if } 1 - \frac{\Pi_i^S}{\tau} < 0 \\ \min\left(1 - \frac{\Pi_i^S}{\tau}, 1\right), \text{ if } 1 - \frac{\Pi_i^S}{\tau} > 0 \end{cases}. \tag{9}$$

where Π_i^S is the expected trading profit of speculator i. The result is summarized in the lemma below.[27]

[26] If noise traders expect to have a liquidity shock with a positive probability, there will be a higher probability for them to prefer cash over equity. To simplify the illustration, I assume that there is no other shock to the liquidity need of noise traders.

[27] For the purpose of presentation, I leave the additional assumptions to the Proof of Lemma 6 in the

Lemma 7 *When firm i innovates at date 0, firm j's decision will be changed by the size of private benefit to noise traders. If* $\tau \leq 2\theta(1-\theta)(\pi_{c,c} - \pi_{c,c-\delta})$*, the feedback effect no longer prevails and firms choose their optimal strategies as stated in Proposition 1. If* $\tau \in (2\theta(1-\theta)(\pi_{c,c} - \pi_{c,c-\delta}), \theta(1-\theta)(\pi_{c-\delta,c} - \pi_{c,c})]$*, speculator i leaves the market and firms' optimal strategies are determined when speculator j trades as a monopolist, the feedback effect is weakened as described by Proposition 5. If* $\tau > \theta(1-\theta)(\pi_{c-\delta,c} - \pi_{c,c})$*, both speculators trade actively, and firms' equilibrium strategies follow Proposition 2.*

7 Concluding remarks

This paper is an attempt to investigate the process when share prices from the secondary market trading feed back to firms' innovating strategies. Using a simple setup in a differentiated Bertrand duopoly, I model an information leakage related to a risky process innovation, which induces an intra-industry knowledge spillover and alters firms' ex-ante decisions in innovation investment. This spillover then provides firms an option to invest as a follower with better knowledge. It may also discourage the up-front investment and leads to a lower efficiency in the product market, when causing too large a decline of innovation rent to the leading firm. Neglecting this channel of information transmission may lead to inappropriate inferences when considering publicly listed firms.

The paper also demonstrates that, by considering the information cost to speculator, the probability of incurring information leakage and hence its impact of the option value of waiting are endogenized in equilibrium. The model therefore sheds light on the two-way causality between the amount of information produced in the stock market and the fundamentals in the real economy. It may also be interesting to consider a different design of information structure. For instance, if firms' investment action can not be immediately observed, the information revealed in stock market may become more obscure. The optimal strategy of both firms and stock market participants will change accordingly. Another example is that firms may also have the ability to exert influence on its share price, such as participating in proprietary trading. This aspect is not modelled in this paper but suggests a good direction for future research.

Finally, one relevant question to ask is that when firms' pre-commitments or strategic disclosures already prevail, how stock trading contributes to technological advances by introducing additional information. It is interesting to explore whether share trading acts to

Appendix.

verify or to obscure the information being revealed via other channels[28]. The answer to this question is out of the scope of this paper, but may provide policy makers with useful implications in practice, particularly when the characteristics of different industries are taken into account.

References

[1] Asker, J., Farre-Mensa, J., & Ljungqvist, A. (2011). Comparing the investment behavior of public and private firms (No. w17394). National Bureau of Economic Research.

[2] Austin, D.H., 1993, "An Event-Study Approach to Measuring Innovative Output: The Case of Biotechnology", *American Economic Review*, *83(2)*, 253-258.

[3] Bakke, T. E., & Whited, T. M. (2010). Which firms follow the market? An analysis of corporate investment decisions. *Review of Financial Studies*, *23*(5), 1941-1980.

[4] Bhattacharya, S. and J.R. Ritter, 1983, "Innovation and Communication: Signalling with Partial Disclosure", *Review of Economic Studies*, *50*, 331-46

[5] Bolton, P. and D.S. Scharfstein, 1990, "A Theory of Predation Based on Agency Problems in Financial Contracting", *American Economic Review*, *80*, 93-106.

[6] Bond, P., A. Edmans, and I. Goldstein, 2012, "The Real Effects of Financial Markets", *Annual Review of Financial Economics, 4(1)*, 339-360.

[7] Brander, J. and T.R. Lewis, 1986, "Oligopoly and Financial Structure: The Limited Liability Effect", *American Economic Review,* 76, 956-970.

[8] Brown, J.R., S.M. Fazzari, and B.C. Petersen, 2009, "Financing Innovation and Growth: Cash Flow, External Equity, and the 1990s R&D Boom", *The Journal of Finance,* LXIV(1), 151-185.

[9] Chen, Q., I. Goldstein, and W. Jiang, 2007, "Price Informativeness and Investment Sensitivity to Stock Price", *Review of Financial Studies, 20(3)*, 619-650.

[28] Amir Ziv (1993) proves that when the incentive for truthful information sharing is endogenized, firms no longer find it in their interest to honestly disclose production information, particularly in a one-stage game when information verification is not quite feasible.

