Observability, Disclosure Regulation, and the Incentive for Technological Change

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Abstract

I examine how ex ante symmetric firms that compete in prices strategically decide to invest in research and development (R&D) of cost-reducing technology when the rival firms are not aware of the investment decision and the actual outcome of the investment. In particular, I investigate whether mandatory disclosure laws are necessary to encourage strategic incentive to invest. I find that the equilibrium investment in the absence of any mandatory disclosure law (under incomplete information with unobservable investment) is same as that of the (symmetric) full information equilibrium and is also socially optimal. This implies that mandatory disclosure rules are not required to induce socially optimal investment in the R&D of cost-reducing technology by competing firms. Moreover, the aggregate investment in the industry may be higher in the absence of any mandatory disclosure rules.

Key-words: Cost-reducing technology; Duopoly; Incomplete information; Mandatory disclosure laws; Price competition; Strategic investment.

JEL Classification: D43, D82, L13.
1 Introduction

Firms improve their production technology through a variety of means, many of which are unobservable to the outside world. This is, in particular, true for a very significant proportion of innovations and other production efficiency gains that arise through learning, internal research and development (R&D), and accumulation of organizational capital. As many of these gains are not patentable and firms retain privacy of information about their actual cost and technology structure, it is difficult for potential competitors and other stakeholders in the industry to readily acquire information about them. Further, as these technological improvements are often realizations of learning and R&D processes that are inherently uncertain, both the actual level of technological improvement as well as the investment or effort expended in these activities may remain unobservable to outsiders. In competitive markets, the absence of such observability is likely to influence the strategic incentive to invest, the extent of actual technological improvements, and the eventual market outcomes. This leads to an important question about whether there is a case for a mandatory disclosure regulation that requires firms to disclose information about their investment in technology improvement and/or the outcome of such investment in terms of improvement in production process. At the very least, if such observability is socially desirable, then anti-trust authorities and regulators such as the Federal Trade Commission need not discourage sharing of information about technology among firms in an industry. This paper attempts to analyze the potential value of mandatory information disclosure about technological improvement in a setting of strategic competition among firms.

In particular, the paper analyzes an ex ante symmetric homogenous good duopoly where firms engage in process innovation (that reduces production cost) and price competition. In particular, firms simultaneously decide whether to invest in cost-reduction and after this, they compete in prices. The realized cost reduction is uncertain and depends on the amount of investment; each firm observes its own realized production cost outcome prior to price setting. I compare the investments generated and the market outcomes under three different (exogenously given) information structures: (1) both the investment decision as well as the realized production cost structure of each firm is observed by its rival prior to price competition, (2) only the investment decision (but not the realized production cost structure) of each firm is observed by its rival prior to price competition, and (3) neither the investment level nor the realized cost structure is observed by the rival. Information structure (1) corresponds to the strongest disclosure requirement and information structure (3) is the weakest (no disclosure required). One can also look at these information structures as
resulting from binding (exogenous) information sharing arrangements among firms (in which case (3) would reflect a situation where the regulators prohibit any such information sharing).

The main result of the paper is that both social welfare as well as the profits of firms are maximized under information structure (3) i.e., when neither the investment nor the realized technological improvement achieved by the rival are observable. Therefore, there is no case for any sort of mandatory disclosure regulation from a social perspective. Further, industry lobbies are likely to oppose any such regulation. I also find that even though welfare is not maximized, the total investment in the industry can reach the highest under information structure (2) where investment is observable.

The literature on the effect of observability of R&D investment and outcomes on the strategic incentive to invest is small. Thomas (1997) examines the incentive for cost reduction by a single firm in an industry where firms differ in their initial cost, and shows that this unilateral incentive for cost reduction is higher when information about actual production cost is privately held. In this paper, I focus on the equilibrium investment in cost reduction by both firms in the industry and their reciprocal incentive to invest; further, I allow for uncertainty in the investment outcomes and the lack of information about both investment choice as well as the realized cost structure. Aoki and Reitman (1992) consider a market where before strategically competing in terms of quantities firms decide whether to invest in cost reducing technology where the investment is observable but outcome of stochastic R&D is not. They find that the disclosure of R&D outcomes (final cost structure) promotes cost reducing innovation. This is, in fact, contrary to what I find in this paper. In particular, when investment decision is observable but not the outcome of the R&D (under the second scenario) I find that firms that strategically compete in prices have higher incentive to invest in cost-reducing R&D under no disclosure compared to full disclosure of R&D outcome. My paper is silent about the strategic incentive of a firm to voluntarily share information; instead I focus on the effect of alternative exogenously given information structures (that can be regarded as the results of different regulatory requirements). Jansen (2010) investigates the strategic incentive of a firm to voluntarily disclose the cost of R&D investment to the rival prior to the choice of investment levels. Further, unlike Jansen I do not study the effect of observability of information about a firm’s own efficiency in cost reduction but rather the investment and the realized outcome of cost reducing innovations.

