Innovation strategies and stock price informativeness

(Job Market Paper)

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Abstract

This paper models the interactions among technological innovation, product market competition and information leakage via the stock market. There are two firms who compete in a product market and have an opportunity to invest in a risky technology either early on as a leader or later once stock prices reveal the value of the technology. Information leakage thus introduces an option of waiting, which enhances production efficiency. A potential leader may nevertheless be discouraged from investing upfront, when anticipating its competitor to invest later in response to good news. I show that an increase in product market competition increases the option value of waiting but has an ambiguous effect on information production. It may thus be the case that intense competition leads to more leakage such that no firm would invest, especially so in a smaller market. Given a moderate level of competition, price informativeness may also improve investment outcome when investment profitability and the market size are relatively large. The model predicts that, under these conditions, the investment of a follower firm is more sensitive to share price movements.

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Keywords: Price efficiency; Information leakage; Innovation; Feedback

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1 Introduction

Innovation is regarded as the mainspring of economic dynamics. While providing firms with advantages in competition, innovation is mostly subject to large irreversible investment, uncertainty, and potentially asymmetric information. In this regard, the financial market contributes to technological evolution by facilitating resource allocation, 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 leaking their proprietary information related to R&D progress, which is one of the main concerns in the IPO decisions of innovation-intensive firms.[1] Information leakage changes the market position of leaders and the innovation rent they can seize, which thus affects their incentives to invest. It consequently influences competition in an industry and social welfare.

The mostly discussed and direct cause of information leakage is mandatory disclosure requirements for public firms. Little attention is paid to an indirect 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 managers with 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 plausible that once stock prices reveal one firm's private information about its innovation progress, this information will be employed by its competitors in their decisions to make similar investments. Consequently, good news about one firm's innovation makes its rival more optimistic about their own opportunities and thus more incentivized to invest.[4]

To address this indirect information leakage, I propose a simple model in which two firms produce differentiated products and compete in a duopoly market. Both firms have an

[1] Brau and Fawcett (2006) report in a survey of CFOs that "Disclosing information to competitors" and "SEC reporting 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), and has been explored in Dow and Gorton (1997), and Subrahmanyam and Titman (1999) among others. See Bond, Edmans and Goldstein (2012) for a survey on the active informational role of prices.

[3] See for instance Chen, Goldstein and Jiang (2007), Bakke and Whited (2010), Edmans, Goldstein and Jiang (2012), Fresard (2012), Zuo (2013) among others.

[4] Choi (1991) uses an example of the break-through of cold super-conductivity in 1986 by IBM. IBM's intermediate success made other firms more optimistic about this technology and increased their investment intensity. Similarly, 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. Shi and Du (2012) document similar results by investigating knowledge spillovers among publicly listed firms.

opportunity to invest in a risky innovation technology which may reduce production cost. If a firm makes an investment early on, i.e., before learning about the technology, it learns privately at the intermediate stage whether the innovation succeeds. Meanwhile, the same information can be acquired at a cost and be traded on by some speculators in the stock market. The second firm can then decide whether to invest in the same technology after observing the leader's and its own share prices. The innovation progress of one firm may consequently be leaked via share price movements to its competitor. When this indirect leakage is factored in firms' decisions ex ante, it provides firms with an option of waiting to learn more about the innovation prospect before making investment decisions.

This channel of information leakage is distinct from the one via mandatory disclosures in two ways. First, the extent of the mandatory disclosure is limited to R&D expenses, R&D acquisition and contracting,[5] while stock prices aggregate private information from various sources and may thus serve better to reveal the true value of the technology. Second and more fundamentally, industry characteristics determine both the value of the option of waiting and speculators' trading profit, which endogenizes the amount of information leakage via the stock market. The indirect leakage can affect the investment outcome when the option of waiting is useful to firms and meanwhile speculators have sufficient incentives to acquire information and trade.

More specifically, I show that the option value of waiting increases in the probability of information leakage and the level of competition in the product market (characterized by the degree of product substitution). The option value however decreases in the market size as well as the profitability of the investment. When the values of corresponding parameters are moderate, the option helps to reduce the resources allocated on unproductive innovations and to encourage effective investments made by the follower firm. Information leakage is not useful if the option value is too low since both firms would prefer to invest earlier. It can even be harmful. This is the case if a potential leader stops investing up front, because he anticipates imitation by a follower provided that the option is very valuable. The resulting competition reduces the benefit from innovating so much as to get no firm to be willing to invest. In this case learning is impossible and the innovation is never adopted.

These effects of information leakage may become part of the equilibrium when there is adequate information production in the stock market, i.e., if the cost of information acquisition to speculators is smaller than their expected trading profit. When this is not the case, fewer speculators are willing to incur the information acquisition cost, which reduces stock

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

price informativeness and consequently the option value. I show that there is a positive impact of product market competition on speculators' trading profits, when the market size is moderate. This is because an increase in competition enlarges the difference between the firm values of the leader and the follower when the innovation succeeds. Speculators are also more incentivized to acquire information given an increase in either investment profitability or the market size of the industry. As a consequence, information production in the stock market and improved efficiency of investment may be both achieved when the investment is more profitable and it takes place in a relatively large market where the level of competition is moderate. When a strong trading incentive of speculators coincides with a high option value of waiting, firms are deterred from investing. This is the case if competition is intense in a relatively small market. Having both the option value and information leakage endogenized in a model thus helps to highlight the real impact of price efficiency in the financial market.

These results show that the indirect information leakage may be most beneficial in an industry during its growth phase with increasing investment return and market size while competition is less intense than at the maturity stage. Under those conditions, we should observe empirically that the investments of follower firms are more sensitive to the share price movements of industry leaders. Moreover, there should be a higher correlation of specific stock returns between leader firms and follower firms. While providing cross-sectional characteristics, these implications are mostly consistent with the empirical evidence uncovered in recent studies. Foucault and Frésard (2012) find a positive relationship between a firm's investment and the market valuation of its peers selling related products. The significance of this link increases with the stock price informativeness of the peers and the demand correlation between products. These authors however do not consider the level of competition in the industry. Ozoguz and Rebello (2013) document similar results and further show that the investment sensitivity to peers' share prices is stronger in an industry with faster growth, higher competition and greater dependence on capital.

Additional implications are also provided by modelling the two-way causality between product market interactions and share price informativeness, which is little mentioned in the literature. In the theoretical model of Foucault and Frésard (2012), for example, only one firm in a duopoly market is given the opportunity to expand the production capacity based on the information revealed from stock prices. The competitor of this firm cannot react.[6] As

[6] 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 up front. The impact of the waiting option on the ex-ante financing decision is not considered.

pointed out previously, however, when information production in the stock market is feasible, a potential leader may be deterred from investing up front in anticipation of insufficient innovation rent due to its competitor's imitation later. This is the case at high levels of competition in relatively small markets. The model thus predicts that, under this condition, there are fewer R&D investments in the industry. Meanwhile, one firm's investment responds less to its own stock price and the stock price of its competitors. The correlation of firms' specific stock returns is also lower. These conjectures can be easily overlooked when one neglects the feedback from share prices to firms' ex-ante decisions.

This work is connected to three strands of literature. First, the indirect information leakage is relevant to firms' financing decisions in the context of product market competition. The literature in this regard usually imposes an exogenous cost (probability) of information leakage when discussing the trade-off between a cheaper capital raised from the equity market and more intensive competition caused by disclosures[7]. While staying away from firms' financing problems, our paper points out that how much innovation-related information is revealed by share prices is industry-specific. This should add extra concerns when firms choose equity to finance their R&D investment.

Second, this paper contributes to the research on firms' strategies in industries with weak intellectual property protection, and particularly to process innovation that is often related to cost reduction. It is also on average more difficult to patent and less costly to copy compared to product innovation. Good examples include the low-cost air travel started by Southwest Airlines in the US and further developed by Ryanair in Europe, and the pioneering implementation of radio frequency identification (RFID) system in the retail industry by Wal-Mart. These leading firms could not prevent their competitors, such as Easyjet and Target Corporation, from adopting a similar business model or technology. The general features of a process innovation are thus contained in the model proposed here.

Finally, this paper also complements the innovation literature on knowledge spillovers that is mostly related to voluntary or strategic disclosures.[8] As shown by Gal-Or (1986) and Raith (1996), voluntary disclosures are not optimal for firms in price competition when there exists an ex-ante uncertainty in the production cost. In that case, a model of indirect information leakage via share prices may provide a better framework to capture knowledge

[7] See Brander and Lewis (1986), Maksimovic (1988), Chemmanur and Fulghieri (1999), Spiegel and Tookes (2008), Chod and Lyandres (2011) 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.

[8] See Jansen (2005 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.

spillovers among public firms that are engaged in price competition.