[10] Chemmanur, T.J. and P. Fulghieri, 1999, "A Theory of the Going-public Decision," *Review of Financial Studies*, *12*, 249-279.

[11] Chod, J. and E. Lyandres, 2009, "Strategic IPOs and Product Market Competition", EFA 2009 Bergen Meetings Paper. Available at SSRN: http://ssrn.com/abstract=1343697

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

[13] Clementi, G.L., 2002, "IPOs and the Growth of Firms," Working paper, New York University.

[14] De Bondt, R. and R. Veugelers, 1991, "Strategic Investment with Spillovers", *European Journal of Political Economy, 7*, 345-366.

[15] Fama, E.F. and Miller, M.H., 1972, *The Theory of Finance*, (Dryden Press Hinsdale, Il).

[16] Farre-Mensa, J. (2011). Why are Most Firms Privately Held?. Available at SSRN 1719204.

[17] Field, A.M., 2005, "Mixed RFID Signals", *The Journal of Commerce*, *6(40)*, 15-18.

[18] Foucault, T., and L. Frésard, 2013, "Learning from Peers' Stock Prices and Corporate Investment", *Available at SSRN 2117150.*

[19] Frésard, L. (2012). Cash savings and stock price informativeness. *Review of Finance*, *16*(4), 985-1012.

[20] Gal-Or, E., 1986, "Information Transmission - Cournot and Bertrand Equilibria", *Review of Economic Studies*, *53*, 85-92.

[21] Grossman, S. and Stiglitz, J., 1980, "On the Impossibility of Informationally Efficient Markets", *American Economic Review*, 70(3), 393-408.

[22] Hall, B.H., 2002, "The Financing of Research and Development", *Oxford Review of Economic Policy, 18*, 35–51.

[23] Hoppe, H.C., 2000, "Second-mover Advantages in the Strategic Adoption of New Technology under Uncertainty", *International Journal of Industrial Organization*, *18,* 315-338.

[24] Huisman, K.J.M., 2001, "Technology Investment: A Game Theoretic Real Options Approach", Kluwer Academic Publishers, Norwell.

[25] Jansen, J., 2004, "Strategic Information Revelation in an R&D Race with Spillovers". Available at SSRN: http://ssrn.com/abstract=517982

[26] Jansen, J., 2006, "The Effects of Disclosure Regulation of an Innovative Firm", in J.P. Choi (ed.) *Recent Developments in Antitrust: Theory and Evidence*, Cambridge MA, MIT Press, pp. 265-291.

[27] Jansen, J., 2008, "Information Acquisition and Strategic Disclosure in Oligopoly", *Journal of Economics & Management Strategy, 17(1)*, 113-148.

[28] Jensen, R., 1982, "Adoption and Diffusion of an Innovation of Uncertain Profitability", *Journal of Economic Theory, 27(1)*, 182-193.

[29] Khanna, N. and M. Schroder, 2010, "Optimal Debt Contracts and Product Market Competition with Exit and Entry", *Journal of Economic Theory, 145*, 156-188.

[30] Kyle, A., 1985, "Continuous Auctions and Insider Trading", *Econometrica*, 53, 1315–1336.

[31] Kuhn, K.U. and X. Vives, "Information Exchange Among Firms and Their Impact on Competition." European Commission Document, Luxembourg: Office for Official Publications of the European Communities, 1995.

[32] Levine, R., 2005, "Finance and Growth: Theory and Evidence", in P. Aghion and S. Durlauf, eds.: *Handbook of Economic Growth*, North-Holland Elsevier Publishers, Amsterdam.

[33] Lyandres, E., 2006, "Capital Structure and Interaction among Firms in Output Markets: Theory and Evidence", *The Journal of Business*, *79(5)*, 2381-2422.

[34] MacKinlay, C.A., 1997, "Event Studies in Economics and Finance", *Journal of Economic Literature*, *34*, March, 13-39.

[35] Magazzini, L., F. Pammolli, M. Riccaboni, and M.A. Rossi, 2009, "Patent Disclosure and R&D Competition in Pharmaceuticals", *Economics of Innovation and New Technology*, *18(5)*, 2009, 467 – 486.

[36] Maksimovic, V., 1988, "Capital Structure in Repeated Oligopolies", *RAND Journal of Economics*, *19*, 389–407.

[37] Maksimovic,V. and P. Pichler, 2001, "Technological Innovation and Initial Public Offerings," *Review of Financial Studies*, *14(2)*, 459-494.

[38] Ozoguz, A., and M. Rebello, 2013, Information, competition, and investment sensitivity to peer stock prices. *Competition, and Investment Sensitivity to Peer Stock Prices* (July 2, 2013).

[39] Pawlina, G. and P.M. Kort, 2001, "Real Options in an Asymmetric Duopoly: Who Benefits from your Competitive Disadvantage?" CentER Discussion Paper 2001-95, Tilburg University.

[40] Raith, M.A., 1996, "A General Model of Information Sharing in Oligopoly", *Journal of Economic Theory*, *71(1)*, 260-288.