The remainder of the paper is organized as follows. Section 2 describes the model. In section 3, I discuss the price and investment equilibria under full and incomplete information. Section 4
briefly compares the outcomes under incomplete information with that of the full information and also with respect to socially optimal outcomes.

2 The model

I consider an oligopolistic market with two ex ante identical firms that compete in prices and produce physically homogenous product. The production technology of each firm can be of two potential types: high-cost (H) and low-cost (L). Each firm produces at constant unit cost. The unit production cost of a high-cost type (defined by \( c_H \)) is greater than that of a low-cost type (defined by \( c_L \)) i.e., \( 0 < c_H < c_L \). There is a unit mass of risk neutral consumers in the market. Consumers have unit demand i.e., each consumer buys at most one unit of the good. Each consumer is willing to pay \( V \) for a unit produced by both firms. I assume that \( V > c_H \).

Firms are initially endowed with high-cost technology i.e., each firm incurs a unit production cost of \( c_H \). Firms can invest in R&D and adoption of a cost-reducing technology. However, the outcome of the investment is uncertain, and the probability of success is positively related to the cost of investment (which can also be interpreted as the amount of investment). The cost of investment is given by \( A \mu_i \) where \( 0 < A < (c_H - c_L) \) and \( \mu_i \in [0, 1] \) \( \forall i = 1, 2 \) is the probability of successful R&D. In other words, a firm successfully adopts the low-cost technology with probability \( \mu_i \) and remains high-cost type with probability \( 1 - \mu_i \). In the first stage, firms simultaneously decide how much to invest (viz., \( A \mu_i \)); alternatively, one can think that firms choose the probability of successful investment in cost-reducing technology i.e., \( \mu_i \). It is obvious that more a firm invests in cost-reducing technological R&D, higher is the probability of being successful. Moreover, observe that depending on the presence of mandatory disclosure laws there could be three alternative situations; (1) both investment and the actual outcome of investment are publicly observed, (2) firms disclose their investment decision but remain unaware of the final outcome of the investment made by the rival firm, and finally (3) if there is no mandatory disclosure law then firms do not reveal any information about each others’ investments and the outcome of the investments. In the rest of the paper, I refer the first one as full information whereas the last two as incomplete information with observable and unobservable investment respectively. The realizations of production technology after investment are independent across firms, and there is no spill over. In the next stage, firms choose prices simultaneously. Finally consumers observe the prices charged by the firms, decide whether to buy,

\footnote{If \( A > (c_H - c_L) \) then firms do not invest in the equilibrium under both full and incomplete information.}
and from which firm to buy.

3 The strategic investment

Under full information (i.e., in the presence of mandatory disclosure laws), firms are not only aware of rivals’ investment decision but also get to know each others’ investment outcome after the first stage. In the second stage price equilibrium, if the firms are of the same type then they aggressively compete and bring down the price to the respective marginal cost earning zero profit. However, the low cost type charges the marginal cost of the high type \( c_H \) and earns positive profit \( (c_H - c_L) \) when the rival is of high cost type whereas the high cost type charges its own marginal cost and earns zero profit. Thus, the \textit{ex ante} expected profit of a firm \( i \) under full information is given by \( \pi_i = \mu_i (1 - \mu_j) (c_H - c_L) \). The first stage expected profit maximization problem of a firm \( i \) under full information is

\[
\max_{\mu_i} \pi_i - A\mu_i = \max_{\mu_i} \left[ (1 - \mu_j) (c_H - c_L) - A \right] \\
\text{s.t. } 0 \leq \mu_i \leq 1
\]

\textbf{Proposition 1} In the presence of mandatory disclosure laws, firms choose either \( \mu_i^* = 1, \mu_j^* = 0 \) or \( \mu_i^* = \mu_j^* = \left( 1 - \frac{A}{(c_H - c_L)} \right) \forall i, j = 1, 2 \) where \( i \neq j \) in the equilibrium.