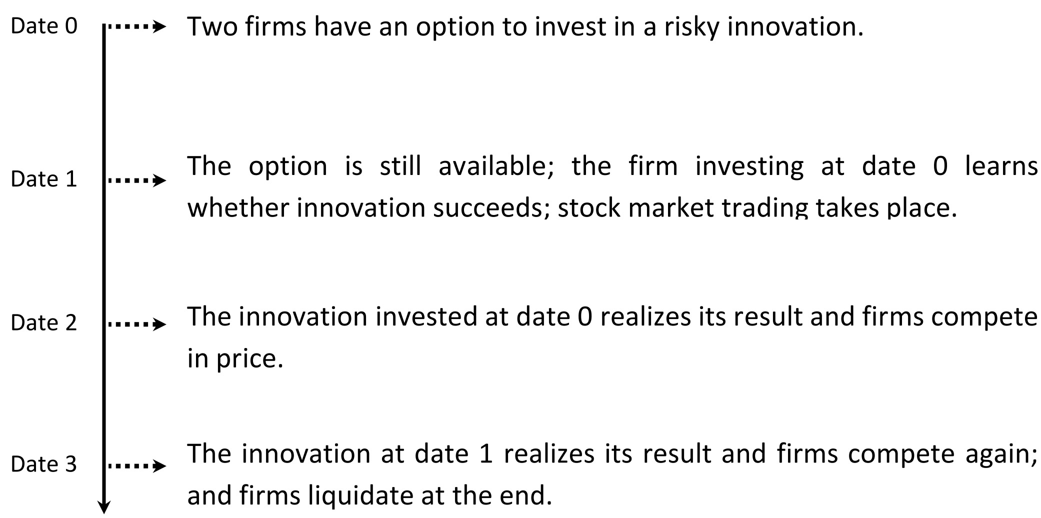
The paper proceeds as follows. Section 2 presents the setup of the model. Firms' equilibrium strategies are computed in Section 3, and speculators' trading incentive and endogenized information leakage are discussed in Section 4. Empirical implications are explained in Section 5. An extension is included in Section 6 regarding 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. 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 and trade on this information if it is profitable. If the other firm decides not to invest at date 0, it can choose whether or not to do so at date 1 after observing the share prices at date 1. Firms then compete in the product market at both dates 2 and 3, and they liquidate at the end of date 3. Next, I explain the set-up in detail.

Figure 1: The Timeline



2.2 The product market

The duopoly firm i and j produce differentiated products without capacity constraints. They produce and sell at dates 2 and 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.[9]

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. If the innovation of the leader firm is found to be effective, the follower innovating at date 1 may thus be disadvantaged in the first-stage product market competition at date 2. This captures a cost of waiting to innovate. The opportunity to invest in this innovation is no longer available after the end of date 1. Firms' decision to invest in innovation is also assumed to be publicly observable.[10] To make the computations more tractable, I follow most of the literature by assuming that the duopolists share the information about production cost just before setting prices.[11]

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

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

[10] 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.

[11] 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.

p_j. $U(q_i, q_j)$ is quadratic, strictly concave and symmetric in q_i and q_j,

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

where $\alpha > 0$ and $0 < \gamma < 1$. The parameter γ measures the substitutability between the goods produced by two firms[12]. The higher is γ, the closer substitutes firms' products are and thus the fiercer their competition is. The following demand function for the goods of firm i maximizes the utility of the representative consumer,

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

provided that quantities are positive. Consequently, firm i sets price p_i to maximize its profit π_i,

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

q_j and π_j of firm j are symmetric to (2) and (3).

2.3 The stock market

Three types of agents exist in the stock market: a noise trader, two speculators and a market maker. The noise trader buys or sells 1 unit of each listed firm for liquidity reason. Trading of the noise trader is uncorrelated across stocks. I endogenize the trading incentive of the noise trader in Section 6 (Extension). Two speculators 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. Finally, the market maker is assumed to be competitive and provide liquidity by setting the share prices based on his rational expectation of a firm's value when observing the submitted orders. The market maker earns zero profit in expectation.

Share trading is assumed to occur at date 1 after innovating firms learns the true prospect of the technology. 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

[12]The qualitative results of this paper hold if $\gamma \in (-1, 0)$, that is, if the products are complements. However, if firms produce complementary goods, it is optimal for the leader to communicate the innovation progress when the innovation succeeds. The leakage via share prices becomes superfluous. I therefore neglect the discussion for $\gamma \in (-1, 0)$.

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 the 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, firm i's best response function of price can be obtained as below[13],

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

Solving the system of best response functions of firm i, we can obtain the equilibrium price p_i^* for firm i,

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

The expression of p_j^* is symmetric to (5). For simplification, I assume $\alpha > c + \delta\frac{\gamma}{2-\gamma-\gamma^2}$ such that q_i and q_j are positive $\forall c_i, c_j \in \{c, c-\delta\}$. Using the equilibrium price p_i^* and p_j^*, and the demand function q_i established in (2), I can then state firm i's profit in equilibrium as a function of c_i and c_j,

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

Firm j's profit π_{c_j,c_i} is symmetric to (6).

Formula (6) shows that firm i's profit increases in its competitor's cost c_j. It is thus not optimal for firms to reveal voluntarily their innovation progress before the product market

[13]This is the Bertrand reaction function of firm i, provided q_j is positive.

competition.[14] Due to the absence of information leakage 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 invest 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 firm i's 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 is to take place. As a result, the expected net profit of firm i is $2\theta\pi_{c-\delta,c-\delta} + 2(1-\theta)\pi_{c,c} - I$ if both firms choose L, and $2\pi_{c,c}$ if both choose N. 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 $\Pi_j(N, L) = 2\theta\pi_{c,c-\delta} + 2(1-\theta)\pi_{c,c}$. Assume that a firm chooses not to invest if $\Pi(A_i, A_j) = 0$. I derive the Nash equilibria and present the equilibrium conditions in Proposition 1.

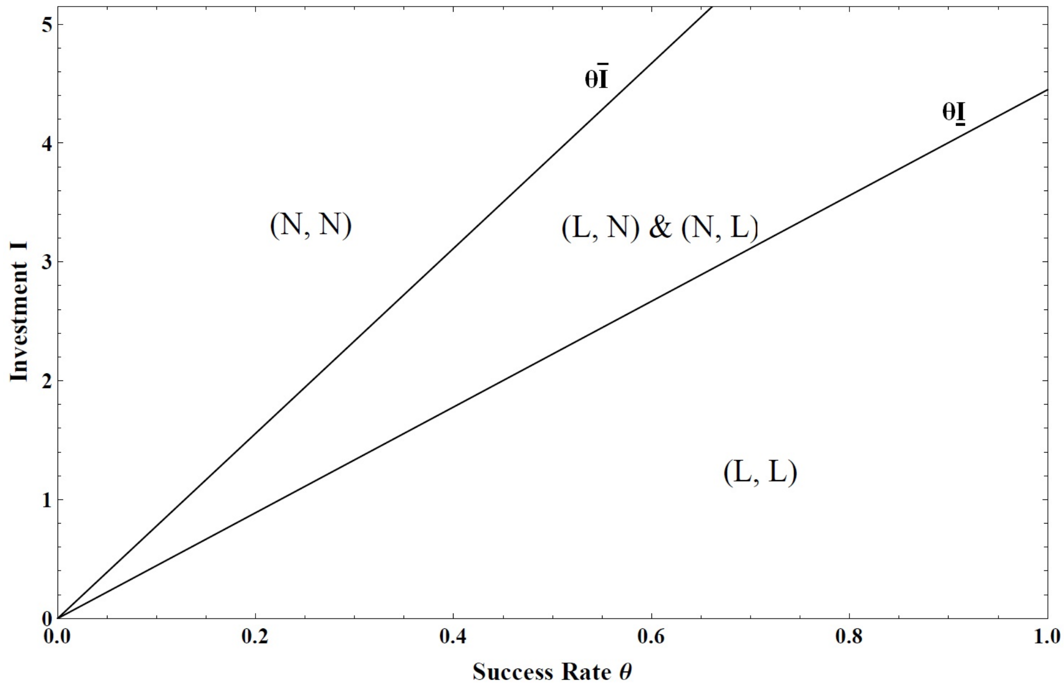
Proposition 1 *If* $I \geq \theta\bar{I}$, *(N, N) is the unique Nash equilibrium; if* $I < \theta\underline{I}$, *(L, L) is the unique Nash equilibrium; and if* $\theta\bar{I} > I \geq \theta\underline{I}$, *there are two equilibria: (N, L) & (L, N), where* $\underline{I} = 2(\pi_{c-\delta,c-\delta}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

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 $\alpha = 6$. 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, $\theta\underline{I}$[15] and $\theta\bar{I}$, separate three regions

[14] 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.

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

Figure 2: Firms' Equilibrium Strategies - Without Leakage (Prop.1)



This figure shows firms' equilibrium strategies without information leakage in a numerical example with $\alpha = 6$, $c = 3$, $\delta = 2$ and $\gamma = \frac{3}{4}$. (N, N) marks the parameter region of no firm investing in equilibrium. (L, L) marks the region of both firm investing, and (L, N) & (N, L) only one firm investing in equilibrium. The black lines are the thresholds, $\theta \underline{I}$ and $\theta \bar{I}$, defined in Propostion 1.

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 introduce the stock market to the economy, where speculators acquire and trade on their private information about firms' investment prospect. I assume that with probability λ, $\lambda \in (0, 1)$, share prices are fully informative about the value of the innovation invested at date 0. With probability $(1 - \lambda)$, share prices reveal no private information. λ is endogenized in Section 4. All other assumptions regarding the competition in the product market remain as previously stated. The equilibrium is now defined as, for a given λ, the investment strategies chosen by firms that maximize expected firm value.

Compared to the benchmark which is a special case with $\lambda = 0$, the private information about one firm's innovation progress is leaked to its competitor via share price. 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 share prices. 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 prices will contain no relevant information. Product market competition still takes place at date 2 and 3.

When prices reveal bad news, it is obvious that a follower would never invest since the investment would be a pure waste. When prices are not informative, a firm choosing not to invest upfront has to decide whether to follow 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 share prices reveal good news about the innovation", and "$\widetilde{F}$" denoting "to invest at date 1 when share prices reveal good news or no private information". The action space for each firm now consists of four pure strategies, $\Omega = \{L, F, \tilde{F}, N\}$. Lemma 2 points out that $\tilde{F}$ cannot be an equilibrium strategy, however.

Lemma 2 *It is a strictly dominated strategy to invest in the innovation at date 1 with no additional information from the stock market, i.e., $\widetilde{F}$ is a strictly dominated strategy.*

The other strategies $\{L, F, N\}$ survive in equilibrium. For a given λ (the probability of information leakage), Proposition 3 summarize firms' strategies in equilibrium.