[41] Schmidt-Dengler, P., 2006, "The Timing of New Technology Adoption: The Case of MRI", 2006 Meeting Papers, No.3. Society for Economic Dynamics.

[42] Shi, H. and Y. Du, 2012, "Corporate Innovation and Spillover Effect". Available at SSRN: http://ssrn.com/abstract=2139216

[43] Singh, N. and X. Vives, 1984, "Price and Quantity Competition in a Differentiated Duopoly", *Rand Journal of Economics,* 15, 546-554.

[44] Spiegel, M. and H. Tookes, 2008, "Dynamic Competition, Innovation and Strategic Financing". *Innovation and Strategic Financing* (July 1, 2008).

[45] Stiglitz, J.E., 1985, "Credit Markets and Capital Control", *Journal of Money, Credit and Banking*, *17*, 133–152.

[46] Stiglitz, J.E., and A. Weiss, 1981, "Credit Rationing in Markets with Imperfect Information", *American Economic Review, 71*, 393–410.

[47] Subrahmanyam, A. and S. Titman, 1999, "The Going-Public Decision and the Development and Financial Markets", *Journal of Finance*, *54(3)*, 1045-1082.

[48] Thijssen, J.J.J. and K.J.M. Huisman., 2001, "Strategic Investment under Uncertainty and Information Spillovers," CentER Discussion Paper, 2001-91, Tilburg University.

[49] Vives, X., 1984, "Duopoly Information Equilibrium: Cournot and Bertrand", *Journal of Economic Theory*, 34, 71–94.

[50] Ziv, A., 1993, "Information Sharing in Oligopoly: The Truth-telling Problem", *Rand Journal of Economics*, 24, 3, 455-465.

[51] Zuo, L., 2013, "The informational Feedback Effect of Stock Prices on Corporate Disclosure."

8 Appendix

Proof of Lemma 1. It is easy to compute firms' profit under each realization of production cost (c_i, c_j).

$$\pi_{c-\delta,c} = \frac{1}{1-\gamma^2}\left(\frac{1-\gamma}{2-\gamma}\right)^2\left[(\alpha - c) + \frac{(2-\gamma^2)\,\delta}{(2+\gamma)\,(1-\gamma)}\right]^2$$

$$\pi_{c-\delta,c-\delta} = \frac{1}{1-\gamma^2}\left(\frac{1-\gamma}{2-\gamma}\right)^2(\alpha - c + \delta)^2$$

$$\pi_{c,c} = \frac{1}{1-\gamma^2}\left(\frac{1-\gamma}{2-\gamma}\right)^2(\alpha - c)^2$$

$$\pi_{c,c-\delta} = \frac{1}{1-\gamma^2}\left(\frac{1-\gamma}{2-\gamma}\right)^2\left[(\alpha - c) - \frac{\gamma\delta}{(2+\gamma)\,(1-\gamma)}\right]^2$$

Since $\frac{(2-\gamma^2)}{(2+\gamma)(1-\gamma)} > 1$ and $-\frac{\gamma}{(2+\gamma)(1-\gamma)} < 0$, $\forall\gamma \in (0,1)$, it is evident that $\pi_{c-\delta,c} > \pi_{c-\delta,c-\delta}$ and $\pi_{c,c} > \pi_{c,c-\delta}$. We therefore obtain $\pi_{c-\delta,c} > \pi_{c-\delta,c-\delta} > \pi_{c,c} > \pi_{c,c-\delta}$. ■

Proof of Proposition 1. It is previously shown in Section 3.1 that $\Pi_i(L,L) = 2\theta\pi_{c-\delta,c-\delta} + 2(1-\theta)\pi_{c,c} - I$, $\Pi_i(N,N) = 2\pi_{c,c}$, $\Pi_i(L,N) = 2\theta\pi_{c-\delta,c} + 2(1-\theta)\pi_{c,c} - I$, and $\Pi_i(N,L) = 2\theta\pi_{c,c-\delta} + 2(1-\theta)\pi_{c,c}$.

Therefore, for firm i to deviate from L to N given its competitor chooses L, it must be true that:

$\Pi_i(L, L) - \Pi_i(N, L) < 0$ and thus $I > 2\theta(\pi_{c-\delta,c-\delta} - \pi_{c,c-\delta}) = \theta\underline{I}$;

For firm j to deviate from N to L given his competitor chooses N, it must be true that: $\Pi_j(N, N) - \Pi_j(L, N) < 0$ and thus $I < 2\theta(\pi_{c-\delta,c} - \pi_{c,c}) = \theta\bar{I}$,

Combining these two conditions, we can obtain the condition for the strategy pairs (N, L) & (L, N) to be the equilibrium. Due to the symmetry of the payoff matrix, if $I > \theta\bar{I}$, (N, N) is the Nash equilibrium; and if $I < \theta\underline{I}$, the equilibrium strategy pair is (L, L). ■

Proof of Lemma 2. There are two parts in this proof. The first is to show that it is optimal for the speculators to submit an order with a fixed size 1. Since the noise trader always submits an order of one unit for each firm, the expected order flow for a listed firm is zero. The market maker will then quote higher based on a total order flow greater than zero, or lower otherwise. The speculators would thus either easily expose their identities by submitting an order with a whole size larger than one, or make lower profit by trading fractional orders. The optimal way to hide his identity and obtain a favorable quote is to submit an order of the same size as the one from the noise trader, regardless of the trading direction.