\textbf{Proof.} Under full information the reaction function i.e., \( \mu_i^* = \arg \max_{\mu_i} \mu_i \left[ (1 - \mu_j) (c_H - c_L) - A \right] \) and expected profit \( \pi_i^* = \max_{\mu_i} \pi_i - A\mu_i \) are given by

\[
\mu_i^* = \begin{cases} 
1 & \text{if } 0 \leq \mu_j < \left( 1 - \frac{A}{(c_H - c_L)} \right) \\
\in [0, 1] & \text{if } \mu_j = \left( 1 - \frac{A}{(c_H - c_L)} \right) \\
0 & \text{if } 1 \geq \mu_j > \left( 1 - \frac{A}{(c_H - c_L)} \right)
\end{cases} \\
\text{if } 0 \leq \mu_j < \left( 1 - \frac{A}{(c_H - c_L)} \right)
\]

\[
\pi_i^* = \begin{cases} 
(1 - \mu_j) (c_H - c_L) - A & \text{if } 0 \leq \mu_j < \left( 1 - \frac{A}{(c_H - c_L)} \right) \\
0 & \text{if } \mu_j = \left( 1 - \frac{A}{(c_H - c_L)} \right) \\
0 & \text{if } 1 \geq \mu_j > \left( 1 - \frac{A}{(c_H - c_L)} \right)
\end{cases} \\
\text{if } 0 \leq \mu_j < \left( 1 - \frac{A}{(c_H - c_L)} \right)
\]

Three Nash equilibria and respective expected profits under full information are

\[
\mu_i^* = 1, \mu_j^* = 0 \text{ and } \pi_i^* = (c_H - c_L) - A, \pi_j^* = 0 \forall i, j = 1, 2 \text{ where } i \neq j
\]
\[ i = \frac{A}{(c_H - c_L)} \] and \[ \pi_i^* = \pi_j^* = 0 \] \hspace{1cm} (4)

Figure 1 illustrates the reaction functions and full information equilibria of the two stage game. In the interior equilibrium (\( E_3 \) in Figure 1) where both firms invest strictly positive amount, each firm earns zero expected profit; however, it is not a stable equilibrium\(^2\). Whereas in the other two possible Nash equilibria (\( E_1 \) and \( E_2 \) in Figure 1) only one firm invests a strictly positive amount (i.e., \( A_i = A \)); the investing firm earns strictly positive expected profit, but non-investing firm earns zero profit.

Next I consider the case where firms are not required to disclose the actual outcomes of their respective investment in the cost-reducing technology; however, the first stage investment decisions are observed by all. Formally, this leads to a two stage Bayesian game. First, I discuss the second stage subgame where firms choose prices simultaneously with the private knowledge of their own production technology\(^3\). Without any loss of generality, I assume that \( \mu_i \geq \mu_j \) \( \forall i, j = 1, 2 \) where \( i \neq j \) i.e., firm \( i \) is more likely to successfully adopt the low-cost technology than firm \( j \).

**Lemma 1 (Price equilibrium under incomplete information)** The high-cost type of firm \( i \) charges a price equal to its own unit production cost \( c_H \) and low-cost type randomizes over \([ (1 - \mu_j) c_H + \mu_j c_L, c_H] \) with probability distributions

\[ F_i(p) = \frac{1}{\mu_i} - \frac{(1 - \mu_j)(c_H - c_L)}{\mu_i (p - c_L)} \] \hspace{1cm} and \hspace{1cm} \[ F_j(p) = \frac{1}{\mu_j} - \frac{(1 - \mu_j)(c_H - c_L)}{\mu_j (p - c_L)} \]

\( \forall i, j = 1, 2 \) where \( i \neq j \). The ex ante expected profits are

\[ \pi_i = \mu_i (1 - \mu_j) (c_H - c_L) \] and \[ \pi_j = \mu_j (1 - \mu_j) (c_H - c_L). \] \hspace{1cm} (5)