Proposition 2 *If $\theta > \frac{1}{2}$, strategy F cannot be sustained in equilibrium, and thus the equilibrium remains as in the description of Proposition 1. If $\theta \leq \frac{1}{2}$, the equilibrium strategies are as follows.*

If $I < \frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I}$, (L, L) is the unique Nash equilibrium;

if $\frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I} \leq I < \min\left\{\theta\tilde{I}, \frac{1}{2}\underline{I}\right\}$, there are two equilibria: (L, F) & (F, L);

if $\frac{1}{2}\underline{I} \leq I < \theta\bar{I}$, there are two equilibria: (L, N) & (N, L);

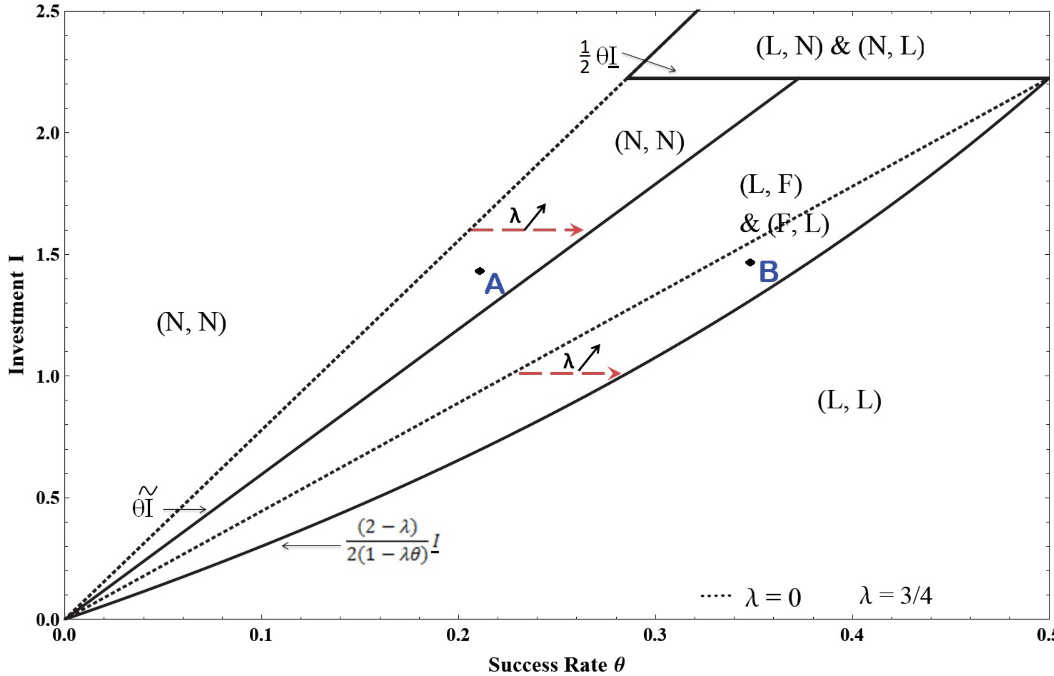
and if $\theta\tilde{I} \leq I < \min\left\{\frac{1}{2}\underline{I}, \theta\bar{I}\right\}$ or if $I \geq \theta\bar{I}$, (N, N) is the unique equilibrium.

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

Note that to assure the existence of a pure-strategy equilibrium, I assume that the value of parameter α is not too high such that $\theta\tilde{I} > \frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I}$ for $\theta = \frac{1}{2}$, i.e., $\alpha < c + \delta\frac{8-4\lambda+\gamma(2\gamma(-2+\lambda)+\lambda)}{2(2+\gamma)(1-\gamma)\lambda}$.

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. Proposition 2 shows that firms' strategies in

Figure 3: Firms' Equilbrium Strategies - With Leakage



This figure shows firms' equilibrium strategies with information leakage in an example with $\lambda = \frac{3}{4}$ (other parameters taking the same values as in Figure 2). (L, F) & (F, L) marks the region in which given $\lambda = \frac{3}{4}$ one firm chooses to lead and the other firm chooses to follow after learning good news from share prices. When λ increases from 0 to $\frac{3}{4}$, the thresholds of strategy F, $\theta\tilde{I}$ and $\frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I}$, are shifted rightwards from the dotted lines to the solid lines.

equilibrium remains unchanged from the benchmark case if the investment costs more than $\frac{1}{2}\underline{I}$. This is the condition for the follower firm not to invest at date 1 even if share prices reveal good news. In addition, choosing F is no longer optimal for the follower firm when the success probability θ is above $\frac{1}{2}$. The intuition is that strategy F is preferable only if the wasteful investment $\lambda(1-\theta)I$ avoided by using the option of waiting outweighs the expected benefit $\lambda\theta(\pi_{c-\delta,c-\delta} - \pi_{c,c-\delta})$ during the market competition at date 3, i.e., $I > \frac{\theta}{2(1-\theta)}\underline{I}$. If $\theta > \frac{1}{2}$, this condition contradicts the threshold for investing upon good news at date 1 (i.e., $I < \frac{1}{2}\underline{I}$).

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

Lemma 3 *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,* $(2-\lambda)\theta(\pi_{c,c-\delta} - \pi_{c-\delta,c-\delta}) + (1-\theta\lambda)I$.

The option value consists of two parts. The first part is the sum of the potential loss in the competition at both date 2 and date 3 if the innovation succeeds, which are respectively $\theta\left(\pi_{c,c-\delta}-\pi_{c-\delta,c-\delta}\right)$ and $(1-\lambda)\,\theta\left(\pi_{c,c-\delta}-\pi_{c-\delta,c-\delta}\right)$. The second part is the amount of investment saved from waiting, $(1-\theta\lambda)\,I$, where $\theta\lambda$ is the joint probability of good news being revealed. In other words, the option value is the difference between $\Pi\left(F,L\right)$ and $\Pi\left(L,L\right)$.

The option value equals zero at the lower threshold of (L,F) & (F,L) in the investment cost, $\frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I}$. When I is above this threshold, (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 invests upon good news at date 1. The efficiency in the product market is improved in (L,F) & (F,L) due to either a more effective investment at the intermediate stage or a reduced wasteful investment, since the follower firm can now invest with a better knowledge about the innovation.

On the other hand, (L,N) & (N,L) are replaced by (N,N) in the region where strategy F reduces the innovation rent of the potential leader to the extent that he no longer profits from investing at date 0. In this scenario, the technology is never adopted and learning about its value is impossible. The information leakage leads to a lower efficiency in production. We thus observe a new threshold $\theta\tilde{I}$ between (N,N) and (L,F) & (F,L), that is below $\theta\bar{I}$.

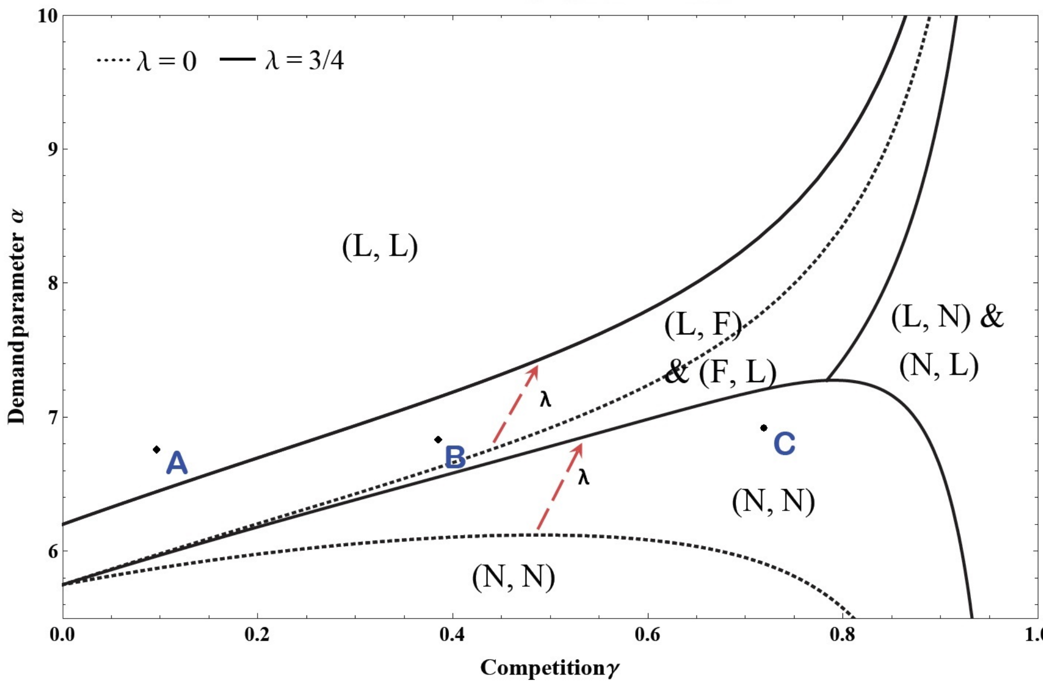
We now take a look at how the option value varies with stock price informativeness as well as the characteristics of the innovation and the product market.

Proposition 3 *The option value of waiting increases in the probability of information leakage λ, the degree of competition γ and the investment cost I. It decreases in the success rate θ, the size of cost reduction δ and the demand parameter α.*

Firstly, it is intuitive that the option is more valuable when share prices are informative with a higher probability (λ), since it becomes more likely for the follower to learn at date 1 the true prospect. Meanwhile, a higher λ also imposes a larger cost of information leakage to the leader firm such that the up-front investment is more likely to be deterred. The consequence is that both thresholds $\frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I}$ and $\theta\tilde{I}$ shift towards the right in Figure 3.