Next, we consider the trading direction of the speculators. If both firms make an investment at date 0, both speculators buy if the innovation succeeds and both of them sell if otherwise. Now consider the case in which only firm i invests at date 0 and learns at date 1 that its innovation will succeed in reducing its production cost c_i. Firm j is then disadvantaged in price competition for at least one stage. Consequently, speculator i buy one share of firm i and speculator j submits a sell order of firm j.

On the other hand, if only firm i invests at date 0 but the innovation fails, firm i incurs a loss I. A failed innovation does not change the price competition in the product market, it however lowers the liquidation value of the firm. As a result, speculator i sells. As for firm j, it will not invest at date 1 when bad news are revealed by the total order flow (share prices). Neither will it when share prices are not informative, because the strategy of investing at the intermediate stage without additional information from the stock market is strictly dominated by the strategy of investing up front.[29] Since the market maker is uninformed when speculators' orders are hidden in the total order flow, his quote of firm j must be lower than the actual liquidation value. Consequently, speculator j will submit a buy order of firm j. ■

[29] If share prices are not informative at date 1, the non-leading firm has the same prior about the innovation as before the game starts. Were it optimal for this firm to invest then, it must be better off to invest up-front, by which it can be assured not to lose in product market competition at either date 2 or 3. The proof of Lemma 3 formally shows this point.

Proof of Lemma 3. The noise trader buys or sells 1 unit of both firms's shares with equal probability and there is no correlation in their orders across firms. Evidently, the total order flow of each firm belongs to the set $\{-2, 0, 2\}$. Suppose only firm i invests at date 0 and its innovation succeeds. $x_i \in \{0, 2\}$ and $x_j \in \{-2, 0\}$ as a consequence. We observe immediately that there are four possible combinations of x_i and x_j, each attached with the same conditional probability $\frac{1}{4}$. Given that firms' innovating activities are publicly observable, the good news of firm i can be inferred by the other agents except when the order flows of both firms are zero. More specifically, when (x_i, x_j) belongs to the set $\{(2, -2), (2, 0), (0, -2)\}$, the private information $c_i = c - \delta$ is fully revealed by informed trading. Order flows thus reveal the private information with probability $\frac{3}{4}$ conditional on that the innovation succeeds, thus a total probability $\frac{3}{4}\theta$. Similarly, the probability of revealing the information that the innovation fails is $\frac{3}{4}(1-\theta)$, and $\frac{1}{4}(1-\theta)$ otherwise. Using the same algorithm, we conclude that the probability of information revelation is the same for the case where both firms invests at date 0. ■

Proof of Lemma 4. From intuition, given that share prices are not informative, the prior of the non-leading firm about the innovation remains unchanged. Were it optimal for this firm to invest at date 1, it must be better off to invest at the beginning of the game. It is because, based on the same prior. the strategy L guarantees that a firm does not lose in product market competition at either date 2 or 3, compared to a possible loss from competition at date 2 due to a late investment in innovation. Therefore, $\widetilde{F}$ is dominated by either L or F.

First, when firm i leads in innovation investment and $x_i = x_j = 0$, the expected payoff of firm j is $\theta(\pi_{c,c-\delta} + \pi_{c-\delta,c-\delta}) + 2(1-\theta)\pi_{c,c} - I$ if it chooses to follow at date 1, and $2\theta\pi_{c,c-\delta} + 2(1-\theta)\pi_{c,c}$ otherwise. Comparing these two payoffs, we know that only when $I < \theta(\pi_{c-\delta,c-\delta} - \pi_{c,c-\delta})$, i.e., $I < \frac{1}{2}\theta\underline{I}$, the follower firm would prefer to invest at $t = 1$, conditional on zero order flows. $\underline{I}$ is as defined in *Proposition 1*.

Next, given firm i chooses L, for $\widetilde{F}$ to be optimal to firm j there needs to be a profitable deviation from the strategy L, i.e., $\Pi_j(L, L) - \Pi_j\left(\tilde{F}, L\right) < 0$. This inequality requires $I > \frac{2\theta}{3(1-\theta)}\underline{I}$.

