Disclosing Endogenous Cost Information

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Abstract

We study voluntary cost disclosure by duopoly firms when they can invest in a cost-reduction technology, i.e., when their private cost is endogenously determined. We find that, contrary to most of the literature, firms disclose their endogenous cost information regardless of the type of competition. The underlying mechanisms and welfare implications, however, are different. Under Bertrand competition, cost disclosure helps a firm avoid aggressive investment in cost reduction to coordinate actions to the mutual advantage of the duopoly firms. Under Cournot competition, disclosing cost information enables a firm to show a hardened stance toward the competing firm. While firms gain from their disclosure decisions under Bertrand competition, their disclosure decisions under Cournot competition place them in a prisoner's dilemma, as both firms would be better off if they chose not to disclose their information. Consequently, consumers may lose under Bertrand competition but gain under Cournot competition.

Keywords: Disclosure, Cournot and Bertrand competition, innovation, cost reduction

JEL Classification: L13, M41

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1 Introduction

Whether and how firms disclose their private information to competitors is an important and well-researched question. The classic literature on firms' information sharing under oligopoly settings (e.g., Vives, 1984, 2008; Gal-Or, 1985, 1986; Shapiro, 1986; Darrough, 1993; Arya, Mittendorf, and Yoon, 2019) documents that whether firms voluntarily disclose information depends on the type of competition in which they are engaged (i.e., Bertrand versus Cournot) and the type of private information they receive (i.e., demand versus cost information).[1] Specifically, firms withhold information in settings of Cournot/demand and Bertrand/cost but share information in settings of Cournot/cost and Bertrand/demand.

These classic results hinge on how information sharing, which increases the precision of the rival's information and increases the correlation of firms' signals, affects firms' expected profit. For instance, when one firm observes a low signal for its unit cost and reveals it to the rival, the focal firm increases output and the rival reduces output under Cournot competition, making sharing a dominant strategy. In contrast, under Bertrand competition, both firms would undercut prices, which is detrimental to the focal firm, thus making concealing the dominant strategy.

Despite these different conclusions, a common feature in those models is that firms' information regarding demand or cost is typically assumed to be drawn from an exogenous probability distribution. Our paper instead begins by noting that a significant proportion of costs is often specific to individual firms and is determined endogenously by each firm.[2] To many firms, cost reduction is a key driver of research and development (R&D) activities. For instance, the Lacq Research Center of the French company Total focuses on innovations that cut the cost and shrink the environmental footprint of Total's activities. The electric vehicle industry is actively working on platform modularity, agile processes, virtual prototyping, and

[1] A stream of literature studying whether firms should disclose private information in entry-exit games, e.g., Darrough and Stoughton (1990) and Wagenhofer (1990), also generates mixed conclusions.

[2] This does not imply that firms are unable to strategically invest to influence demand. See Arya et al. (2023) for an example of such behavior. Furthermore, our framework also allows us to investigate firms' endogenous demand-enhancing investment; see the discussion at the end of introduction.

complexity management to increase R&D efficiency and thus to reduce costs.[3] In addition, many firms adopt automation to save labor costs and the recent progress in generative artificial intelligence such as ChatGPT provides more tools for firms to save labor costs. For example, fast-food franchisees are turning to automated drive-throughs. A TD Bank survey finds that 37% of respondents plan to use labor-saving technology, such as self-service kiosks and automated "ghost" kitchens.[4]

Despite abundant evidence that cost is endogenously determined through firms' investments in cost-cutting innovations, it remains unclear how these innovation activities in cost reduction affect firms' incentives to disclose costs. We aim to fill this gap. Specifically, we consider a noncooperative game of duopoly firms with private information. Two firms, which are engaged in either Cournot or Bertrand competition, make decisions regarding disclosure first and quantity (or prices) in the product market second. Our only departure from the literature is to recognize the endogenous nature of firms' production costs. Specifically, a firm decides whether or not to disclose cost information and whether or not to invest in a cost-reduction technology to reduce its marginal production cost before it decides on its production quantity or product prices. Therefore, in the setting in which the cost of production is endogenously determined, disclosing cost information is equivalent to disclosing the firms' cost-reduction investment.

Evaluating the trade-off between the benefits and drawbacks of disclosing endogenous cost information, we observe that disclosure can be sustained in equilibrium even when firms engage in Bertrand competition. This result differs from the standard result in the classic information-sharing literature in duopoly settings when private cost is exogenous. When firms' costs are endogenously determined by their own investment decisions, they would rather share information than conceal it in the Bertrand/cost setting. However, although

[3]See R&D Priorities: Cost Reduction and the Environment, February 13, 2019, TotalEnergies; and Improving battery electric-vehicle profitability through reduced structural costs, September 2020.

[4]See A restaurant owner says raising wages to $15 would solve her labor shortage - but she'd have to hike menu prices. Instead, she's turning to automated drive-thrus, Business Insider, July 5, 2021; and Greater Use of Mobile Loyalty Apps Expected to Impact Franchise Restaurants in 2020, February 3, 2020.

firms still disclose cost information in the Cournot/cost setting, the underlying mechanism is substantially different from that documented in the literature, which we explain below.

Under Bertrand competition, firms are inclined to disclose their endogenous cost information as it helps them avoid "overinvestment" in cost reduction and coordinate their actions for mutual benefit. When a firm invests in cost reduction, it lowers its marginal production cost, enabling it to offer lower product prices to consumers. However, if the focal firm discloses its investment decision, the competing firm, upon observing this decision and the cost information, responds by reducing product prices. This price reduction adversely affects the focal firm's profits.

On the other hand, when the focal firm decides not to disclose cost information, the competing firm cannot observe or respond to the investment in cost reduction. Consequently, the negative effect on the focal firm's profits is muted. Without internalizing this negative effect, the focal firm pursues aggressive investment in cost reduction.[5] In equilibrium, the competing firm must hold consistent beliefs about the level of the focal firm's investment. Thus, the aggressive investment by the focal firm ultimately triggers further price cuts from the competing firm, which adversely affects the focal firm's profits.

Therefore, under Bertrand competition, the focal firm seeks to signal less aggressive investment through disclosure, which helps mitigate firm competition and maintain higher product prices. In this sense, disclosure enables firms to avoid aggressive investments in cost reduction, leading to better coordination in maintaining high product prices. However, this coordination leads to higher firm profits at the expense of lower consumer surplus.

In contrast, under Cournot competition, disclosure of the focal firm's cost-reduction investment and the resulting cost information helps the focal firm avoid "underinvestment." In this way, the focal firm gains a competitive advantage over the competing firm. Again, investment lowers the focal firm's marginal production cost and boosts its production. Under

[5] In our model, investment is binary, meaning it involves a decision to either invest or not. When we refer to "aggressive investment," we are indicating that the expected value of investment is higher. In other words, if we consider a mixed strategy in investment, a firm is more likely to choose to invest when adopting an aggressive approach.

Cournot competition, where firms' production decisions are strategic substitutes, disclosure by the focal firm allows the competing firm to observe the cost reduction and scale back its subsequent production. However, if the focal firm conceals its cost information, the deterrence effect vanishes. Therefore, by disclosing its aggressive cost reduction investment, the focal firm gains a competitive advantage over the competing firm.

Nonetheless, when we consider the two firms' equilibrium disclosure and investment decisions under Cournot competition, as both firms disclose and aggressively invest, inter-firm competition is greatly intensified, which ultimately erodes both firms' profits. In fact, the two firms are trapped in a prisoner's dilemma; that is, they would have made higher profits if both had opted not to disclose their information. Unlike under Bertrand competition, consumers benefit from fiercer firm competition and lower product prices, which can also improve total surplus.