The option value decreases when the profitability of the innovation investment increases due to a higher benefit from investing up front. Investment profitability is characterized by the parameters θ, I and δ. Let us look at Figure 3. When the success rate is small (e.g., at point A) for a given I, the option prevents the follower from wasting its investment with a high probability. The profitability at this point is however sufficiently low to the potential leader given that its competitor is likely to follow. In contrast, the option value becomes so small when $I < \frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I}$ such that F is no longer optimal, whilst at point B, the size of profitability and option value suffice to accommodate the incentive to both the leader and the follower. The same reasoning can be applied regarding the required investment I and the size of cost reduction δ.[16]

Figure 4: Firms' Equilbrium Strategies - Demand/Competition



This figure shows the impact of industry competition and the market size on firms' strategies in equalibrium. The dotted lines represent the thresholds of the benchmark case. When the probability of information leakage increases, these thresholds are shifted upwards. The solid lines represent the thresholds for $\lambda = \frac{3}{4}$.

Figure 4 shows the impact of industry competition and the market size on equilibrium strategies, with $\theta = 0.4$ and other parameters remaining unchanged. When γ increases, products of firm i and j become closer substitutes, and the competition level in the industry increases. While both $\pi_{c-\delta,c-\delta}$ and $\pi_{c,c-\delta}$ drop for a higher γ, the decreases of $\pi_{c-\delta,c-\delta}$ is more significant. This is because having the same production cost as its competitor, a firm is obliged to reduce more its product price under a higher level of competition in order to

[16] See Figure A1 in the Appendix for firms' equilibrium strategies when the size of cost reduction varies.

attract demand from the consumer. Expecting its competitor to invest at date 0, a firm thus has a lower incentive to invest at the same time. 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 up front. When γ increases to point B, one firm takes the option to wait. While at point C, the innovation rent to the leading firm becomes too low and (N, N) emerges in equilibrium. Note that the information leakage does not affect the equilibrium outcome when γ is approaching 1, i.e., products become perfect substitutes.

Figure 4 also shows the impact of the demand parameter α that is associated with the market size. Using the demand function in (2) and the equilibrium price in (5), we can obtain the demand intercept and the price elasticity of demand[17]. It is then easy to see that a higher α leads to a larger intercept of demand and a lower price elasticity, and therefore a larger market size in the industry. When the consumption expands given a higher α, a successful innovation brings a more significant advantage in competition and thus a stronger incentive for firms to invest up front. The option value of delay drops as a consequence.

It is clear so far that, the information leakage with a given probability λ is beneficial to an industry when the innovation is associated with a relatively high profitability and a sufficient market size and when the competition is not too intense. Informative 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 more profitable, and the competition is lower. The opposite can be said for industries at the stage of maturity, where the competition is intense and the improvements on the prevailing technologies carry small impact on production.

In the next section, I discuss speculators' trading strategies and how the probability of information leakage is endogenized in this economy.

4 Participation of Speculators

4.1 Trading strategies

Assume that both firms are publicly listed and each of the two speculators are 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 limits on exposure that a trader is willing to take. Let us denote the order

[17] The demand intercept equals $\frac{\alpha}{1+\gamma}$, and the price elasticity of demand E_{di} equals $-\frac{\gamma}{1-\gamma^2}\frac{p_i}{q_i}$.

submitted by the speculator of firm i and j by x_i and x_j, respectively. Recall that if no investment takes place at date 0, speculators do not trade at the next date since no private information is there for acquiring, thus $x_i = x_j = 0$.

When at least one firm invests at date 0, speculators can acquire perfect information about the true state of the world ω, $\omega \in \{s, f\}$. $\omega = s$ if the innovation is successful, and $\omega = f$ otherwise. Speculators' orders are thus functions of ω, i.e., $x_i(\omega)$ and $x_j(\omega)$. Although speculators are allowed to choose any order size to submit, they follow nevertheless the optimal trading strategy defined by the lemma below.

Lemma 4 *When both firms invest at date 0, if speculators learn $\omega = s$, i.e., the innovation will succeed,* $\begin{cases} x_i(s) = 1 \\ x_j(s) = 1 \end{cases}$ *and if they learn $\omega = f$, i.e., the innovation will fail,* $\begin{cases} x_i(f) = -1 \\ x_j(f) = -1 \end{cases}$.

When only firm i invests at date 0, if speculators learn $\omega = s$, $\begin{cases} x_i(s) = 1 \\ x_j(s) = -1 \end{cases}$*, and if they learn $\omega = f$* $\begin{cases} x_i(f) = -1 \\ x_j(f) = 1 \end{cases}$. *The strategies are symmetric when only firm j invests at date 0.*

Recall that the noise trader buys or sells 1 unit of both firms's shares with equal probability and there is no correlation of their orders across firms. Let X_i and X_j denote the total 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 about ω is not revealed. If we assume that information acquisition incurs no cost, both speculators trade actively when at least one firm invests in the innovation. Lemma 5 follows immediately.

Lemma 5 *When both speculators are active, the probability of information leakage (λ) is $\frac{3}{4}$.*

4.2 Speculator's profit

The probability of leakage λ may however vary with the trading incentive of speculators once we impose an information cost. To understand this, I first compute speculators' expected profit and show how the profitability of their information acquisition can be affected.

Recall that trading is profitable to speculators only when $X_i = X_j = 0$, which occurs with probability $\frac{1}{4}$. If firm i invests as a leader at date 0, we know from Lemma 2 that firm

j does not invest if $X_i = X_j = 0$. Given that the profit functions of both firms are publicly known, the market maker is then able to anticipate the optimal strategy of firm j and quotes the price P_i and P_j as exactly the expected firm values, if $X_i = X_j = 0$. We can obtain the expected trading profits of speculator i and j, denoted by $\Psi_i(L, F)$ and $\Psi_j(F, L)$, which are respectively $\theta(1-\theta)(\pi_{c-\delta,c} - \pi_{c,c})$ and $\theta(1-\theta)(\pi_{c,c} - \pi_{c,c-\delta})$.[18] It is easy to observe $\Psi_i(L, F) > \Psi_j(F, L)$. When both firms invest at date 0, private information contained in share prices is no longer used for firms' decision making. In this case, the market maker quotes the same price for two firms, $P_i = P_j = \Pi_{i,j}(L, L)$, and both speculators expect to earn $\theta(1-\theta)(\pi_{c-\delta,c-\delta} - \pi_{c,c})$.

Speculators' trading profits are not related to the investment cost I, due to the assumption that firms' investment actions can be observed by all agents. The next proposition summarizes the impact of other parameters on speculators' trading profits.

Proposition 4 *Regardless of firms' strategies in equilibrium, speculators' expected trading profit increases in both δ and α.*

If (L, L) is the equilibrium strategy, speculators' profit decreases in γ;

If firm i invests as the leader, speculator i's profit $\Psi_i(L, F)$ increases in γ for $\alpha < \bar{\alpha}$, and decreases in γ otherwise; while speculator j's profit $\Psi_j(F, L)$ increases in γ for $\alpha > \underline{\alpha}$, and decreases in γ otherwise, where $\bar{\alpha} = c + \frac{\gamma\left(8-8\gamma^2+4\gamma^4-\gamma^6\right)\delta}{(1-\gamma)^2(8-6\gamma^2+4\gamma^3+7\gamma^4+2\gamma^5)}$ and $\underline{\alpha} = c + \frac{\gamma\left(4+\gamma^2-2\gamma^4\right)\delta}{(1-\gamma)^2(2+\gamma)(4+2\gamma+4\gamma^2+3\gamma^3)}$, $\bar{\alpha} > \underline{\alpha}$.

Intuitively, the size of cost reduction δ has a positive impact on the profitability of the investment and therefore the dispersion of firms' payoffs, provided that at least one firm invests in the innovation. Similarly, a higher α, associated with a bigger market size, enlarges the leader's advantage as well as the follower's disadvantage in competition.

The effect of the competition level (γ) is less straightforward. As shown previously, speculator i's profit depends on the difference between $\pi_{c-\delta,c}$ and $\pi_{c,c}$. Assuming firm i chooses to be the leader and its innovation succeeds, an increase of γ has two effects: a negative impact on the product price and a positive impact on the demand. The net effect depends on the market size. For $\alpha < \bar{\alpha}$, a higher γ and thus a higher competition level enables the leader firm to seize a higher market share that is sufficient to compensate the price impact, and thus $(\pi_{c-\delta,c} - \pi_{c,c})$ increases. The dominance of the demand impact becomes weaker when the market size increases, i.e., $\frac{\partial_i^2 \Psi_i(L,F)}{\partial\gamma\partial\alpha} < 0$, and it is eventually reversed when

[18]Note that the expected trading profits of speculators in the parameter region (L, N) & (N, L) have the same expressions.

$\alpha > \bar{\alpha}$. Similarly, speculator j's profit depends on the difference between $\pi_{c,c}$ and $\pi_{c,c-\delta}$. In a sufficiently large market, intense competition reduces the follower firm's market share and pricing power more than when both firms have the same production cost. This effect goes down when α becomes smaller, i.e., $\frac{\partial_j^2 \Psi_j(F,L)}{\partial\gamma\partial\alpha} > 0$, and it is reversed if $\alpha < \underline{\alpha}$. At last, if (L, L) is chosen in equilibrium, two firms are equally positioned in competition. An increase in γ reduces firms' payoff more significantly when the innovation succeeds (the production cost is lower) than otherwise, i.e., $\frac{\partial \pi_{c_i,c_j}}{\partial\gamma\partial c_i} > 0$ if $c_i = c_j$. Consequently, speculators' expected trading profit decreases in γ.