These two conditions, $I < \frac{1}{2}\theta\underline{I}$ and $I > \frac{2\theta}{3(1-\theta)}\underline{I}$ cannot be both satisfied at the same time, $\forall\theta \in (0, 1)$. $(L, \widetilde{F})$ and $(\widetilde{F}, L)$ thus cannot be Nash equilibria. ■

Proof of Proposition 2. First, I compute the equilibrium conditions for the strategy pairs (L, F) and (F, L). The expected payoff of firm i choosing the strategy F when its competitor chooses L, is $\Pi_i(F, L)$, $\Pi_i(F, L) = \theta\left(\frac{5}{4}\pi_{c,c-\delta} + \frac{3}{4}\pi_{c-\delta,c-\delta}\right) + 2(1-\theta)\pi_{c,c} - \frac{3}{4}\theta I$. For (L, F) &

(F, L) to be a Nash equilibrium, we again need to have a profitable deviation for firm i from the strategy L to F when firm j chooses L. $\Pi_i(L, L) - \Pi_i(F, L) = \theta\left(\frac{5}{4}\pi_{c-\delta,c-\delta} - \frac{5}{4}\pi_{c,c-\delta}\right) - \left(\frac{4-3\theta}{4}\right) I < 0$, which gives $I > \frac{5\theta}{2(4-3\theta)}\underline{I}$. Considering that firm i prefer not to invest at $t = 1$ based on zero order flows if $I > \frac{1}{2}\theta\underline{I}$, $\frac{5\theta}{2(4-3\theta)} > \frac{1}{2}\theta$, $\forall\theta \in [0, 1]$, two conditions are satisfied when $I > \frac{5\theta}{2(4-3\theta)}\underline{I}$.

It is similar to compute the condition for a firm to deviates from N to F given that its competitor chooses L, since the firm should find it profitable to invest in the innovation upon observing a good signal from share trading. We need to have $\Pi_i(N, L) - \Pi_i(F, L) < 0$, that is, $I < (\pi_{c-\delta,c-\delta} - \pi_{c,c-\delta}) = \frac{1}{2}\underline{I}$. Notice that when $\theta > \frac{1}{2}$, the inequality $\frac{5\theta}{2(4-3\theta)}\underline{I} < I < \frac{1}{2}\underline{I}$ does not hold, and thus the strategy (L, F) cannot result in the equilibrium if $\theta > \frac{1}{2}$.

Next, we already know that firm j deviates from L to N when $I > \theta\underline{I}$ if firm i's strategy is L. Combining the condition for firm j to deviate from F to N when firm i chooses L, that is, $I > \frac{1}{2}\underline{I}$, it is evident that for $\theta \geq \frac{1}{2}$ both inequalities are satisfied when $I > \theta\underline{I}$, and for $\theta < \frac{1}{2}$, $I > \frac{1}{2}\underline{I}$ suffices. From the proof of Proposition 1, we show that firm i does not deviate from L to N when firm j chooses N if $I < \theta\bar{I}$. The conditions for (L, N) and (N, L) to be equilibria is, if $\theta > \frac{1}{2}$, thus $\theta\underline{I} < I < \theta\bar{I}$.

If $\theta \leq \frac{1}{2}$, we then need to compare $\frac{1}{2}\underline{I}$ and $\theta\bar{I}$. If $\theta > \frac{1}{2}\frac{\underline{I}}{\bar{I}}$, i.e., $\frac{1}{2}\underline{I} < \theta\bar{I}$, we can easily observe that the condition for (L, N) and (N, L) to be equilibria is $\frac{1}{2}\underline{I} < I < \theta\bar{I}$, and the conditions for (L, F) and (F, L) to be equilibria is $\frac{5\theta}{2(4-3\theta)}\underline{I} < I < \frac{1}{2}\underline{I}$.

If however $\theta < \frac{1}{2}\frac{\underline{I}}{\bar{I}}$, i.e., $\frac{1}{2}\underline{I} > \theta\bar{I}$, the conditions $I > \frac{1}{2}\underline{I}$ and $I < \theta\bar{I}$ are contradictory. Consequently, $\forall\theta < \frac{1}{2}\frac{\underline{I}}{\bar{I}}$, when $\theta\bar{I} < I < \frac{1}{2}\underline{I}$ and firm i chooses strategy N, it is profitable for the other firm to deviate from L to N. Also, if firm i chooses L, the other firm prefers F over N, which nevertheless leads to a profitable deviation for firm i to give up the strategy of leading. The strategy pair returns to (N, N). In other words, expecting the other firm to choose F, firm i deviates from the strategy L to N and the other firm can no longer enjoy the spillover as a follower. This is profitable for firm i if $\Pi_i(L, F) < \Pi_i(N, N)$, that is, if I is higher than $\theta\left(\frac{5}{4}\pi_{c-\delta,c} + \frac{3}{4}\pi_{c-\delta,c-\delta}\right) - 2\theta\pi_{c,c}$. We therefore reach a unique equilibrium (N, N) when $I > \theta\left(\frac{5}{4}\pi_{c-\delta,c} + \frac{3}{4}\pi_{c-\delta,c-\delta}\right) - 2\theta\pi_{c,c}$.