The above lemma implies that there does not exist any Bayesian price equilibrium in pure strategies. The low-cost type has competitive advantage over the high-cost type since \( V - c_L > V - c_H \); thus, if the investing firm becomes low-cost type it enjoys market power and steals all business in the state when the rival (investing firm) remains high-cost type, but also has an incentive

\(^2\)For \( \epsilon > 0 \), if firm \( j \) chooses \( 1 - \frac{A}{(c_H - c_L)} - \epsilon \) then firm \( i \) deviates away from \( 1 - \frac{A}{(c_H - c_L)} \) and does not have any incentive to revert back as firm \( i \) earns higher profit at any \( \mu_i^* < 1 - \frac{A}{(c_H - c_L)} \). Similar argument can be made for firm \( j \) for a given deviation by firm \( i \).

\(^3\)Spulber (1995) and Routledge (2010) consider Bertrand price competition under asymmetric information about rival’s cost when firms face downward sloping market demand.
to undercut the rival in case it is of low-cost type too. In the unique price equilibrium, the low-cost type randomizes price over an interval \([p, c_H]\) to balance these incentives. The equilibrium profit of a low-cost type is \(\pi_L = (1 - \mu_j) (c_H - c_L)\) for any price \(p \in [p, c_H]\). This yields the lower bound of the mixed strategy price support \(p = (1 - \mu_j) c_H + \mu_j c_L\). If \(\mu_i > \mu_j\), low cost type of firm \(i\) has mass point on the upper bound; in other words, firm \(i\) has higher probability of charging the upper bound \((c_H)\) of the price distribution than firm \(j\) does. Note that the low-type of firm \(j\) earns the same profit \((\pi_L)\), but there is no mass point on the upper bound \((c_H)\) for firm \(j\). Also, if \(\mu_i = \mu_j\) then there is no mass point on the upper bound of low-cost type of either firm.

At any price \(p \in [(1 - \mu_j) c_H + \mu_j c_L, c_H]\) the low cost type firm can sell to the entire market if either the rival is of high-cost type or it is not undercut by the low-cost rival and thus, earns expected profit of \((\pi_L)\); this implies \((1 - \mu_j) (p - c_L) + (1 - F_j(p)) \mu_j (p - c_L) = (1 - \mu_j) (c_H - c_L)\) and \((1 - \mu_i) (p - c_L) + (1 - F_i(p)) \mu_i (p - c_L) = (1 - \mu_j) (c_H - c_L)\). Thus, I get

\[
F_i(p) = \frac{1}{\mu_i} - \frac{(1 - \mu_j) (c_H - c_L)}{\mu_i (p - c_L)} \quad \text{and} \quad F_j(p) = \frac{1}{\mu_j} - \frac{(1 - \mu_j) (c_H - c_L)}{\mu_j (p - c_L)}.
\]

Note that \(F_i(p) = F_j(p)\) if \(\mu_i = \mu_j\). The high-cost type charges its own marginal cost and earns zero profit in the equilibrium i.e., \(\pi_H = 0\). I calculate the expected profits of firm \(i\) and firm \(j\) as \(\pi_i = \mu_i \pi_L + (1 - \mu_i) \pi_H = \mu_i (1 - \mu_j) (c_H - c_L)\) and \(\pi_j = \mu_j \pi_L + (1 - \mu_j) \pi_H = \mu_j (1 - \mu_j) (c_H - c_L)\) respectively. To be more precise, in this case,

\[
\pi_i = \mu_i (1 - \mu_j) (c_H - c_L) \quad \text{if} \quad \mu_i \leq \mu_j
\]

\[
= \mu_i (1 - \mu_j) (c_H - c_L) \quad \text{if} \quad \mu_i \geq \mu_j.
\]

In the first stage, firm \(i\) chooses \(\mu_i\) to maximize expected profit from investment given that rival firm \(j\) has chosen \(\mu_j\). In other words, firm \(i\) solves the following constrained expected profit maximization problem:

\[
\max_{\mu_i} \pi_i - A \mu_i = \begin{cases} 
\max_{\mu_i} \mu_i [(1 - \mu_i) (c_H - c_L) - A] & \text{s.t. } 0 \leq \mu_i < \mu_j \\
\max_{\mu_i} \mu_i [(1 - \mu_j) (c_H - c_L) - A] & \text{s.t. } \mu_j < \mu_i \leq 1
\end{cases}
\]  

(6)

The following proposition describes the Bayesian Nash investment equilibrium under incomplete information with observable investment.