Our paper has both empirical and regulatory implications. First, we show that firms choose to voluntarily disclose cost information regardless of the type of competition when their cost is endogenously determined by their cost reduction activities. Therefore, for industries in which cost-reduction is more important, our model predicts that there will be more voluntary disclosure of gross margins, operating leverage, and cost structures, and less redacted disclosure, as empirically proxied by, e.g., Verrecchia and Weber (2006). Second, we show that while there is more disclosure, firms are actually less involved in cost-reducing investments under Bertrand competition, whereas the reverse is true under Cournot competition. Therefore, our model predicts a negative association between more disclosure (or less redaction) and cost reduction investments under Bertrand competition but a positive association under Cournot competition, which potentially provides another way of empirically testing whether certain industries are engaged in Cournot or Bertrand competition.[6] Finally, our results shed some light on the exchange of information among firms, which is a

[6] Nevertheless, we acknowledge that empirically distinguishing Cournot from Bertrand competition is extremely hard.

contentious topic in the antitrust field and receives substantial attention from regulators.[7] Our results suggest that to prevent such information exchange, regulators may need to discourage disclosure (e.g., by increasing the cost of such disclosure), as firms would otherwise voluntarily choose to disclose. However, from the perspective of improving consumer surplus and social welfare, regulators may not want to suppress such disclosure in the Cournot competition case.

Our paper advances the information-sharing literature to provide a better understanding of the incentives for and consequences of firms' cost disclosure (and nondisclosure) by highlighting the endogenous nature of a firm's production cost. In addition to the above classic papers, several studies examine firms' disclosure policies in oligopoly markets. For instance, Pae (2002) shows that an incumbent firm is better off by pre-committing to disclosing both demand and cost information. Hwang and Kirby (2000) also examine firms' disclosure policies in a strategic entry game. Suijs and Wielhouwer (2014) introduce exogenous uncertainty about cost and demand into Cournot and Bertrand competition models and find that disclosure regulation may eliminate the prisoner's dilemma that firms face when both choose not to disclose in Bertrand or Cournot competition with cost uncertainty. In contrast, in our setting with endogenous cost uncertainty, firms are trapped in a prisoner's dilemma when both choose to disclose in a Cournot setting due to the firms' endogenous choice of whether to reduce their costs (and then disclose). More recently, Xiong and Yang (2021) introduce firms' learning information from asset prices into a Cournot competition model and find that the classic nondisclosure result in the setting of Cournot/demand is overturned.

In a closely related study, Arya and Mittendorf (2011) also endogenize firms' production costs by taking a different approach. In Arya and Mittendorf (2011), disclosure of vertical contracts reveals a retailer's cost, and contracts (and thus the retailer's cost) are optimally

[7]For example, U.S. President Joe Biden signed an executive order in 2021 to encourage the Federal Trade Commission (FTC) and Department of Justice (DOJ) to strengthen antitrust guidance to prevent firms from collaborating to suppress wages or reduce benefits by sharing wage and benefit information with one another. See Fact Sheet: Executive Order on Promoting Competition in the American Economy, July 9, 2021, for details.

set by suppliers. However, our setting closely follows the horizontal competition situation studied in the classic information-sharing literature and cost is affected by cost-reduction investments (or innovative activities). In this way, we complement Arya and Mittendorf (2011) to provide a better understanding of the role of endogenous cost in shaping firms' disclosure incentives.

More recently, Arya et al. (2023) incorporate firms' endogenous investment decisions to increase demand (which has a potential spillover effect on competitors), in addition to firms' private information about the exogenous component of demand. They consider the disclosure of such information, which affects firms' subsequent endogenous and unobservable investment decisions, rather than the disclosure of the investment itself, as in our paper. This approach allows them to study additional issues involving the interaction between investment and disclosure timing. In this way, we complement Arya et al. (2023) to provide a better understanding of the role of endogenous investment in shaping firms' incentives to disclose different types of information (i.e., information about cost versus demand and information about the investment itself versus information that is useful for investment).

It is worth noting that our model can also be adapted to examine the disclosure of demand-enhancing investment. In particular, a firm can make investments to enhance the demand for its own product as well as the demand for its rival firm, as modelled in Arya et al. (2023), thus capturing positive investment spillover effects. The disclosure decisions of firms in this modified model pertain to whether they choose to disclose their investment to the rival firm. Due to the complexity of the model, we are only able to conduct numerical analysis. Nevertheless, the mechanism analysis of cost-reducing investment that we have performed can be applied to this new setting to investigate how disclosure decisions impact subsequent pricing and quantity competition among firms, as well as how disclosure strategies are endogenously determined.

Our paper is also related to the literature on innovation and disclosure to the extent that innovation activity/R&D spending affects firms' production costs. In our model, as cost is endogenously determined, disclosing investment activities is equivalent to disclosing cost information. Hughes and Kao (1991) study the effects of different disclosure rules for R&D on competition in oligopolistic industries. Although Sengupta (2016) and Baik and Kim (2020) also explore the implications of the observability of R&D investments for firm profits, consumer surplus and social welfare, they do not study firms' endogenous disclosure decisions regarding their investments, which is the main focus of our paper. Relatedly, Sundaram et al. (1996) develop an empirical measure of the market value of firms' competitive strategic behavior using the market reaction of firms and their competitors announcing changes in R&D expenditures.

The paper proceeds as follows. Section 2 describes the model setup. Section 3 examines firms' equilibrium investment and disclosure decisions. Section 4 discusses the implications of our results, and Section 5 concludes.

2 The Model

We study an economy in which firms choose whether to disclose their cost information, while also making investment decisions regarding cost-reduction technologies. The key departure from the literature (e.g., Vives, 1984; Gal-Or, 1985, 1986; Darrough, 1993) is that firms' production cost is endogenously determined rather than drawn from an exogenous probability distribution.

There are two firms, firm 1 and firm 2, that compete in the product market. We consider two types of product-market competition: Bertrand competition and Cournot competition. If firms engage in Bertrand competition, the demand function for firm i's product is given by

$$D_i = 1 - p_i + \theta p_j, \tag{1}$$

where $i, j \in \{1, 2\}$ and $i \neq j$. Instead, if the two firms compete on quantity (Cournot competition), the inverse demand function for firm i's product becomes:

$$p_i = 1 - Q_i - \theta Q_j. \tag{2}$$

In equations (1) and (2), the parameter $\theta \in [0, 1]$ captures the extent of price and quantity competition, respectively, within the two firms. The higher the value of θ, the greater the competitive pressure between the two firms.[8]

Both firms' initial marginal production cost is c, where $c \in [0, \frac{1}{2}]$.[9] On date 0, firms can invest in a cost-reduction technology to reduce their marginal production cost. Specifically, by investing in the technology, a firm can reduce its marginal production cost from c to 0. Otherwise if the firm does not make any investment, its marginal production cost remains at c. That is, the two ex ante identical firms may end up with different marginal costs. This investment costs a fixed amount K, where $K \geq 0$.[10] Examples of cost-reduction activities abound. For instance, retailers can curtail expenses by developing websites and mobile apps to serve consumers, while semiconductor manufacturers invest significantly in research and development (R&D) activities to decrease production costs. Additionally, contemporary innovations such as generative artificial intelligence and automations contribute to the reduction of production costs for various firms.