By the same algorithm, for (L, L) to be a Nash equilibrium, we need to ensure when one firm chooses L and the other one firm cannot profit from deviation by choosing any other action except L. That leads to the inequalities below:

$\Pi_i(L, L) - \Pi_i(F, L) > 0 \Longrightarrow I < \frac{5\theta}{2(4-3\theta)}\underline{I}$;

$\Pi_i(L, L) - \Pi_i\left(\tilde{F}, L\right) > 0 \Longrightarrow I < \frac{2\theta}{3(1-\theta)}\underline{I}$;

$\Pi_i(L, L) - \Pi_i(N, L) > 0 \Longrightarrow I < \theta\underline{I}$.

Notice that $\frac{5\theta}{2(4-3\theta)}$ is always lower than $\frac{2\theta}{3(1-\theta)}$ and it is lower than θ when $\theta < \frac{1}{2}$. Combining also the conditions obtained in the proof of Lemma 2, we can then obtain the equilibrium conditions in this proposition, that is, if $\theta < \frac{1}{2}$, $(L,\, L)$ is the equilibrium when $I < \frac{5\theta}{2(4-3\theta)}\underline{I}$; if $\theta > \frac{1}{2}$, $(L,\, L)$ is the equilibrium when $I < \theta\underline{I}$. ■

Proof of Corollary 2. The option value of waiting is the difference in one firm's expected profit choosing between the strategy F and L when its competitor invests at date 0, which is $\Pi_i\left(F, L\right) - \Pi_i\left(L, L\right) = \left(1 - \frac{3}{4}\theta\right) I - \frac{5}{8}\theta\underline{I}$. The first order derivative with respect to parameter θ, I, α, are, respectively, $-\frac{3}{4}-\frac{5}{8}\underline{I} < 0$, $1-\frac{3}{4}\theta > 0$, and $-\frac{5\left(2-\gamma^2\right)\delta\theta}{2(2-\gamma)^2(1+\gamma)(2+\gamma)} < 0$. Its first order derivative with respect to γ is $\frac{4(\alpha-c)(1-\gamma)^2\left(8+\gamma^2(-6+\gamma(4+\gamma(7+2\gamma)))\right)\delta+4\left(8+\gamma\left(-2+\gamma^2\right)(4+\gamma(-1+\gamma(-2+\gamma(3+\gamma)))\right)\delta^2}{(4-\gamma^2)^3(1-\gamma^2)}$, which is positive $\forall\gamma \in (0, 1)$. ■

Proof of Proposition 3. Recall that speculators obtain perfect signal of the state of the world. Speculator i thus learns good news for firm i with probability θ, and makes a profit $(2\pi_{c-\delta,c} - I) - P_i$ from a buy order of firm i. Similarly, he earns $P_i - (2\pi_{c,c} - I)$ when learning bad news, which occurs with probability $1-\theta$. Given the probability of having zero order flows being $\frac{1}{4}$, speculator i's ex-ante expected profit is $\theta\left(1-\theta\right)\left(\pi_{c-\delta,c} - \pi_{c,c}\right)$, denoted by $\Pi_i^S|L, N$.[30] Similarly, the expected profit of speculator j, $\Pi_j^S|N, L$, is $\theta\left(1-\theta\right)\left(\pi_{c,c} - \pi_{c,c-\delta}\right)$. Using the same algorithm for the case of both firms investing at date 0 with $P_i = P_j = \Pi\left(L, L\right)$, we know both speculator i and j expect to earn $\theta\left(1-\theta\right)\left(\pi_{c-\delta,c-\delta} - \pi_{c,c}\right)$.

$\Pi_i^S(A_i, A_j)$ for each (A_i, A_j) is concave in θ and linear in δ and α. By taking the first order derivative of $\Pi_i^S(A_i, A_j)$, with respect to θ, we see that all derivatives are negative when $\theta > \frac{1}{2}$ and positive otherwise. Similarly, the first order derivatives of $\Pi_i^S(A_i, A_j)$ for each strategy profile is positive respect to both both δ and α. ■

Proof of Lemma 6. This lemma concerns the case where speculator j exits the stock market while speculator i continues to acquire information and trade in firm i[31]. The feasible set of order flow is $\{-2, 0, 2\}$ for firm i , and $\{-1, 1\}$ for firm j. So the possible combinations are $\{2, 1\}$, $\{2, -1\}$, $\{0, 1\}$, and $\{0, -1\}$ when the innovation is successful, and $\{-2, 1\}$, $\{+2, -1\}$, $\{0, 1\}$, and $\{0, -1\}$ when the innovation fails. Evidently, the order submitted by speculator i is hidden when the set $(x_i, x_j) \in \{(0, -1), (0, +1)\}$, which occurs with probability $\frac{1}{2}$. The share price P_i is thus informative with probability $\frac{1}{2}$. ■

Proof of Proposition 4. The threshold for the follower firm to invest based on observing good news in the share price is not affected by the probability of information revelation in the

[30] The difference in notation is to indicate that N is the ex post action taken by firm j upon observing zero order flows.