**Proposition 2** Under incomplete information with observable investment, firms choose \(\mu_i^* = 1\)
and \( \mu_j^* = \frac{1}{2} \left( 1 - \frac{A}{(c_H - c_L)} \right) \) \( \forall i, j = 1, 2 \) where \( i \neq j \) in the Bayesian Nash investment equilibrium.

**Proof.** Suppose \( \arg \max \mu_i \pi_i - A \mu_i = \mu_i^* \) and \( \pi_i^* = \max \mu_i \pi_i - A \mu_i \). For the first part of (6)

\[
\mu_i^* = \begin{cases} 
\mu_j & \text{if } \mu_j \leq \frac{1}{2} \left( 1 - \frac{A}{(c_H - c_L)} \right) \\
\frac{1}{2} \left( 1 - \frac{A}{(c_H - c_L)} \right) & \text{if } \mu_j > \frac{1}{2} \left( 1 - \frac{A}{(c_H - c_L)} \right)
\end{cases}
\] (7)

\[
\pi_i^* = \begin{cases} 
\mu_j \left[ (1 - \mu_j) (c_H - c_L) - A \right] & \text{if } \mu_j \leq \frac{1}{2} \left( 1 - \frac{A}{(c_H - c_L)} \right) \\
\frac{\left[ (c_H - c_L) - 4(c_H - c_L)^2 \right]}{4(c_H - c_L)} & \text{if } \mu_j > \frac{1}{2} \left( 1 - \frac{A}{(c_H - c_L)} \right)
\end{cases}
\] (8)

Consider the second part of (6).

\[
\mu_i^* = \begin{cases} 
1 & \text{if } 0 \leq \mu_j < \left( 1 - \frac{A}{(c_H - c_L)} \right) \\
\mu_j & \text{if } \mu_j = \left( 1 - \frac{A}{(c_H - c_L)} \right) \\
\mu_j \left[ (1 - \mu_j) (c_H - c_L) - A \right] & \text{if } \left( 1 - \frac{A}{(c_H - c_L)} \right) < \mu_j \leq 1
\end{cases}
\] (9)

\[
\pi_i^* = \begin{cases} 
(1 - \mu_j) (c_H - c_L) - A > 0 & \text{if } 0 \leq \mu_j < \left( 1 - \frac{A}{(c_H - c_L)} \right) \\
0 & \text{if } \mu_j = \left( 1 - \frac{A}{(c_H - c_L)} \right) \\
\mu_j \left[ (1 - \mu_j) (c_H - c_L) - A \right] < 0 & \text{if } \left( 1 - \frac{A}{(c_H - c_L)} \right) < \mu_j \leq 1.
\end{cases}
\] (10)

To find the best response function of firm \( i \) for any given \( \mu_j \), I compare the derived expected profits of firm \( i \) in (8) and (10). Note that \( (1 - \mu_j) (c_H - c_L) - A > \mu_j \left[ (1 - \mu_j) (c_H - c_L) - A \right] \) which means that if \( 0 \leq \mu_j \leq \frac{1}{2} \left( 1 - \frac{A}{(c_H - c_L)} \right) \) the best response of firm \( i \) is \( \mu_i^* = 1 \). Also \( (1 - \mu_j) (c_H - c_L) - A \geq \frac{\left[ (c_H - c_L) - 4(c_H - c_L)^2 \right]}{4(c_H - c_L)} \) \( \forall \mu_j \leq \left( 1 - \frac{A}{(c_H - c_L)} \right) \) which implies that \( \mu_i^* = 1 \) if \( \frac{1}{2} \left( 1 - \frac{A}{(c_H - c_L)} \right) \leq \mu_j \leq \left( 1 - \frac{A}{(c_H - c_L)} \right) \). However, \( (1 - \mu_j) (c_H - c_L) - A \geq \frac{\left[ (c_H - c_L) - 4(c_H - c_L)^2 \right]}{4(c_H - c_L)} \) for \( \mu_j \geq \left( 1 - \frac{A}{(c_H - c_L)} \right) \); thus, best response of firm \( i \) is \( \mu_i^* = \frac{1}{2} \left( 1 - \frac{A}{(c_H - c_L)} \right) \) if \( 1 - \frac{\left( (c_H - c_L) + A \right)^2}{4(c_H - c_L)^2} \leq \mu_j \leq 1 \). To summarize, the reaction function of firm \( i \) under incomplete information is given by