Firms also decide whether or not to disclose their cost information on date 0. If a firm decides to reveal its cost information (or equivalently, its investment decision), the competing firm observes its marginal production cost. Otherwise, the firm's marginal production cost

[8]For simplicity, we use the same variable θ to capture the extent of competition under Bertrand and Cournot competition. That is, the two θ values are different parameters. This approach is appropriate as we do not conduct any comparisons between Bertrand and Cournot competition. Alternatively, we could start from a representative consumer's utility function and derive the demand and inverse demand functions (Singh and Vives, 1984), which will add complexity to the terms but do not change our insight.

[9]Note that $c \leq \frac{1}{2}$ ensures that no firm is driven out of the market by competition; that is, the demand for a firm's product under Bertrand competition or the price for its product under Cournot competition is always nonnegative.

[10]Our model insights remain valid if we instead assume that the cost-reduction technology reduces the firm's marginal cost from c to a nonzero value, let's say $c - \Delta$, where $0 < \Delta < c$. In addition, there are other ways to model the cost-reduction technology. For instance, a reduction of x can cost an amount $K = k \cdot x^2$. We numerically confirm that our key insight holds under this continuous cost reduction technology.

remains unobservable to the rival.

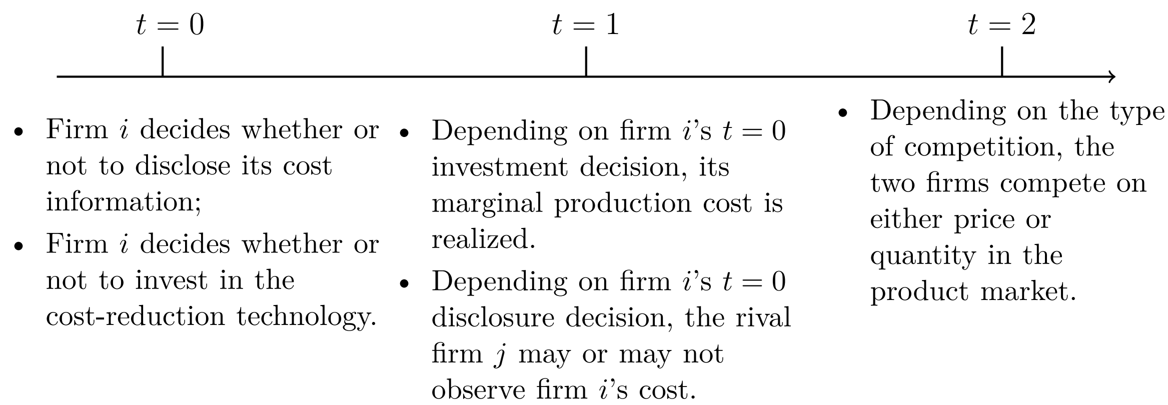


Figure 1: Sequence of events

To summarize, the economy is defined by three exogenous parameters $\{c, \theta, K\}$, and the sequence of events is depicted in Figure 1. On date 0, firm i makes its disclosure and cost-reduction investment decisions. On date 1, the marginal production cost for firm i can be either 0 or c, depending on whether the firm decides to invest in cost reduction or not. Furthermore, depending on firm i's disclosure choice on date 0, firm j may or may not observe firm i's marginal production cost. Finally, on date 2, the two firms compete in the product market.

3 Disclosing Endogenous Cost Information

In this section, we begin by discussing Bertrand competition and subsequently transition to Cournot competition. In the subsequent analysis, we utilize superscripts B and C to represent Bertrand and Cournot competition, respectively, while employing subscripts d and n to distinguish between the disclosure and nondisclosure regimes.

3.1 Bertrand Competition

3.1.1 Optimal Investment in Cost Reduction

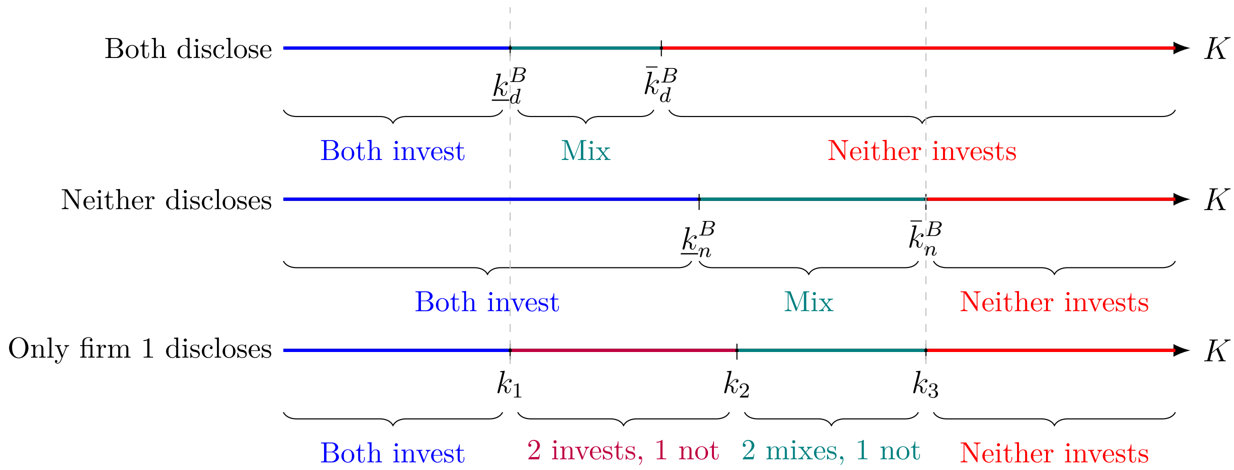
While the disclosure and investment decisions are assumed simultaneous, we follow the reordering invariance criterion proposed by In and Wright (2018) and consider the reordered game in which the disclosure decision is made prior to the investment decision. This allows us to filter out a large number of unreasonable equilibrium outcomes; see In and Wright (2018) for a detailed discussion. Thus, under Bertrand competition, we first characterize the two firms' optimal investment choices. The investment choice depends upon the information available to the firm. For firm i this information consists of the reported information from the rival firm and the known values of the parameters c, θ, and K. Thus, we discuss firms' equilibrium investment decisions in the continuation game following each possible combination of disclosure policies. The following Lemma 1 summarizes the results. Figure 2 graphically illustrates this lemma.

Lemma 1 (Investment decisions under Bertrand competition). Suppose firms engage in Bertrand competition. Define: $\underline{k}_d^B = k_1 \equiv \frac{c(2-\theta^2)(2(2+\theta)-c(2-\theta^2))}{(4-\theta^2)^2}$, $\bar{k}_d^B \equiv \frac{c(2-\theta^2)(2(2+\theta)-c(2-\theta(2+\theta)))}{(4-\theta^2)^2}$, $\underline{k}_n^B \equiv \frac{c}{2-\theta} - \frac{c^2}{4}$, $k_2 = \frac{c\left(4(2+\theta)+c(\theta^2+4\theta-4)\right)}{4(4-\theta^2)}$, $\bar{k}_n^B = k_3 \equiv \frac{c(1+c)}{2-\theta} - \frac{3c^2}{4}$, and it follows that $\underline{k}_d^B = k_1 < \underline{k}_n^B(\bar{k}_d^B) < k_2 < \bar{k}_n^B = k_3$.

(1) Suppose that both firms disclose their cost information. There exists a unique symmetric equilibrium such that when $K \leq \underline{k}_d^B$, both firms invest; when $K \geq \bar{k}_d^B$, neither firm invests; and when $\underline{k}_d^B < K < \bar{k}_d^B$, each firm invests with probability $a_d^B \in (0,1)$, where $a_d^B = \frac{1}{2\theta}\left(\frac{2(2+\theta)}{c} + (\theta^2+2\theta-2) - \frac{(4-\theta^2)^2}{c^2(2-\theta^2)}K\right)$.