4.3 Endogenized information leakage

Let us now assume that it costs ϵ for each speculator to acquire information about the innovation progress. Speculators will participate only when their net expected payoff is positive, i.e., $\epsilon < \Psi$. As a result, three possible outcomes can arise corresponding to the size of ϵ relative to other parameters: both speculators stop acquiring information (i.e. exit the market) and firms chooses strategies at date 0 as in the benchmark (Proposition 1); both speculators are active; the speculator earning a higher expected profit remains active while the other one quits. The third outcome can occur in equilibrium in which only one firm chooses the strategy L and the expected profit of the speculator of the follower firm is not sufficient to cover the information cost ϵ. Recall that the information acquisition of speculators take place after observing firms' actions at date 0. In equilibrium, firms' innovation strategies correspond to the number of active speculators in expectation.

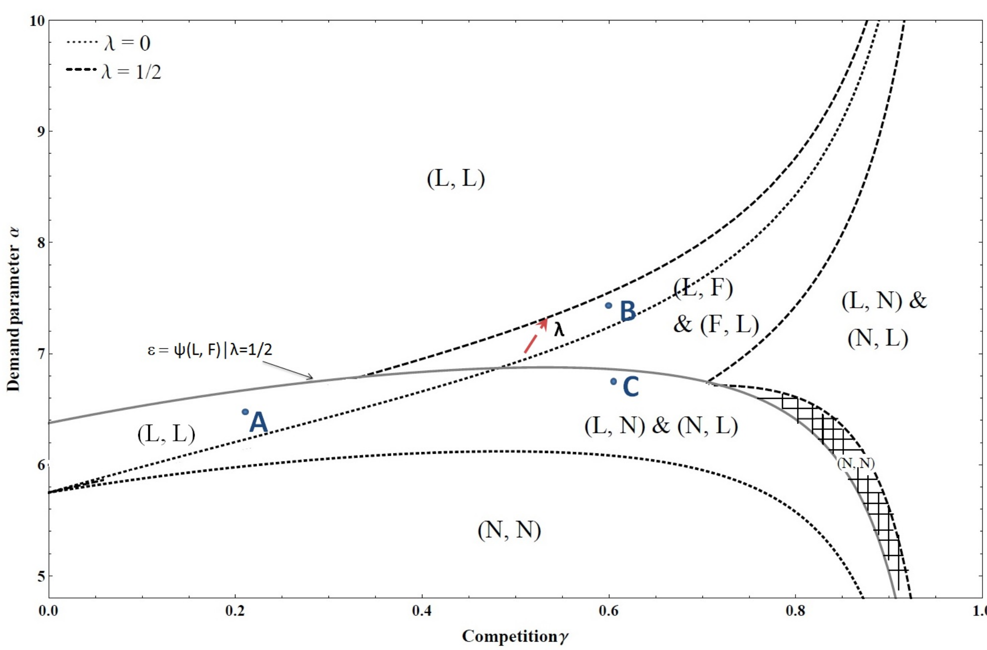
The equilibrium is thus defined as follows: (i) A trading strategy for speculators that maximizes their expected payoffs, given the investment strategies of the firms, (ii) the investment strategies by the firms that maximize expected firm value given all other strategies, (iii) a price-setting strategy by the market maker that allows him to break even in expectation, given the strategies taken by the speculators and firms.

We next have a look at the case that should both speculators trade actively, only firm i invests at date 0 in equilibrium and speculator i earns a higher expected profit than speculator j. If the parameter values are such that ϵ is between $\Psi_i(L, F)$ and $\Psi_j(F, L)$ and speculator j exits the market. This leaves speculator i the only informed trader in the stock market, thereafter called the monopoly speculator. Share prices become less informative with a monopoly speculator, since the market maker can no longer update his belief about the state of the world based on the 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 information leakage (λ) is $\frac{1}{2}$.*

Relating to Proposition 2 and 3, we know that both firms are inclined to innovate at date 0 when the profitability of the innovation investment is particularly high (i.e., a large δ). In this case, speculators have strong incentives to trade, but the information is less useful to firms in the product market. It is similar regarding the market size that a very high α provides speculators with a strong incentive to trade while the information leakage has little impact on the investment outcome. Under the opposite conditions (a very small δ or α), speculators have a low incentive to acquire information, while the option is very valuable such that information leakage could deter the potential leader. Nevertheless, the lack of price informativeness may actually help to alleviate this problem.

Figure 5: Equilbrium - Endogenous Leakage (High ϵ)



This figure shows the equilibrium outcome of a numerical example in which the information cost is sufficiently high ($\epsilon = 2.1$) such that there may be a monopoly speculator trading in the stock market. The grey solid line is the cutoff for the monopoly trading profit to be equal to the information cost. Below the grey line, the monopoly speculator does not acquire information and thus there is no informed trading.

We can now look at the equilibrium outcome with an endogenous information leakage. To visualize how it is different from having an exogenous probability of leakage, I present two numerical examples separately in Figure 5 and 6, with respectively a high information acquisition cost ($\epsilon = 2.1$) and a low cost ($\epsilon = 0.2$). Assume again that firm i is the leader.

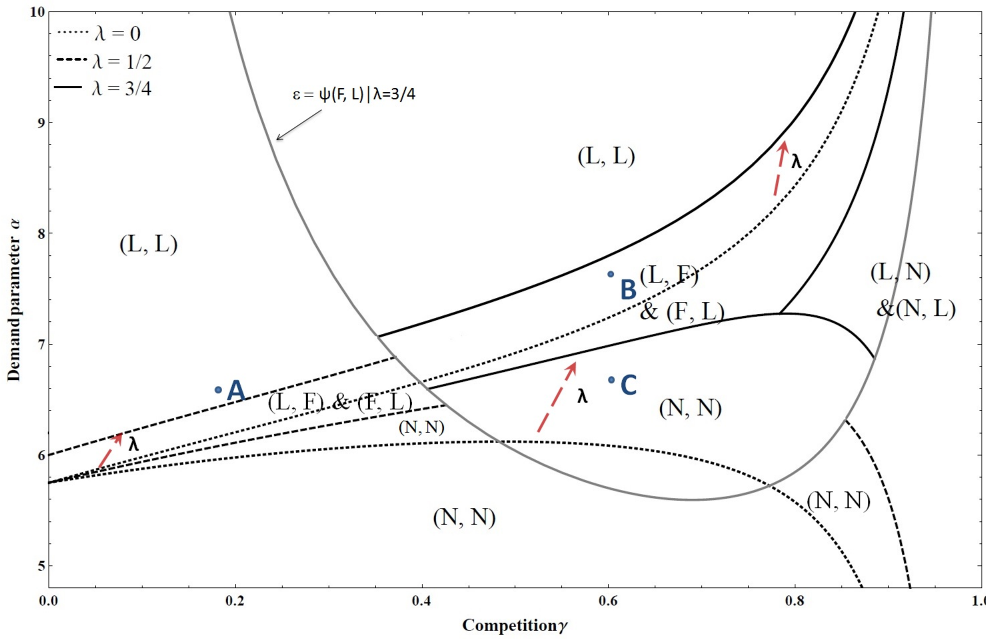
Let us first look at the example in Figure 5, in which the expected profit of speculator of the follower firm j is not sufficient to cover the information cost and thus speculator j leaves the market. Speculator i may remain active depending on the values of parameters α and γ. The gray line represents the cutoff where the information cost is equal to the monopoly trading profit of speculator i, i.e., $\epsilon = \Psi_i (L, F) \, | \lambda = \frac{1}{2}$. Below this cutoff line, speculator i also stops acquiring information and hence there is no informed trading.

First, observe at point A in Figure 5 both a small market size and low competition give sufficient disincentives to speculator i, such that the equilibrium goes back to (L, L) in the benchmark case ($\lambda = 0$). The outcome with an exogenous λ being $\frac{1}{2}$ at point A would be (L, F) & (F, L). The expected profit to speculator i at point C is still not sufficient due to a small market size, and there is no information production in the stock market. As a comparison, information leakage has a real impact at point B with a higher value of α by enabling the follower firm to choose strategy F. Notice in the gridded region in Figure 5, where the competition is intense in the product market, the monopoly speculator has a strong incentive and the option is valuable to the follower. This alignment deters the leader from investing up front. Information leakage ($\lambda = \frac{1}{2}$) switches the equilibrium from (L, N) & (N, L) to (N, N).

Next, Figure 6 shows an example with a sufficiently low cost of information acquisition such that the speculator of the follower firm may also have incentive to participate. The gray line here represents the cutoff of zero trading profit to the speculator of the follower j, netting the information cost, i.e., $\epsilon = \Psi_j (F, L) \, | \lambda = \frac{3}{4}$. Therefore, below this cutoff line, speculator j exits the market and leaves speculator i the monopoly trader. Consequently, λ becomes $\frac{1}{2}$ below this cutoff. Again, in Figure 6 the information leakage does not affect firms' strategies at point A. Were the information leakage exogenous ($\lambda = \frac{3}{4}$), the follower firm would find it optimal to use the option of waiting and choose F. Nevertheless, speculator j does not trade at point A due to a low expectation of trading profit. As a comparison, we observe that when γ increases to point B, both speculators have incentive to trade while the option value is sufficient for firm j to act as a follower and not too high to deter firm i from investing up front. Price informativeness has a positive impact on the investment outcome.

Now look at point C which has the same location as in the previous figure. When the information is more expensive such that only speculator i stays active in the stock market, as in Figure 5, the lack of trading incentive for the monopoly speculator at C leads to the equilibrium (L, N) & (N, L). Given a much lower information cost in the example here, the equilibrium outcome becomes nevertheless (N, N). A high option value is now accompanied

Figure 6: Equilbrium - Endogenous Leakage (Low ϵ)



This figure shows the equilibrium outcome of a numerical example with a low information cost ($\epsilon = 0.2$). In this case, both speculator may be active in the market. The gray line represents the cutoff where the speculator of the follower firm earns zero expected profit netting the information cost and he stops acquiring information in the region below this cutoff. The probability of information leakage drops from to $\frac{1}{2}$ below the gray line.

by a strong trading incentive of the speculator of the follower firm. This deters the potential leader and exerts a negative impact on the investment outcome.