\[
\mu_i^* = \begin{cases} 
1 & \text{if } 0 \leq \mu_j \leq \frac{1 - \left( (c_H - c_L) + A \right)^2}{4(c_H - c_L)^2} \\
\frac{1}{2} \left( 1 - \frac{A}{(c_H - c_L)} \right) & \text{if } \frac{1 - \left( (c_H - c_L) + A \right)^2}{4(c_H - c_L)^2} \leq \mu_j \leq 1
\end{cases}
\] (11)

\( \forall i, j = 1, 2 \) where \( i \neq j \). Two asymmetric Bayesian Nash equilibria of the investment game under incomplete information are

\[
\mu_i^* = 1, \mu_j^* = \frac{1}{2} \left( 1 - \frac{A}{(c_H - c_L)} \right)
\] (12)
which yield the following *ex ante* expected profits for firm $i$ and firm $j$

\[
\pi_i^* = \frac{(c_H - c_L) - A}{2}, \quad \pi_j^* = \frac{((c_H - c_L) - A)^2}{4(c_H - c_L)}.
\] (13)

Figure 2 depicts the reaction functions of firms (denoted by (11)). Observe that, there are two asymmetric\(^4\) Bayesian Nash equilibria (represented by $E_4$ and $E_5$ in Figure 2). In particular, one firm chooses $\mu_i$ such that it becomes low-type with probability one; it also implies that the firm invests maximum possible amount ($A$). Whereas the other firm invests less, remains high-cost type with a strictly positive probability, and earns less profit. Both firms make strictly positive investment to generate uncertainty about the cost structure and thus, in turn, earn strictly positive expected profit. Note that firms do not behave in the similar fashion in the asymmetric equilibrium under full information. It is because under full information full disclosure of final outcome of R&D investment reveals the type of the firms and thus, there is no uncertainty left that can generate positive expected profit. Further, increase in cost differential $(c_H - c_L)$ increases market power and profitability of the low-cost type which in turn, creates higher strategic incentive to invest.

Finally, I study the equilibrium investment behavior when the probability of successful investment in cost reducing technology is also a private knowledge i.e., firms do not disclose their investment behavior to the rival. In particular, firms choose probability of success simultaneously in the first stage and do not disclose the decision to each other. A firm comes to know its own type but is unaware of both the probability of success and the actual outcome of the investment made by the rival. In the next stage, firms choose prices simultaneously. I solve the game by backward induction. Note that in this multi-stage imperfect information game, the nature of pricing equilibrium outcomes of the second stage is similar to that of the incomplete information one discussed in Lemma 1.

**Proposition 3** *In the absence of any mandatory disclosure law (i.e., under incomplete information with unobservable investment), firms choose $\mu_i^* = \mu_j^* = \left(1 - \frac{A}{(c_H - c_L)}\right)$ $\forall i, j = 1, 2$ where $i \neq j$ in the Bayesian Nash investment equilibrium.*

**Proof.** Suppose $\mu_i = \mu_j = \overline{\mu}$ is a Nash equilibrium. Given $\mu_j = \overline{\mu}$, if firm $i$ deviates to $\mu_i \neq \overline{\mu}$ then the rival firm $j$ does not observe this deviation and believes that firm $i$ has chosen $\overline{\mu}$. Thus, it is easy to prove why symmetric equilibrium does not exist. Assume that $\mu_i = \mu_j = \tilde{\mu}$. Given $\mu_j = \tilde{\mu}$, firm $i$ has a strictly positive incentive to deviate to $\mu_i > \tilde{\mu}$ since firm $i$ earns higher expected profit if it decides to invest more than its rival.