(2) Suppose that neither firm discloses its cost information. There exists a unique equilibrium such that when $K \leq \underline{k}_n^B$, both firms invest; when $K \geq \bar{k}_n^B$, neither firm invests; and when $\underline{k}_n^B < K < \bar{k}_n^B$, each firm invests with probability $a_n^B \in (0,1)$, where $a_n^B = \frac{4c-4K(2-\theta)-c^2(2-3\theta)}{2c^2\theta}$.

(3) Suppose that only firm 1 discloses its cost information. When $K \leq k_1$, both firms invest; when $K \geq k_3$, neither firm invests; when $k_1 < K \leq k_2$, firm 1 does not invest, but firm 2 invests; and when $k_2 < K < k_3$, firm 1 does not invest, but firm 2 invests with probability $a_{dn}^B = \frac{(2+\theta)\left(4c-c^2(2-3\theta)-4(2-\theta)K\right)}{2c^2\theta^2}$.



This figure plots firms' investment decisions, as characterized in Lemma 1. Note that apart from the relative position of $\bar{k}_n^B$ and $\bar{k}_d^B$, the relative positions of the other thresholds are unaffected by parameter values. That is, both $\bar{k}_d^B > \bar{k}_n^B$ and $\bar{k}_d^B < \bar{k}_n^B$ are plausible.

Figure 2: Investment under Bertrand competition

Part (1) of Lemma 1 examines the subgame where both firms disclose their cost information. It reveals the existence of a threshold, denoted as $\underline{k}_d^B$, such that when the fixed investment cost is below this threshold, both firms invest in cost-reduction technology. Conversely, if the fixed cost exceeds another threshold, denoted as $\bar{k}_d^B$, neither firm chooses to make the investment. In cases where the fixed cost falls within an intermediate range (i.e., $\underline{k}_d^B < K < \bar{k}_d^B$), both firms adopt a randomized strategy, alternating between investing and not investing in cost reduction. In the scenario where neither firm discloses their cost information, as demonstrated in Part (2) of Lemma 1, the investment behavior of the firms follows a similar pattern.

In the subgame where only one firm discloses its cost information, the investment strategies of the two firms may become asymmetric. Without loss of generality, in Part (3) of

Lemma 1, we assume that only firm 1 discloses its cost information. Similar to Parts (1) and (2) of the Lemma, both firms opt to invest in cost reduction when the fixed cost is low, while refraining from doing so when the fixed cost is high. However, when the fixed cost takes intermediate values, the investment behavior of the two firms diverges: the firm that discloses its cost information, in this case, firm 1, tends to invest less in cost-reduction technology.

Perhaps surprisingly, why does the disclosing firm invest less in cost reduction? To address this question, we derive firms' expected profit and decompose its investment incentive. Denote firm i's investment as $\iota_i \in \{0, 1\}$, where $\iota_i = 1$ indicates an investment while $\iota_i = 0$ indicates no investment. Thus, given its own investment decision ι_i and the other firm j's product price p_j, firm i chooses price p_i to maximize the expected profit as

$$\pi_i = (1 - p_i + \theta p_j)(p_i - (1 - \iota_i) \cdot c) - K \cdot \iota_i. \tag{3}$$

Maximizing the profit function yields firm i's best response p_i as follows:

$$p_i = \frac{1}{2}\left(1 + \theta p_j + (1 - \iota_i) \cdot c\right). \tag{4}$$

Inserting the price function (4) back into the expected profit (3) generates firm i's equilibrium expected profit:

$$\pi_i(\iota_i) = \frac{1}{4}\big(1 + \theta p_j - (1 - \iota_i) \cdot c\big)^2 - K \cdot \iota_i. \tag{5}$$

We then apply the chain rule to $\pi_i(\iota_i)$ and express the firm's investment incentive as follows:

$$\frac{d\pi_i}{d\iota_i} = \underbrace{-K}_{\text{investment cost } (<0)} + \underbrace{\frac{1}{2}\big(1 + \theta p_j - (1 - \iota_i) \cdot c\big) \cdot c}_{\text{lower marginal cost } (>0)} + \underbrace{\frac{\theta}{2}\big(1 + \theta p_j - (1 - \iota_i) \cdot c\big)\frac{\partial p_j}{\partial \iota_i}}_{\substack{\text{disclosure: complementary pricing effect } (<0) \\ \text{nondisclosure: } (=0)}}. \tag{6}$$

The first two terms in equation (6) capture the standard trade-off encountered by a firm when contemplating an investment in cost reduction. All else being equal (i.e., assuming the other firm's price p_j remains fixed), increased investment aids the firm in reducing its marginal costs. However, this investment also entails costs. This trade-off persists regardless of whether the firm discloses its investment or not.

The third term in equation (6) captures how firm i's disclosure affects its investment incentive through the impact on the rival firm's price. To identify this additional effect, it is necessary to determine the sign of the partial derivative $\frac{\partial p_j}{\partial \iota_i}$. We specify the rival firm's belief about firm i's investment strategy as $\hat{\iota}_i$. Consequently, the rival firm conjectures firm i's price to be $\hat{p}_i$. Based on these beliefs and following a similar approach to the one used to derive equation (4), we compute the rival firm's best response price as follows:

$$p_j = \frac{1}{2}\left(1 + \theta \hat{p}_i + (1 - \iota_j) \cdot c\right). \tag{7}$$

Therefore, the impact of firm i's disclosure on the rival firm's pricing strategy depends on how it influences the rival firm's perception of its cost-reduction investment and pricing.

When firm i does not disclose its investment, the rival firm's beliefs $\hat{\iota}_i$ and $\hat{p}_i$ are independent of firm i's actual investment ι_i. As the beliefs must be consistent in equilibrium, regardless of firm i's actual investment, these belief functions are fixed at the equilibrium levels: $\hat{\iota}_i = \iota_i^*$ and $\hat{p}_i = p_i^*$. Consequently, according to equation (7), the rival firm's pricing strategy does not respond to firm i's actual investment. This implies that the third term in equation (6) vanishes, i.e., $\frac{\partial p_j}{\partial \iota_i} = 0$.

In contrast, when firm i discloses its investment, the rival firm can perfectly observe firm i's marginal production cost and, thus, infer its price. As a result, the rival firms' beliefs adjust with the actual investment ι_i. In the language of game theory, the rival firm's information sets under disclosure degenerate to a singleton and the belief distributions assign probability one to the single node. By replacing $\hat{p}_i = p_i$ in equation (7) and finding the interaction of the two firms' best response strategies (3) and (7), we can derive the two firms' optimal pricing strategies as follows:

$$p_i = \frac{2+\theta+c\big(2(1-\iota_i)+\theta(1-\iota_j)\big)}{4-\theta^2,} \text{ and } p_j = \frac{2+\theta+c\big(2(1-\iota_j)+\theta(1-\iota_i)\big)}{4-\theta^2}. \quad (8)$$

It immediately follows that the rival firm's pricing strategy responds negatively to firm i's investment, indicated by $\frac{\partial p_j}{\partial \iota_i} < 0$. Therefore, the third term in equation (6) takes a negative sign. We refer to this effect as the "complementary pricing effect," which only applies when a firm discloses.