These examples show clearly the difference in the real impact of an endogenized information leakage compared to an exogenous leakage. Conclusion 1 and 2 summarize the discussions above.

Conclusion 1 *Stock price informativeness improves the investment outcome when the profitability of the investment and the market size are relatively large.*

Conclusion 2 *When speculators' trading incentive varies with product market competition, stock price informativeness worsens the investment outcome when the competition level is relatively high in a small market. It may improve the investment efficiency when the competition is not so intense.*

In addition, I show in Figure A2 in the Appendix a numerical example with a moderate information cost ($\epsilon = 1.05$), in which the monopoly speculator i remains always active. At the same location of point C, firms' equilibrium strategies are (L, F) & (F, L). Comparing it to Figure 5 and 6, we observe that the information cost has a non-monotonic effect on investment strategies in equilibrium.

Information cost depends on how difficult it is to understand the nature of an innovation technology and the true value of the technology to a certain industry. Cost of acquiring information and trading to speculators can also come from low analyst coverage, low transparency of firms' disclosure policies and restrictions on short selling, which are often subject to regulatory constraints. The regulatory concerns are particularly relevant to growing and innovation-intensive industries that rely heavily on equity financing due to volatile returns, inherent riskiness of investment, and limited collateral value of intangible assets.[19] Conclusion 1 and 2 show that these industries may also benefit largely from investment efficiency that is promoted by price efficiency in the stock market. The non-monotonic impact of the cost parameter ϵ implies the intricacy in the related policies. A detailed discussion in this regard is nevertheless beyond the scope of this paper.

5 Empirical Implications

The model provides empirical implications from two aspects. First, when information leakage occurs via trading in the stock market, we expect to observe a link between the share price of one firm and the investment taken by its competitor. More specifically, discussions in the previous section conclude that price efficiency in the stock market enables firms to act as followers when the market size and the investment profitability are neither too small nor too large. There may not be sufficient incentive for speculators to acquire information if the parameter values are too small. Or in the opposite case, the option is not valuable and both firms invest up front. The model thus provides the first implication, which is a direct consequence of Conclusion 1. See Table A3 in the Appendix for possible empirical proxies for the model's parameters.

IMPLICATION 1: *The investment of followers is more sensitive to share price movements of leading competitors in an industry with a relatively large market size and profitable investment opportunities than otherwise.*

Additionally, Conclusion 2 says information efficiency in the stock market share prices

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

can have a negative effect on the investment outcome depending on the competition intensity in the industry. Proposition 3 states that the option of waiting becomes more valuable for a higher γ. When the competition level rises, the alignment between speculators' incentive and the option value makes it possible for one firm to act as a follower. When market competition is intense, it however drives out the up-front investment, especially in an industry with a relatively small market where the competition advantage to the leader is low. Implication 2 thus follows.

IMPLICATION 2: *The investment of followers is more sensitive to share price movements of leading competitors when the level of competition increases in the product market. This sensitivity is however weakened when competition becomes intense particularly in a smaller market.*

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, the functionality of the technology itself, and the development of supporting technologies. 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. Investment returns and implementation risks vary accordingly. As a consequence, the relationship between investments and share prices should differ for a given technology adopted across industries and in different periods. This gives another interpretation of Implication 1 and 2.

While providing cross-sectional characteristics, Implication 1 and 2 are mostly consistent with the empirical evidence uncovered in recent studies. Foucault and Frésard (2012) find a positive relationship between a firm's investment and the market valuation of its peers selling related products, the significance of which increases in the stock price informativeness of the peers and the correlation of product demand. These authors however do not consider the level of competition in the industry. Ozoguz and Rebello (2013) document similar results and further show that this link is stronger in an industry with faster growth, higher competition and greater dependence on capital.

Analogically, we should observe the difference in the correlation of firms' specific returns and their investment behaviors. Since the market return is not modelled in this paper, the correlation of firms' specific returns is equivalent to the price correlation. Consider that both speculators are active. Stock prices of firms are perfectly correlated if they both invest up front. In the parameter regions where (L, L) is replaced by (L, F) & (F, L), price correlation obviously goes down. Empirically, it should also be similar in the region where (L, L) is replaced by (N, N) since the specific return related to this innovation investment no long exists if no firm invests in it. On the other hand, the information leakage increases the correlation in the parameter region where (L, F) & (F, L) replace (L, N) & (N, L). This is because with probability $(\lambda\theta)$ the follower firm invests in the innovation and makes the same profit as the leader during the product market competition at date 3, which reduces the variance of market maker prices The amount of investment taken by firms also becomes larger in this region. In the parameter regions where (L, L) is replaced by (N, N)., the correlation of firms' specific returns is reduced and so is the amount of investment. Implication 3 follows.

IMPLICATION 3: *The model suggests that the correlation of firms' specific returns is positively related the amount of R&D investment made by firms. This link is stronger when share prices are more informative.*

Another observation is that a higher probability (λ) of information leakage (e.g., a second firm going public) may lead to a lower amount of investment in the industry. This happens in equilibrium when speculators' incentives are aligned with the option value of waiting such that either one firm switches from L to F and invests only upon good news (e.g., point B in Figure 5) or the leader is deterred from investing up front (e.g., point C in Figure 6). A higher λ can also lead to more investment in the region where the non-leading firm switches from N to F and invests with a higher probability at date 1. This thus provides a cross-section implication regarding the amount of R&D investment.

IMPLICATION 4: *The amount of R&D investment may be lower in an industry in which share prices of competing firms are more informative, the market size and investment profitability are larger and when the level of competition higher. It can also occur when the competition is intense while the market size is relatively small.*[20]

Foucault and Frésard (2012) find that the investments of private firms, after they go public, are less correlated to their peers' share prices because these firms can thereafter learn from their own stock prices. The results in this paper suggest the cross-sectional difference in this aspect. The numbers of firms traded actively by speculators change the probability of information leakage and thus the option value of waiting. When this is taken into account in

[20] This may thus provide a partial explanation to the empirical evidence that public firms invest less and 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 less responsive to investment opportunities, and associate their findings with agency costs.

firms' decisions ex-ante, as discussed previously, the characteristics of the product market and the R&D investment determines whether firms invest in the same (or a similar) innovation after the IPO of their rivals. It is summarized below.

IMPLICATION 5: *After a private firm goes public, the sensitivity of its investment to its competitors' share prices increases if these firms are in an industry with a relatively high competition and large market size, and if their R&D investments are associated with a relatively high profitability.*

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)). That is, when price informativeness allows the follower firm to switch from strategy N to F in equilibrium, firms have more correlated investment.

IMPLICATION 6: *A higher correlation of R&D investments among publicly-listed competing firms may be found in an industry with a relatively large market where both the competition level and the investment profitability are moderate.*

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 leakage via share prices is beneficial to the consumer when the non-leading firm choosing the strategy F over N compared to the benchmark case. It, however, has a negative impact either when the potential leader is deterred from investing at date 0 or when one firm switches its strategy from L to F. As a result, whether consumers benefit from having more information revealed from the stock market depends on the parameter values in this economy.

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 5, 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 1 *The expected total surplus in the product market is higher with a leader and a follower firm than with only one firm investing. It is however reduced when the up-front investment is deterred such that firms' strategies change from (L, N) & (N, L) to (N, N).*

Corollary 1 shows that the impact of information leakage on the total surplus in the product market has a similar pattern as on consumer welfare, except that it is ambiguous in the parameter region where (L, L) is replaced by (L, F) and (F, L). However, it is certain that when information leakage deters the potential leader from investing upfront, it not only undermines production efficiency but further reduces the total surplus in the product market.

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 unconcerned 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

$$u_{k_i} = \begin{cases} b_{k_i}, & \text{if } X_{k_i} = z_i \\ 0, & \text{otherwise} \end{cases}, \; z_i \in \{-1, 1\}, \tag{7}$$

where z_i denotes the state of world and X_{k_i} is the trading order of the k^{th} 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.[21] 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 k^{th} noise trader's private benefit, we can find the threshold k_i^* for the indifferent noise trader. We can express k_i^* as

$$k_i^* = \begin{cases} \max\left(1 - \frac{\Psi_i}{\tau}, 0\right), \text{ if } 1 - \frac{\Psi_i}{\tau} < 0 \\ \min\left(1 - \frac{\Psi_i}{\tau}, 1\right), \text{ if } 1 - \frac{\Psi_i}{\tau} > 0 \end{cases}. \tag{8}$$

where Π_i^S is the expected trading profit of speculator i. The result is summarized in the lemma below.[22]

Lemma 7 *When firm i innovates at date 0, firm j's decision will be changed by the size of private benefit. 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

The financial market plays an important role in allocating scarce resource via information exchange and revelation given that prices contain information that can improve capital allocation (Fama and Miller, 1972). The impact of information efficiency on the real economy starts to change when one takes into account the feedback effect from prices on corporate

[21] 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.

[22] For the purpose of presentation, I discuss the additional assumptions in the Proof of Lemma 6 in the Appendix.

decisions, since the expected cash flows of the asset are endogenized in equilibrium. This paper is an attempt to investigate this process when share prices from the secondary market feed back to firms' innovating strategies. Using a simple setup in a differentiated Bertrand duopoly, I model 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 information leakage 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. This is the case if the leader firm anticipates that its innovation rent becomes insufficient when being imitated by a follower firm. When it is costly for traders in the stock market to acquire private information, the amount of information leakage and hence its impact on the option value of waiting are both endogenized in equilibrium. I show that stock price informativeness may worsen the investment outcome when there is intense competition in a relatively small market. 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.