[31] Even without limits of exposure, it can be shown easily that trading only firm i's shares is more profitable than trading in both firms which would reveal private information with probability $\frac{3}{4}$.

stock market. As a consequence, the equilibrium conditions do not change from Proposition 1 when $I \geq \frac{1}{2}\underline{I}$. If $I < \frac{1}{2}\underline{I}$, using the same algorithm as in the proof of Proposition 2, we can find the boundary conditions for the leading firm deviates to N when expecting its competitor to invest based on good news. That is, if $I > \theta\left(\frac{3}{2}\pi_{c-\delta,c} + \frac{1}{2}\pi_{c-\delta,c-\delta}\right) - 2\theta\pi_{c,c}$, there is a unique equilibrium $(N,\, N)$. Similarly, firm i deviates from F to L when expecting the other firm to choose L, if $I < \frac{3\theta}{2-\theta}\left(\pi_{c-\delta,c-\delta} - \pi_{c,c-\delta}\right)$, which gives the condition for the unique equilibrium $(L,\, L)$. ■

Proof of Proposition 5. Let $CS^t_{A_i,A_j}$ denote the sum of consumer surplus at date t in the equilibrium where firms choose the action (A_i, A_j), and let c_i^t, p_i^t, and q_i^t denote the production cost, price and the output for firm i at date t, $t = 2, 3$. The innovating firm will have the production cost $c - \delta$ with probability θ, or c otherwise. For example, when $(A_i, A_j) = (L, L)$ and the innovation is successful, product prices and demands can be computed: $p^2_{i,j} = p^3_{i,j} = \frac{(1-\gamma)\alpha+c-\delta}{2-\gamma}$, $q^2_j = q^3_j = \frac{\alpha-c+\delta}{(2-\gamma)(1+\gamma)}$.

The total consumer surplus over two stages is, conditional on that the innovation succeeds, the sum of $CS^2_{L,L|\theta}$ and $CS^3_{L,L|\theta}$, which equals $\frac{2(\alpha-c+\delta)^2}{(2-\gamma)^2(1+\gamma)}$. This expression can be simplified to $\frac{2}{1-\gamma}\pi_{c-\delta,c-\delta}$, using the notation defined in (8). Similarly, if the innovation fails, the consumer surplus over date 2 and 3 is $\frac{2(\alpha-c)^2}{(2-\gamma)^2(1+\gamma)}$, expressed by $\frac{2}{1-\gamma}\pi_{c,c}$ by the notation in (9). The ex-ante expected consumer surplus is therefore $\frac{2}{1-\gamma}\left(\theta\pi_{c-\delta,c-\delta} + (1-\theta)\,\pi_{c,c}\right)$ if both firms innovate at date 0, and $\frac{2}{1-\gamma}\pi_{c,c}$ if no firm invests.

Using the same method, I compute the expected consumer surplus for the equilibrium (L, N). $CS_{L,N}$ equals $2\theta CS^2_{L,N|\theta} + 2\,(1-\theta)\,CS^2_{L,N|1-\theta}$, as the surplus will have the same value at both dates. Similarly, let $CS_{L,F}$ denote the expected consumer surplus for the equilibrium (L, F). We know already from *Lemma 2* that the non-leading firm will follow at date 1 only when order flows reveal good news. $CS_{L,F}$ thus consists of two parts; the expected consumer surplus at date 2, which is equivalent to $\frac{1}{2}CS_{L,N}$, and the surplus $CS^3_{L,F}$ (at date 3). $CS^3_{L,F}$ includes $\frac{3}{4}\theta CS_{L,L|\theta}$ when good news being revealed, $\frac{3}{4}\,(1-\theta)\,CS_{L,N|1-\theta}$ when bad news being revealed, and $\frac{1}{4}CS_{L,N}$ when order flows reveal no private information. $CS_{L,N|1-\theta} = CS_{L,L|1-\theta}$ since the production cost of both firms remains unchanged if the innovation fails. The expression for $CS_{L,F}$ can then be simplified to $\frac{5}{8}CS_{L,N} + \frac{3}{8}CS_{L,L}$. The difference between $CS_{L,L}$ and $CS_{L,F}$ is thus $\frac{5}{8}\left(CS_{L,L} - CS_{L,N}\right)$, which is positive because of the following.

The sum of consumer surplus over two stages conditioning on the innovation success is the sum of $CS^2_{L,L|\theta}$ and $CS^3_{L,L|\theta}$. If innovation succeeds, the total consumer surplus equals to $\frac{2(\alpha-c+\delta)^2}{(2-\gamma)^2(1+\gamma)}$, which can be expressed by $\frac{2}{1-\gamma}\pi_{c-\delta,c-\delta}$ by using equation (8). Similarly, if the

innovation fails, the total consumer surplus over two stages is $\frac{2(\alpha-c)^2}{(2-\gamma)^2(1+\gamma)}$, expressed by $\frac{2}{1-\gamma}\pi_{c,c}$ by equation (9). $CS_{L,L}$ then equals $\frac{2}{1-\gamma}\left(\theta\pi_{c-\delta,c-\delta}+(1-\theta)\pi_{c,c}\right)$ if both firms innovate at date 0.