Comparing the disclosure and nondisclosure settings reveals that under disclosure, a firm invests less in cost-reduction technology. When firm i invests in cost reduction and discloses this investment, the rival firm recognizes that firm i can now lower its product price due to the reduced marginal cost. In Bertrand competition, where strategic complementarity exists, firm i's price reduction creates an incentive for the rival firm to undercut its prices as well. As a result, competition intensifies, eroding firm i's profit. This explains the negative complementary pricing effect. Consequently, the disclosing firm, firm i, aims to internalize this negative effect by reducing its investment in cost reduction. In contrast, if a firm remains silent about its cost-reduction investment, the negative impact of the third term disappears, as the rival firm cannot observe or respond to firm i's actual investment. Therefore, the absence of negative consequences prompts the nondisclosing firm to pursue more aggressive investment than the disclosing firm. This explains the equilibrium investment behavior of the two firms in the subgame when only one firm discloses cost information.

Furthermore, the aggressive investment in cost reduction by firm j can reduce firm i's investment incentive, leading to a decrease in firm i's expected profit. To formally illustrate this strategic substitution effect in firms' investments, we express firm i's expected profit as a function of its own investment ι_i and the rival firm's investment ι_j. Substituting the optimal prices (8) into firm i's expected profit function (5) yields the following:

$$\pi_i(\iota_i, \iota_j) = \frac{\Big(2 + \theta + c \cdot \big(\theta(1-\iota_j) - (2-\theta^2)(1-\iota_i)\big)\Big)^2}{(4-\theta^2)^2} - K \cdot \iota_i. \tag{9}$$

The cross partial derivative of $\pi_i(\iota_i, \iota_j)$ is given by $\frac{\partial^2 \pi_i(\iota_i,\iota_j)}{\partial \iota_i \partial \iota_j} = -\frac{2\theta c^2\,(2-\theta^2)}{(4-\theta^2)^2} < 0$. This negative value indicates that the investments made by the two firms are strategic substitutes. In other words, as firm j increases its investment aggressiveness (i.e., ι_j increases), firm i's investment incentives decrease (i.e., $\frac{\partial \pi_i(\iota_i,\iota_j)}{\partial \iota_j}$ decreases).

In summary, the complementary pricing effect, inherent in Bertrand competition, prompts a firm that discloses its cost-reduction investment to decrease its own investment to prevent intensified competition between the firm. However, this reduced investment incentive, combined with the rival firm's aggressive investment behavior, might put the disclosing firm at a disadvantage due to the strategic substitutability in firms' cost-reduction investments. These two factors are the main driving forces behind firms' disclosure decisions in equilibrium, as we will demonstrate in Section 3.1.2.

3.1.2 Optimal Disclosure of Cost Information

In this section, we examine firms' optimal disclosure choices. We make the assumption that once the firms' disclosure choices are made, they become common knowledge. This allows us to utilize backward induction to analyze and determine firms' disclosure decisions. Specifically, in Section 3.1.1, we have calculated the equilibrium in the continuation game following the firms' disclosure choices. By creating a payoff matrix that summarizes the expected net profit of both firms in each subgame based on whether they and their rivals disclose or not, we can then use this matrix to identify the equilibrium disclosure choices.

According to Figure 2, when the investment cost is either too low (i.e., $K < k_1 = \underline{k}_d^B$) or too high (i.e., $K > k_3 = \bar{k}_n^B$), both firms consistently either invest or refrain from investing, regardless of their disclosure decisions. Therefore, we focus on the more intriguing scenario of an intermediate cost when determining the equilibrium, specifically, $\underline{k}_d^B = k_1 < K < k_3 = \bar{k}_n^B$.

Figure 3 illustrates the representative patterns of firms' expected profits in a 2×2 matrix for various values of the fixed cost K given c and θ. The underline denotes each firm's best response considering the other firm's disclosure decision. The letter above each number indicates the firm's optimal investment strategy in the subgame as characterized in Section 3.1.1. Specifically, 'I' denotes investment, 'NI' denotes non-investment, and 'Mix' denotes randomization between investment and non-investment. Furthermore, Proposition 1 provides a characterization of the optimal disclosure decisions.

Firm 1 \ Firm 2	disclosure	nondisclosure
disclosure	Mix, Mix 0.546, 0.546	NI, I $\underline{0.522}$, $\underline{0.793}$
nondisclosure	I, NI $\underline{0.793}$, $\underline{0.522}$	I, I 0.516, 0.516

(a) $K = 0.31$

Firm 1 \ Firm 2	disclosure	nondisclosure
disclosure	NI, NI $\underline{0.746}$, $\underline{0.746}$	NI, I $\underline{0.522}$, 0.743
nondisclosure	I, NI 0.743, $\underline{0.522}$	I, I 0.466, 0.466

(b) $K = 0.36$

Firm 1 \ Firm 2	disclosure	nondisclosure
disclosure	NI, NI $\underline{0.746}$, $\underline{0.746}$	NI, I $\underline{0.522}$, 0.703
nondisclosure	I, NI 0.703, $\underline{0.522}$	Mix, Mix 0.456, 0.456

(c) $K = 0.4$

Firm 1 \ Firm 2	disclosure	nondisclosure
disclosure	NI, NI $\underline{0.746}$, $\underline{0.746}$	NI, Mix 0.713, 0.731
nondisclosure	Mix, NI 0.731, 0.713	Mix, Mix $\underline{0.731}$, $\underline{0.731}$

(d) $K = 0.49$

Panels (a)–(d) display the expected profits of the two firms for various values of K under Bertrand competition. In each cell, the first (second) number represents the expected profit of firm 1 (2). The underline denotes each firm's best response considering the other firm's disclosure decision. The letter above each number indicates the firm's investment strategy in the subgame following firms' disclosure decisions. Specifically, 'I' denotes investment, 'NI' denotes non-investment, and 'Mix' denotes randomization between investment and non-investment. The other parameters are $c = 0.5$ and $\theta = 0.9$. Under these parameters, we have the following thresholds $k_1 = \underline{k}_d^B = 0.304$, $\bar{k}_d^B = 0.356$, $\underline{k}_n^B = 0.392$, $k_2 = 0.463$, and $k_3 = \bar{k}_n^B = 0.494$.

Figure 3: Endogenous disclosure decisions under Bertrand competition

Proposition 1 (Disclosure decisions under Bertrand competition). Suppose firms engage in Bertrand competition. Define $\bar{K} = \frac{c\left(3c\theta^2 - 4c + 4\theta + 8\right)}{4(4-\theta^2)}$ (the other thresholds are given in Lemma

1), and it follows that $\min\{\underline{k}_n^B, \bar{k}_d^B\} < \bar{K} < k_3$.

(1) When $k_1 < K < \min\{\underline{k}_n^B, \bar{k}_d^B\}$, there co-exist three equilibria: (disclosure, nondisclosure), (nondisclosure, disclosure), and both firms randomize between disclosure and nondisclosure, with probability $\beta = \frac{2+\theta}{c\theta} + \frac{\theta(2+\theta)-2}{2\theta} - \frac{K(4-\theta^2)^2}{2c^2\theta(2-\theta^2)}$ in disclosing cost information. We select the symmetric equilibrium, that is, the one in which both firms adopt mixed strategies in disclosure.

(2) When $\min\{\underline{k}_n^B, \bar{k}_d^B\} < K < \bar{K}$, (disclosure, disclosure) is the unique equilibrium.

(3) When $\bar{K} < K < k_3$, there co-exist two equilibria: (disclosure, disclosure) and (nondisclosure, nondisclosure). We select the equilibrium that Pareto dominates, that is, the one in which both firms disclose cost information.

Proposition 1 and Figure 3 collectively offer key insights in our paper. In contrast to the findings in the classic literature (e.g., Gal-Or, 1986; Vives, 1984), our analysis reveals a consistent tendency for firms to disclose their cost information in a Bertrand competition setting. In other words, neither firm chooses to completely withhold their cost information.