Even though this paper focuses on the context of innovation strategies, it provides a framework that can be applied to a wide array of corporate decisions in practice, where the payoff of one firm's action is strategically affected by similar actions taken by its competitors or industry peers. Examples are, but not limited to, investments in enlarging production capacities, vertical integrations for the purpose of reducing input price or operating cost, and outsourcing strategies.

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 verify or to obscure the information being revealed via other channels[23]. 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 via stock prices may become more obscure. The optimal strategy of both firms and stock market participants will change accordingly. The answers to these questions are beyond the scope of this paper, but they may provide policy makers with implications in practice, particularly when the characteristics of different industries are taken into account.

[23] 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.

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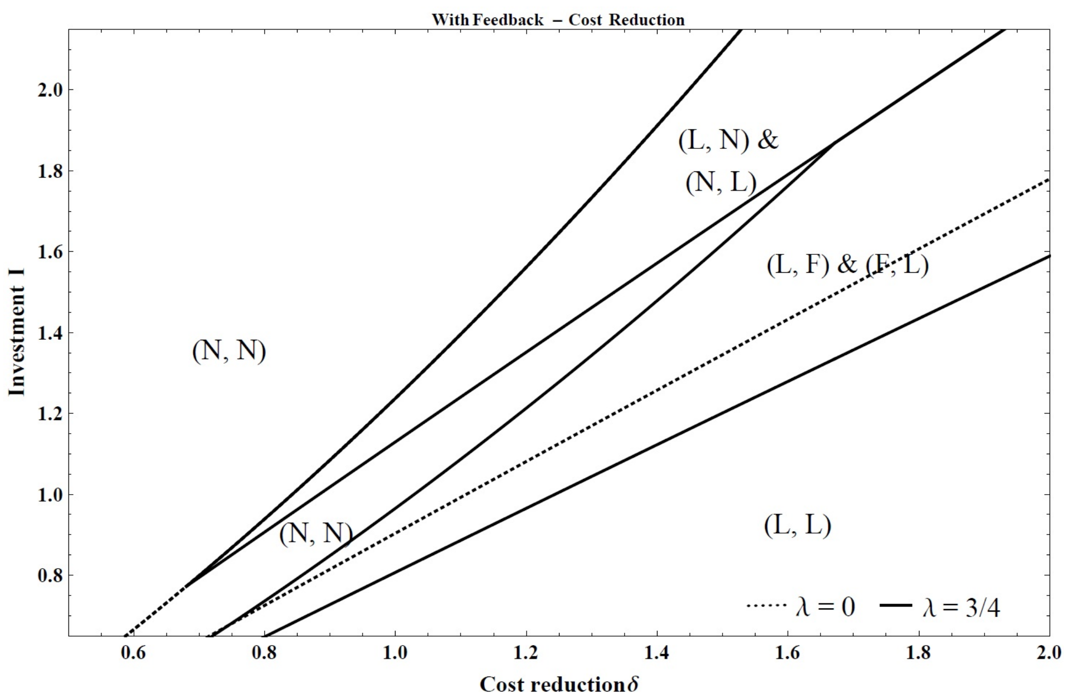
8 Appendix

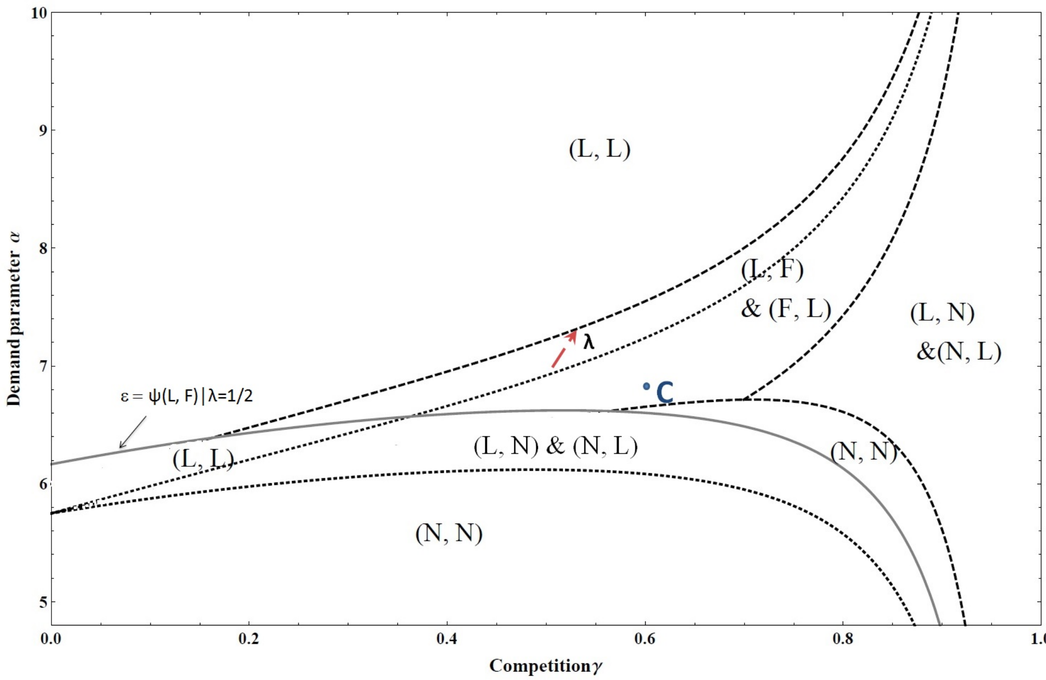
8.1 Appendix A

Figure A1: Equilibrium Strategies - Cost Reduction



This figure shows firms' equilibrium strategies with information leakage in a numerical example with $\alpha = 6, c = 3,\ \theta = 0.4, \gamma = \frac{3}{4}$. (N, N) marks the parameter region of no firm investing in equilibrium. (L, L) marks the region of both firm investing, and (L, N) & (N, L) only one firm investing in equilibrium.

Figure A2: Equilbrium - Endogenous Leakage (Moderate ϵ)



This figure shows the equilibrium outcome of a numerical example in which the information cost is moderate ($\epsilon = 1$). There may be a monopoly speculator staying active in the stock market. The grey solid line is the cutoff for the monopoly trading profit to be equal to the information cost. Below the grey line, the monopoly speculator does not acquire information and thus there is no informed trading. Point C in the figure is at the exactly the same location as in Figure 5 and 6. Observe that the equilibrium is now switched to (L, F) & (F, L) since given a lower information cost compared to Figure 5, the speculator of the leader firm now has incentive to acquire information and trade.

Table A3. Possible Empirical Proxies for the Model's Parameters		
Parameter	Description	Possible Empirical Proxies
ε	Cost of information acquisition & liquidity cost	• Analyst coverage • Share turnover • Dollar trading volume
γ	Competition level in the industry	• Industry HHI • Difference in market shares
	Product similarity	• Text-based analysis of Hoberg and Phillips (2012)
	Competitors identification	• Three-digit SIC classification • Text-based Network Industry Classification developed by Hoberg and Phillips (2012)
α	Market size (price elasticity)	• Total sales • Unit value of consumption
θ, δ, I	Investment profitability	• Firm specific return • Operating profit
λ	Probability of information leakage	• Number of insider transactions • Adjusted probability of informed trading in a stock developed by Jefferson Duarte
Other Variables of Interest		
	Identification of leaders and followers in an industry	• Thomas Register of American Manufacturers • Survey data
	Amount of Investment	• Cash flows of R&D expenditures
	Opportunities to innovate	• Number of patents • R&D expenditure

8.2 Appendix B: Proofs

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. When there is no information leakage, we can use the proof of Lemma 1 to obtain the following; $\Pi_i(L,L) = 2\theta\pi_{c-\delta,c-\delta}+2(1-\theta)\pi_{c,c}-I$, $\Pi_i(N,N) = 2\pi_{c,c}$, $\Pi_i(L,N) = 2\theta\pi_{c-\delta,c}+2(1-\theta)\pi_{c,c}-I$, 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 firm j chooses L, it must be true that: $\Pi_i(L,L)-\Pi_i(N,L) < 0$ and thus $I > 2\theta(\pi_{c-\delta,c-\delta}-\pi_{c,c-\delta})$. Let $\underline{I} = 2(\pi_{c-\delta,c-\delta}-\pi_{c,c-\delta})$.

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

These two inequalities must be both satisfied for the strategy pairs (N, L) & (L, N) to be the equilibria, i.e., $\theta\bar{I} > I > \theta\underline{I}$. 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. 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.

Mathematically, assume firm i leads in innovation investment. Conditioning on $X_i = X_j = 0$, the difference in the expected profit between choosing $\widetilde{F}$ and N, $\theta\pi_{c-\delta,c-\delta}-I-\theta\pi_{c,c-\delta}$. Therefore firm j choose $\widetilde{F}$ over N when $I < \theta(\pi_{c-\delta,c-\delta}-\pi_{c,c-\delta})$, i.e., $I < \frac{1}{2}\theta\underline{I}$.