$CS_{L,L}-CS_{L,N}$
$=\frac{2}{1-\gamma}\left(\theta\pi_{c-\delta,c-\delta}+(1-\theta)\pi_{c,c}\right)-\left[2\theta CS^2_{L,N|\theta}+\frac{2(1-\theta)}{1-\gamma}\pi_{c,c}\right]$
$=2\theta\left(\frac{\pi_{c-\delta,c-\delta}}{1-\gamma}-CS^2_{L,N|\theta}\right)$

By using formula (1), we can obtain $CS^2_{L,N|\theta}$,

$CS^{t_2}_{L,N|\theta}=\alpha\frac{2\alpha-2c+\delta}{(2-\gamma)(1+\gamma)}-\frac{\delta^2}{2(1-\gamma)^2(2+\gamma)^2}-\frac{(1-\gamma)\left(\alpha^2+p_ip_j\right)-\left(p_i^2+p_j^2\right)+2\gamma p_ip_j}{1-\gamma^2}$, where $p_i=c-\delta$, and $p_j=c$.

$\frac{\pi_{c-\delta,c-\delta}}{1-\gamma}-CS^2_{L,N|\theta}=\frac{\delta(2(\alpha-c)(1-\gamma)(2+\gamma)^2+\delta(4-3\gamma^2-2\gamma^3))}{2(-4+\gamma^2)^2(1-\gamma^2)}$, which is negative only when γ is sufficiently close to 1. Note that when products become very close substitutes, firms will choose (L,N) & (N,L) in equilibrium and the consumer surplus for (L,L) no longer concerns us. Therefore, $CS_{L,L}$ is greater than $CS_{L,N}$. $CS_{L,F}$ is then also greater than $CS_{L,N}$ since the difference between them is $\frac{3}{8}\left(CS_{L,L}-CS_{L,N}\right)$.

At last the difference between $CS_{L,N}$ and $CS_{N,N}$ is $2\theta\left(CS^2_{L,N|\theta}-\frac{\pi_{c,c}}{1-\gamma}\right)$. It can be simplified to $\frac{\delta}{(2-\gamma)^2(1+\gamma)}\left(a-c+\frac{\delta\left(4-3\gamma^2\right)}{2(1-\gamma)(2+\gamma)^2}\right)$, which is positive. We thus know that $CS_{L,N}>CS_{N,N}$. ■

Proof of Lemma 6. To restrict the analysis to pure strategy equilibrium, I assume first that whether speculators acquire information is publicly observable. Next, if the parameters take values as such all noise traders quit trading and so do the speculators. Expecting the exit of speculators, noise traders may however want to return to the market. To simplify the analysis, I assume the market maker's pricing rule to be that he would consider the orders as being submitted by the speculators and set the prices disadvantageous to noise traders. I also let the information cost ϵ be trivial here to simplify the analysis, which however makes speculators strictly prefer not to participate when expecting to earn zero profit.

In the case where only firm i innovates at date 0, it is easy to see $\tilde{\Pi}^S_i>\Pi^S_i>\tilde{\Pi}^S_j>\Pi^S_j$ based on the computation of speculators' expected profit. Formula (14) then enables us to conclude that $\tilde{k}^*_i<k^*_i<\tilde{k}^*_j<k^*_j$. When both firms find it optimal to innovate at date 0 with informed trading in stock market, their strategies stay the same with or without feedback effect. Due to the symmetry in speculators' trading profit, either both speculators submit orders of equal size, that is, $k^*_i=k^*_j=\min\left(1-\frac{\Pi^S_i(L,L)}{\tau},1\right)$. Or it occurs that τ is so low that both k^*_i and k^*_j fall to zero. Consequently no noise trader finds it profitable to trade and stock market breaks down. We go back to the economy in the benchmark case. Firms'

optimal strategy in innovation remains unchanged, however.

Next, consider the case in which firms' equilibrium strategies are affected by the feedback effect. For the case where firm i leads in innovating and firm j follows at a later date, it is easy to obtain $k_i^* = 1 - \frac{\theta}{\tau}(1-\theta)(\pi_{c-\delta,c} - \pi_{c,c})$ and $k_j^* = 1 - \frac{\theta}{\tau}(1-\theta)(\pi_{c,c} - \pi_{c,c-\delta})$, $k_i^* < k_j^*$. If $k_i^* = 0$ but $k_j^* > 0$, that is, noise traders quit trading firm i and leave speculator j the monopolist. The expected loss to the noise trader of firm j is thus $2\theta(1-\theta)(\pi_{c,c} - \pi_{c,c-\delta})$ that determines the new threshold for the noise traders of firm j, denoted by $\tilde{k}_j^*$, $\tilde{k}_j^* < k_j^*$. If τ is even lower than $2\theta(1-\theta)(\pi_{c,c} - \pi_{c,c-\delta})$, i.e., noise traders of firm j would incur a loss higher than their private benefit when speculator j is the monopolist. As a consequence, all noise traders quit and market breaks down completely. ■