However, the specific equilibrium disclosure strategies may vary depending on different parameters. As we will explain in detail below, this variation is determined by the interplay between strategic complementarity in firms' pricing decisions and strategic substitutability in firms' investment decisions. The former effect encourages firms to disclose their cost information and adopt a conservative investment approach, leading to coordination on high product prices. On the other hand, the latter effect motivates firms to refrain from disclosing their cost reduction efforts and instead invest aggressively in cost reduction to gain a competitive advantage. Overall, given c and θ, as the investment cost K increases, the strategic substitutability effect becomes less significant, allowing the strategic complementarity effect to dominate.

Firstly, when the investment cost K is low, i.e., $K < \min\{\underline{k}_n^B, \bar{k}_d^B\}$, as indicated in Part (1) of Proposition 1 and Panel (a) of Figure 3, the strategic substitutability effect prevails over the strategic complementarity effect. Under nondisclosure, a firm is more inclined to pursue aggressive investment in cost reduction, which forces the rival firm to invest less. Due to the low investment cost, such an aggressive investment strategy is easily feasible and credible.

In this scenario, given that the rival firm has chosen nondisclosure, it becomes too costly for a focal firm to adopt the same nondisclosure strategy and engage in intensive investment and price competition. Instead, the focal firm is better off differentiating itself by disclosing its cost information. By doing so, it can soften the competition and preserve its profits. As a result, two asymmetric pure strategies emerge in equilibrium: (disclosure, nondisclosure) and (nondisclosure, disclosure). Given that the two firms are ex-ante identical, symmetric equilibrium is a reasonable solution concept and we select the symmetric mixed strategy equilibrium where both firms adopt a mixed strategy in disclosure.

Secondly, when the investment cost K increases, i.e., $K > \min\{\underline{k}_n^B, \bar{k}_d^B\}$, the equilibrium of (disclosure, disclosure) can always be sustained. This is the case in Parts (2) and (3) of Proposition 1 and Panels (b)-(d) of Figure 3. As the investment cost increases, the strategic substitutability effect in firms' investment decisions weakens, while the strategic complementarity effect in their pricing decisions becomes more prominent. In other words, both firms recognize the benefits of coordinating on high product prices, as it leads to increased profitability in a Bertrand competition scenario. By leveraging the coordination benefit of disclosure – specifically, internalizing the negative complementary pricing effect and adopting a conservative investment strategy – firms can effectively achieve this collusive behavior.

Compared to the scenario when K is low, if the other firm discloses cost information, the focal firm would not deviate by choosing nondisclosure to exploit the strategic substitutability effect. This is due to the fact that the high cost associated with implementing the cost-reduction investment strategy makes it an expensive approach to deter the rival firm's investment through nondisclosure. As a result, the equilibrium of (disclosure, disclosure) can always be sustained.

Thirdly, when K is even higher, i.e., $K > \bar{K}$, as indicated in Part (3) of Proposition 1 and Panel (d) of Figure 3, in addition to (disclosure, disclosure), the equilibrium of (nondisclosure, nondisclosure) can also be sustained. This can be attributed to the further diminished strategic substitutability effect and the strengthened incentive for firms to coordinate on limiting investment and maintaining high product prices.

Recall that a firm can utilize the strategic substitutability effect by choosing nondisclosure. Under nondisclosure, a firm is inclined to engage in aggressive cost-reduction investments and subsequent price cutting, thereby deterring the rival firm's investments. When the investment cost is low (i.e., $K < \bar{K}$), this strategy proves effective in granting the focal firm a comparative advantage. As demonstrated in Panels (a)-(c) of Figure 3, when the rival firm opts for nondisclosure, the focal firm benefits from disclosing to avoid intense head-to-head competition.

However, when K is very high (i.e., $K > \bar{K}$), if the rival firm chooses nondisclosure, it is more advantageous for the focal firm to adopt the same nondisclosure strategy. Instead of using disclosure to scale back its own investment and mitigate inter-firm competition, choosing the same nondisclosure strategy proves more effective in reducing investment. At this point, engaging in head-to-head competition requires both firms to be highly conservative in their cost-reduction investments since the high investment cost can easily erode profits from the product market, particularly considering the aggressive price competition from the rival firm. Therefore, (nondisclosure, nondisclosure) can also be sustained in equilibrium. Given the coexistence of the two equilibria when $K > \bar{K}$, we select (disclosure, disclosure) based on Pareto dominance, following the literature (Fudenberg and Tirole, 1991).

Finally, our numerical analysis reveals that when both firms disclose their cost information, the consumer surplus is lower compared to the scenario where neither firm discloses. Consequently, firms achieve higher profits at the expense of reduced consumer surplus. Moreover, the decrease in consumer surplus outweighs any gains, resulting in lower total surplus under (disclosure, disclosure) compared to (nondisclosure, nondisclosure).

3.2 Cournot Competition

This Section parallels Section 3.1 but we focus on Cournot competition. As in Section 3.1, we first characterize firms' optimal investment choices in the subgame following their disclosure decisions in Section 3.2.1. We then move backward to examine firms' equilibrium disclosure decisions in Section 3.2.2.

3.2.1 Optimal Investment in Cost Reduction

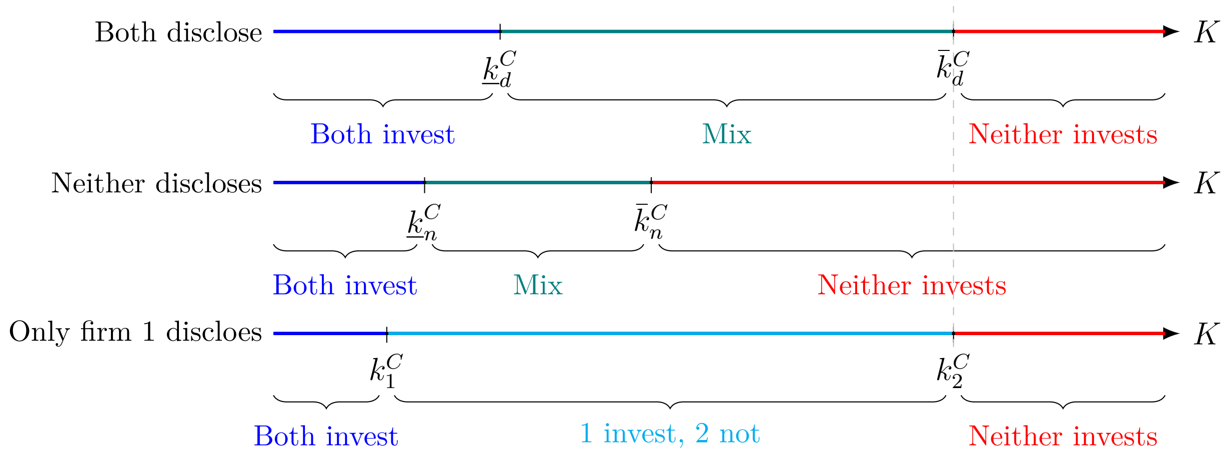
Given firms' disclosure decisions, the following Lemma 2 summarizes their optimal investment choices in the subgame and Figure 4 graphically illustrates it.