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\(^4\)It is easy to prove why symmetric equilibrium does not exist. Assume that $\mu_i = \mu_j = \tilde{\mu}$. Given $\mu_j = \tilde{\mu}$, firm $i$ has a strictly positive incentive to deviate to $\mu_i > \tilde{\mu}$ since firm $i$ earns higher expected profit if it decides to invest more than its rival.
the low-cost type of firm $i$ randomizes over a price interval $p \in [(1 - \bar{p}) c_H + \bar{p} c_L, c_H]$ and earns $(1 - \bar{p}) (c_H - c_L)$. If it deviates to $\mu_i$, the *ex ante* expected profit of firm $i$ i.e., $\pi_i = \mu_i \pi_L + (1 - \mu_i) \pi_H$, is given by

$$\pi_i = \mu_i (1 - \bar{p}) (c_H - c_L).$$

The expected profit from deviation is maximized at

$$\mu_i \begin{cases} 
1 & \text{if } 0 \leq \bar{p} < \left(1 - \frac{A}{(c_H - c_L)}\right) \\
\in [0, 1] & \text{if } \bar{p} = \left(1 - \frac{A}{(c_H - c_L)}\right) \\
0 & \text{if } 1 \geq \bar{p} > \left(1 - \frac{A}{(c_H - c_L)}\right)
\end{cases}$$

Similarly, if $\mu_i = \bar{p}$ I can find the profit from deviation for firm $j$ and the value of $\mu_j$ that maximizes the expected profit from deviation. Thus, neither firm has no incentive to deviate if $\mu_i^* = \mu_j^* = \bar{p} = \left(1 - \frac{A}{(c_H - c_L)}\right)$. Next, I check whether $\mu_i = 1$ and $\mu_j = 0$ is a Nash equilibrium. In this case, $p_i = p_j = c_H$, $\pi_i = [(c_H - c_L) - A]$ and $\pi_j = 0$. Given $\mu_i = 1$, if firm $j$ deviates i.e., $\mu_j > 0$ then it earns strictly positive profit; further, this expected profit from deviation is maximized at $\mu_j = 1$. Therefore, I can conclude that $\mu_i = 1$ and $\mu_j = 0$ is not a Nash equilibrium.

Observe that the investment equilibrium described in the above proposition is identical to the symmetric investment equilibrium under full information. It is precisely because the gain from deviation are the same in both cases. However, unlike full information firms earn strictly positive profit in this case. Moreover, there is no asymmetric investment equilibrium. The reason is as follows. Since the rival cannot observe a firm’s actual investment, the firm with higher investment (under asymmetric case) can take this advantage and reduce its investment by making the rival believe that it is still the aggressive investor.

### 4 Discussion

One of the objectives of this paper is to compare the incomplete information outcomes with that of the full information. In other words, I examine the effects of the presence of mandatory disclosure laws on the strategic incentive to invest in the cost-reducing technology. Under incomplete information both firms always invest strictly positive amount in cost reducing technology and earn strictly positive expected profit. It is primarily because incomplete information about each others actual investment outcome reduces aggressive price competition among firms; as a result firms enjoy more
market power compared to full information. Further, one can conclude that both firms together make more investment in cost reducing technology when the actual outcome of the investment is pure private knowledge if \((c_H - c_L) \leq 3A\).

Social surplus is maximized when a firm charges its own marginal cost. Thus, the expected total surplus is equal to

\[
(\mu_i\mu_j + \mu_i(1 - \mu_j) + \mu_j(1 - \mu_i))(V - c_L) + (1 - \mu_i)(1 - \mu_j)(V - c_H) - A(\mu_i + \mu_j)
\]

which is maximized at

\[
\mu_i^S = \mu_j^S = 1 - \frac{A}{(c_H - c_L)}
\]

\(\forall i, j = 1, 2\) where \(i \neq j\). Thus, the symmetric full information and incomplete information (with unobservable investment) equilibria are socially optimal. However, incomplete information equilibrium will be less desirable for the consumers as consumer surplus is definitely lower under incomplete information.

References


Figure 1

\[ \begin{align*}
E_2 & \quad (0, 1) \\
E_3 & \quad \left(1 - \frac{A}{c_H - c_L}, \quad 1 - \frac{A}{c_H - c_L}\right) \\
E_1 & \quad (1, 0)
\end{align*} \]
\[ E_5 \left( \frac{1}{2} \left( 1 - \frac{A}{c_H - c_L} \right), 1 \right) \]

\[ E_4 \left( 1, \frac{1}{2} \left( 1 - \frac{A}{c_H - c_L} \right) \right) \]