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. For a given probability of information leakage, $\Pi_j\left(\tilde{F}, L\right) = \theta\left(\pi_{c,c-\delta} + \pi_{c-\delta,c-\delta}\right) + 2\left(1-\theta\right)\pi_{c,c} - \left(1 - \lambda\left(1-\theta\right)\right) I$. To have $\Pi_j\left(L, L\right) - \Pi_j\left(\tilde{F}, L\right) < 0$, it must be $I > \frac{\theta}{2\lambda(1-\theta)}\underline{I}$. The conditions $I < \frac{1}{2}\theta\underline{I}$ and $I > \frac{\theta}{2\lambda(1-\theta)}\underline{I}$ cannot be both satisfied at the same time, $\forall\theta \in (0,1)$, $\lambda \in (0,1)$. $(L, \widetilde{F})$ 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). Given the probability of information leakage being λ, the expected payoff of firm i choosing F when firm j chooses L, is $\Pi_i\left(F, L\right) = \theta\left(\left(2-\lambda\right)\pi_{c,c-\delta} + \lambda\pi_{c-\delta,c-\delta}\right) + 2\left(1-\theta\right)\pi_{c,c} - \lambda\theta I$. For $(A_i, A_j) = (F, L)$ to be a Nash equilibrium, it has to be profitable for firm i to deviate from the strategy L to F when firm j chooses L, i.e., $\Pi_i\left(L, L\right) - \Pi_i\left(F, L\right) < 0$. This leads to $I > \frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I}$.

Similarly for firm i to deviates from N to F given firm j choosing L, it has to be $\Pi_i\left(N, L\right) - \Pi_i\left(F, L\right) < 0$, i.e., $I < \frac{1}{2}\underline{I}$. Notice that when $\theta > \frac{1}{2}$, the inequality $\frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I} < I < \frac{1}{2}\underline{I}$ does not hold. Thus, the strategy (L, F) cannot be the equilibrium if $\theta > \frac{1}{2}$.

On the other hand, for F to be an equilibrium strategy it must be profitable for firm j to choose L over N, when expecting firm i to follow when learning good news at date 1. This is true because if the leader firm does not invest at date 0, share prices no longer contain private information and the other firm cannot act a follower either. We therefore need $\Pi_j\left(L, F\right) > \Pi_j\left(N, N\right)$, which gives $I < \theta\left(\left(2-\lambda\right)\pi_{c-\delta,c} + \lambda\pi_{c-\delta,c-\delta}\right) - 2\theta\pi_{c,c}$. Let this expression be $\theta\tilde{I}$.

(L, F) and (F, L) are the equilibria when all three conditions above are satisfied, that is, $\frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I} < I < \min\left\{\theta\tilde{I}, \frac{1}{2}\underline{I}\right\}$, $\forall\theta \leq \frac{1}{2}$. Note that to ensure the existence of a pure-strategy equilibrium, we need $\theta\tilde{I} > \frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I}$, $\forall\theta \in \left(0, \frac{1}{2}\right)$ and $\lambda \in (0,1)$. This can be guaranteed with $\theta\tilde{I} > \frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I}$ for $\theta = \frac{1}{2}$, or equivalently with α lower than $c + \delta\frac{8-4\lambda+\gamma(2\gamma(-2+\lambda)+\lambda)}{2(2+\gamma)(1-\gamma)\lambda}$.

Next, it is similar to compute the equilibrium condition for (L, N) and (N, L). We already know that firm j deviates from L to N when $I > \theta\underline{I}$ if firm i chooses L. Also from the proof of Proposition 1, we know that given $I < \theta\bar{I}$ firm i chooses L over N when firm i chooses N. Combining the condition $I > \frac{1}{2}\underline{I}$ for firm j to deviate from F to N, 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. Proposition 1 shows that given firm j choosing N, firm i prefers L to N if $I < \theta\bar{I}$. The conditions for (L, N) and (N, L) to be equilibria are: $\theta\underline{I} < I < \theta\bar{I}$ if $\theta > \frac{1}{2}$; and $\frac{1}{2}\underline{I} < I < \theta\bar{I}$ If $\theta \leq \frac{1}{2}$.

The threshold $\theta\tilde{I}$ and $\theta\bar{I}$ then define the equilibrium conditions for (N, N). If $I > \frac{1}{2}\underline{I}$, (N, N) is the unique equilibrium when $I > \max\left\{\frac{1}{2}\underline{I}, \theta\bar{I}\right\}$; and if $I \leq \frac{1}{2}\underline{I}$, (N, N) is the unique equilibrium when $\frac{1}{2}\underline{I} \geq I > \theta\tilde{I}$.

By the same algorithm, for $(L,\ L)$ to be a Nash equilibrium, we need to ensure when firm j chooses L and firm i cannot profit from deviating to any other action than L. That is, $I < \frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I}$ and $I < \theta\underline{I}$. Notice that $\frac{(2-\lambda)\theta}{2(1-\lambda\theta)}$ is lower than θ when $\theta < \frac{1}{2}$. Combining the conditions obtained previously, we know $(L,\ L)$ is the equilibrium when $I < \frac{(2-\lambda)\theta}{2(1-\lambda\theta)}\underline{I}$ for $\theta < \frac{1}{2}$, and when $I < \theta\underline{I}$ for $\theta > \frac{1}{2}$. ■

Proof of Lemma 3. The option value of waiting comes from the benefit of delaying the investment to a firm until it learns good news at date 1, anticipating that the competitor invests at date 0. Therefore, its value is the difference between $\Pi(F, L)$ and $\Pi(L, L)$. Using the proof of Proposition 2, we can obtain easily the expression $(2-\lambda)\,\theta\,(\pi_{c,c-\delta} - \pi_{c-\delta,c-\delta}) + (1-\theta\lambda)\,I$. ■

Proof of Proposition 3. The option value of waiting is the difference between $\Pi_i(F, L)$ and $\Pi_i(L, L)$ which is $(2-\lambda)\,\theta\,(\pi_{c,c-\delta} - \pi_{c-\delta,c-\delta}) + (1-\theta\lambda)\,I$.

The first order derivative of the option value with respect to θ and α are respectively, $(2-\lambda)\,(\pi_{c,c-\delta} - \pi_{c-\delta,c-\delta}) - \lambda I$ and $-\frac{2\left(2-\gamma^2\right)\delta\theta(2-\lambda)}{(2-\gamma)^2(1+\gamma)(2+\gamma)}$, both negative. Similarly, the first order derivative with respect to I is $(1-\theta\lambda) > 0$, $\forall\theta \in (0, 1)$ and $\lambda \in (0, 1)$.

The impact of competition level γ on the option value depends on the relative magnitude of $\frac{\partial}{\partial\gamma}\pi_{c,c-\delta}$ to $\frac{\partial}{\partial\gamma}\pi_{c-\delta,c-\delta}$. The difference is

$$\frac{2(\alpha-c)(1-\gamma)^2\left(8+\gamma^2(-6+\gamma(4+\gamma(7+2\gamma)))\right)\delta+2\left(8+\gamma\left(-2+\gamma^2\right)(4+\gamma(-1+\gamma(-2+\gamma(3+\gamma))))\right)\delta^2}{\left(4-\gamma^2\right)^3\left(1-\gamma^2\right)},$$

which is positive $\forall\gamma \in (0, 1)$ and $\alpha > c + \delta\frac{\gamma}{2-\gamma-\gamma^2}$, the latter being the condition to gurantee the positive quantities of q_i and q_j $\forall c_i, c_j \in \{c, c-\delta\}$. ■

Proof of Lemma 4. 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 firm i. 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.[24] 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. ■

Proof of Lemma 5. 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 Proposition 4. When both firms choose strategy L, $\Psi(L, L) = \theta(1-\theta)(\pi_{c-\delta,c-\delta} - \pi_{c,c})$. When firm i chooses to invest at date 0, and firm j is the non-leading firm, we have $\Psi_i(L, N) = \theta(1-\theta)(\pi_{c-\delta,c} - \pi_{c,c})$ and $\Psi_j(N, L) = \theta(1-\theta)(\pi_{c,c} - \pi_{c,c-\delta})$.

$\Psi_i(A_i, A_j)$ for each (A_i, A_j) above is concave in θ and linear in δ and α. By taking the

[24] 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.

first order derivative of $\Psi_i(A_i, A_j)$, 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 $\Psi_i(A_i, A_j)$ for each strategy profile is positive respect to both both δ and α.

Next, let us check the impact of γ on the expected trading profit of speculators of the leader firm and the follower separately. For the leader firm, let it be firm i, ■

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. 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 $\frac{1}{2}$.

Note that even without limit of exposure to speculators, it can be shown easily that trading only the share0 of the leader firm is more profitable than trading in both firms which would reveal private information with probability $\frac{3}{4}$. ■

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: $p^2_{i,j} = p^3_{i,j} = \frac{(1-\gamma)\alpha + c - \delta}{2-\gamma}$, $q_j^2 = q_j^3 = \frac{\alpha - c + \delta}{(2-\gamma)(1+\gamma)}$.

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 (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 $\frac{2}{1-\gamma}\pi_{c-\delta,c-\delta}$. 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 $\frac{2}{1-\gamma}\pi_{c,c}$. $CS_{L,L}$ 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 $CS^2_{L,N|\theta}$, which equals
$\alpha\frac{2\alpha-2c+\delta}{(2-\gamma)(1+\gamma)} - \frac{\delta^2}{2(1-\gamma)^2(2+\gamma)^2} - \frac{(1-\gamma)\left(\alpha^2+p_ip_j\right)-\left(p_i^2+p_j^2\right)+2\gamma p_ip_j}{1-\gamma^2}$, 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 Corollary 1. Let TS_{A_i,A_j} denote the total surplus in the product market in the equilibrium (A_i, A_j). We know that

$$TS_{A_i,A_j} = CS_{A_i,A_j} + \Pi_i\left(A_i, A_j\right) + \Pi_j\left(A_j, A_i\right).$$

Combining the proof of Proposition 2 and the proof of Proposition 5, the results follow immediately. ■

Proof of Lemma 7. 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 $\tilde{\Psi}_i > \Psi_i > \tilde{\Psi}_j > \Psi_j$ based on the computation of speculators' expected profit in Section 3.4 and 4.1. 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, $k_i^* = k_j^* = \min\left(1 - \frac{\Psi_i(L,L)}{\tau}, 1\right)$. 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. ■