Lemma 2 (Investment decisions under Cournot competition). Suppose firms engage in Cournot competition. Define: $\underline{k}_d^C \equiv \frac{4c(2-c-\theta)}{(4-\theta^2)^2}$, $\bar{k}_d^C = k_2^C \equiv \frac{4c(1+(1-c)(1-\theta))}{(4-\theta^2)^2}$, $\underline{k}_n^C \equiv \frac{c}{2+\theta} - \frac{c^2}{4}$, $k_1^C \equiv \frac{c\left(c\left(\theta^2+4\right)+4(\theta-2)\right)}{4(\theta^2-4)}$, $\bar{k}_n^C \equiv \frac{4(4-2c+c\theta)}{4(2+\theta)}$, and it follows that $k_1^C < \underline{k}_n^C < \underline{k}_d^C(\bar{k}_n^C) < \bar{k}_d^C = k_2^C$.

(1) Suppose that both firms disclose their cost information. There exists a unique symmetric equilibrium such that when $K \leq \underline{k}_n^C$, both firms invest; when $K \geq \bar{k}_n^C$, neither firm invests; and when $\underline{k}_n^C < K < \bar{k}_n^C$, each firm invests with probability $a_d^C \in (0,1)$, where $a_d^C = \frac{4c(2-\theta)-4c^2(1-\theta)-K(4-\theta^2)^2}{4c^2\theta}$;

(2) Suppose that neither firm discloses its cost information. There exists a unique symmetric equilibrium such that when $K \leq \underline{k}_d^C$, both firms invest; when $K \geq \bar{k}_n^C$, neither firm invests; and when $\underline{k}_d^C \leq K \leq \bar{k}_n^C$, each firm invests with probability $a_n^C \in (0,1)$, where $a_n^C = \frac{4c-c^2(2-\theta)-4K(2+\theta)}{2c^2\theta}$.

(3) Suppose that only firm 1 discloses its cost information. When $K \leq k_1^C$, both firms invest; and when $k_1^C < K \leq k_2^C$, firm 1 invests whereas firm 2 does not; when $K > k_2^C$, neither firm invests.



This figure plots firms' investment decisions, as characterized in Lemma 2. In addition to the relative position of $\underline{k}_d^C$ and $\bar{k}_n^C$, the relative positions of other thresholds are independent of parameter values; that is, both $\underline{k}_d^C > \bar{k}_n^C$ and $\underline{k}_d^C < \bar{k}_n^C$ are possible.

Figure 4: Investment under Cournot competition

Part (1) of Lemma 2 examines the investment behavior of firms when both firms disclose their cost information. It reveals that if the fixed investment cost is below a low threshold, both firms invest in cost-reduction technology. On the other hand, if the investment cost exceeds a high threshold, neither firm invests in cost reduction. When the investment cost is intermediate, falling between these two thresholds, firms engage in randomized investment behavior, alternating between investment and no investment. A similar pattern emerges in the investment behavior of the two firms when neither firm discloses its cost information, as demonstrated in Part (2) of Lemma 2 and illustrated in Figure 4.

In the case where only one firm discloses its cost information (assuming, without loss of generality, that firm 1 makes the disclosure), Part (3) of Lemma 2 reveals distinct investment strategies for the two firms. When the fixed cost is low, both firms choose to invest in cost reduction, whereas when the fixed cost is high, both firms refrain from investing in cost reduction. Interestingly, when the fixed cost is intermediate, the investment strategies diverge: the disclosing firm invests in cost reduction, while the non-disclosing firm chooses not to invest. This finding stands in stark contrast to the results observed under Bertrand competition, as mentioned in Part (3) of Lemma 1.

Why does the disclosing firm invest more in cost reduction under Cournot competition? As in Section 3.1.1, we calculate the firms' expected profits and decompose their investment incentive. Following a similar procedure, we show that firm i's equilibrium expected profit is:

$$\pi_i(\iota_i) = \frac{1}{4}\big(1 - \theta Q_j - (1 - \iota_i) \cdot c\big)^2 - K \cdot \iota_i, \tag{10}$$

which is the counterpart of equation (5) under Bertrand competition. By applying the chain rule to the expected profit, we can express firm i's investment incentive as follows:

$$\frac{d\pi_i}{d\iota_i} = \underbrace{-K}_{\text{investment cost } (<0)} + \underbrace{\frac{1}{2}\big(1 - \theta Q_j - (1 - \iota_i) \cdot c\big) \cdot c}_{\text{lower marginal cost } (>0)} - \underbrace{\frac{\theta}{2}\big(1 - \theta Q_j - (1 - \iota_i) \cdot c\big)\frac{\partial Q_j}{\partial \iota_i}}_{\substack{\text{disclosure: substitution quantity effect } (>0) \\ \text{nondisclosure: } (=0)}} . \tag{11}$$

Similar to the case of Bertrand competition, as shown in equation (6), the first two terms in equation (11) represent the standard trade-off that a firm faces when considering an investment in cost reduction. These terms capture the effects of increased investment on a firm's marginal cost and the associated costs incurred by the investment. This trade-off exists irrespective of whether a firm's investment is disclosed or not.

The third term in equation (11) represents an additional effect that only arises when the firm discloses its cost-reduction investment. Unlike the negative complementary pricing effect observed in Bertrand competition, this effect in Cournot competition is a positive "substitution quantity effect," resulting from the strategic substitutability inherent in Cournot competition.

Specifically, when firm i invests in cost reduction and discloses this investment, the rival firm, firm j, becomes aware that firm i has a lower marginal cost and can increase its production. In Cournot competition, where firms make simultaneous production decisions with strategic substitutability, firm j responds by reducing its subsequent production level. Consequently, the aggressive investment in cost reduction by firm i creates a competitive advantage by compelling the rival firm to decrease its production.

On the other hand, if firm i remains silent about its cost-reduction investment, the impact of the third term in equation (11) disappears. In this case, the rival firm does not adjust its production based on firm i's actual investment, but rather acts based on its beliefs about firm i's investment, which are fixed at the equilibrium level. As a result, the disclosing firm has a greater incentive to invest more in cost reduction compared to a firm that does not disclose its investment.

Furthermore, similar to the case of Bertrand competition, investments in cost reduction by firms in Cournot competition also exhibit strategic substitutability. Consequently, the disclosing firm's aggressive investment not only compels the rival firm to reduce its production, but also discourages it from making significant investments. This further strengthens the competitive advantage of the disclosing firm. As will be shown in Section 3.2.2, these two factors, namely the strategic substitutability in firms' production and investment decisions, play crucial roles in determining the disclosure strategy for firms.

3.2.2 Optimal Disclosure of Cost Information

We proceed to analyze the equilibrium disclosure decisions of the two firms in Proposition 2. Similar to Section 3.1, we focus on the case where the fixed investment cost falls within an intermediate range (specifically, $k_1^C < K < k_2^C$), as disclosure decisions have no impact on the investment and production games when the fixed cost is either too high or too low. To illustrate the findings, Figure 5 depicts representative patterns of the two firms' expected profits under different disclosure decisions for various values of K given c and θ. The investment notations above each number follow those in Figure 3.

Proposition 2 (Disclosure decisions under Cournot competition). Suppose that firms engage in Cournot competition. When $k_1^C < K < k_2^C$, (disclosure, disclosure) is the unique equilibrium.

Firm 1 \ Firm 2	disclosure	nondisclosure
disclosure	I, I $\underline{0.0089}$, $\underline{0.0089}$	I, NI $\underline{0.126}$, 0.001
nondisclosure	NI, I 0.001, $\underline{0.126}$	Mix, Mix 0.009, 0.009

(a) $K = 0.11$

Firm 1 \ Firm 2	disclosure	nondisclosure
disclosure	Mix, Mix $\underline{0.005}$, $\underline{0.005}$	I, NI $\underline{0.106}$, 0.001
nondisclosure	NI, I 0.001, $\underline{0.106}$	Mix, Mix 0.018, 0.018

(b) $K = 0.13$

Firm 1 \ Firm 2	disclosure	nondisclosure
disclosure	Mix, Mix $\underline{0.011}$, $\underline{0.011}$	I, NI $\underline{0.086}$, 0.001
nondisclosure	NI, I 0.001, $\underline{0.086}$	NI, NI 0.030, 0.030

(c) $K = 0.15$

Firm 1 \ Firm 2	disclosure	nondisclosure
disclosure	Mix, Mix $\underline{0.028}$, $\underline{0.028}$	I, NI $\underline{0.036}$, 0.001
nondisclosure	NI, I 0.001, $\underline{0.036}$	NI, NI 0.030, 0.030

(d) $K = 0.2$

Panels (a)–(d) display the expected profits of the two firms for various values of K under Cournot competition. In each cell, the first (second) number represents the expected profit of firm 1 (2). The underline denotes each firm's best response considering the other firm's disclosure decision. The letter above each number indicates the firm's investment strategy in the subgame following firms' disclosure decisions. Specifically, 'I' denotes investment, 'NI' denotes non-investment, and 'Mix' denotes randomization between investment and non-investment. The other parameters are $c = 0.5$ and $\theta = 0.9$. Under these parameters, the thresholds are $\underline{k}_n^C = k_1^C = 0.110$, $\underline{k}_d^C = 0.118$, $\bar{k}_n^C = 0.149$, and $\bar{k}_d^C = k_2^C = 0.206$.

Figure 5: Endogenous disclosure decisions under Cournot competition

In contrast to Bertrand competition, Proposition 2 and Figure 5 demonstrate that disclosing cost information is always the dominant strategy for each firm in Cournot competition. Consequently, in equilibrium, both firms choose to disclose their cost information. While the equilibrium outcome aligns with the findings of the classic literature (e.g., Gal-Or, 1986), the underlying mechanism differs. The clear preference for disclosure stems from the fact that, under Cournot competition, strategic substitutability characterizes both the firms' investment decisions and production decisions.

More specifically, disclosing cost investments enables a firm to deter not only its rival's investment but also their subsequent production. As discussed in Section 3.2.1, when a firm discloses its investment in cost reduction, the rival firm infers the resulting low marginal cost and expects increased production. Consequently, the rival firm responds by reducing their own production. Additionally, the cost-reduction investment decisions of the two firms exhibit strategic substitutability, as one firm's investment intensifies inter-firm competition, leading the competing firm to be less inclined to invest.

In summary, these two factors indicate that firms consistently seek to establish a competitive advantage through aggressive cost-reduction investments. This strategic effect only materializes when investment behavior is observable to competitors. Therefore, revealing cost information emerges as a dominant strategy for firms, resulting in an equilibrium where both firms choose to disclose their costs.

Corollary 1 (Prisoner's dilemma). Under Cournot competition, the two firms could have achieved higher profits if they had concealed their cost information.

Furthermore, Figure 4 illustrates how the firms' disclosure strategies intensify competition between them, leading to a prisoner's dilemma scenario, as formally stated in Corollary 1. In other words, the firms could have attained higher profits if they had kept their cost information concealed.

However, despite the negative impact on firm profits due to heightened competition, numerical results indicate that consumers benefit from this situation. Both consumer surplus and total surplus are higher in equilibrium compared to the scenario where neither firm discloses their cost information.

4 Implications

Our results have several empirical and policy implications.

First, we show that regardless of the nature of competition, the two firms may voluntarily disclose more cost information, when this cost is endogenously determined by their investment decisions in cost-reduction activities such as innovation and R&D. Therefore, we predict that for industries in which cost-reduction activities are relatively important (e.g., industries in which the profit margin is low, so cost innovation is important), firms will disclose more cost information than they do in industries with which cost-reduction activities are relatively unimportant. For example, firms can choose to voluntarily disclose more information about gross margins, operating leverage, and cost structures in their 10-Ks and 10-Qs (to the extent that the cost structure is within the relevant range, the disclosure of cost structure approximates the disclosure of marginal cost in our setting), and can choose to redact less information (see, e.g., Verrecchia and Weber (2006) and Glaeser (2018) for empirical proxies for information redaction). In particular, our implication is robust to different types of competition, thereby alleviating some of the criticisms in the literature regarding the difficulty of measuring product market competition, e.g., the ambiguity of the relationship between product market competition and the proprietary costs of different disclosure methods (e.g., Leuz, 2004; Lang and Sul, 2014).

Second, while we predict that firms are inclined to voluntarily disclose cost information regardless of the nature of product market competition, the implications for firms' investment decisions in cost-reduction and profits are different. Under Bertrand competition, compared to the (nondisclosure, nondisclosure) scenario, the (disclosure, disclosure) equilibrium is characterized by less investment and higher profits. In contrast, under Cournot competition, the (disclosure, disclosure) equilibrium exhibits more investment and lower profits, compared to (nondisclosure, nondisclosure). We therefore expect to observe a negative association between more disclosure (or less redaction) and cost-reducing investments in a Bertrand industry and a positive association between more disclosure (or less redaction) and firm investments in a Cournot industry. To the extent that it is difficult to determine a priori whether an industry is Cournot or Bertrand, our implications provide a potential solution (see, e.g., Brander and Zhang, 1990). Nevertheless, we acknowledge that empirically distinguishing Courtnot and Bertrand competition is difficult.

Third, we examine the parameter region where disclosure affects firm investment. Specifically, as shown in Lemmas 1 and 2, the two firms' disclosure decisions affect their investment decisions when $k_1 < K < k_3$ under Bertrand competition or when $k_1^C < K < k_2^C$ under Cournot competition. The following corollary shows that when the two firms engage in fiercer competition in the product market, these regions become larger, i.e., disclosure is more likely to affect firm investment, than when firms engage in less-fierce competition. In other words, the implication from the corollary is that a more competitive industry should be associated with stronger association between more disclosure (or less redaction) and cost-cutting investments than a less competitive industry.

Corollary 2 (The region where disclosure matters). When the two firms engage in more intense competition, the region where their disclosure affects firm investment becomes larger. Specifically, the region $k_3 - k_1$ increases with θ under Bertrand competition, and the region $k_2^C - k_1^C$ increases with θ under Cournot competition.

Finally, our results also have implications for whether security regulators such as the SEC should mandate disclosure of such cost improvements. As discussed in the introduction, the Biden administration, concerned about firms sharing information to collude against their workers, is considering ways to prevent such collusive behavior. Our results provide justification for security regulators to make it more costly to disclose such information as firms would have an incentive to do so voluntarily. However, whether no disclosure will benefit consumers and society at large depends on the nature of competition. In the case of Cournot competition, such disclosure results in more competition among firms and actually benefits consumers and society. Therefore, making it more costly for firms under Cournot competition to share such information may hurt the consumers and the society. However, making it more costly for firms under Bertrand competition to share such information will benefit consumers and society.

5 Conclusion

This paper studies firms' disclosure policies regarding cost information when a cost-reduction technology can be implemented to reduce marginal production costs. We find that regardless of the type of competition, i.e., Bertrand or Cournot, firms may disclose their cost information, and this result stands in stark contrast to the literature. Under Bertrand competition, cost disclosure helps firms avoid "overinvestment" in cost reduction, thereby maintaining high product prices and high firm profits. Under Cournot competition, cost disclosure encourages a firm to engage in "overinvestment" such that its competitor is forced to scale back investment and reduce subsequent production, which provides the focal firm a competitive advantage. However, neither firm ultimately gains the advantage, as fiercer competition erodes their profits; that is, the two firms may be trapped in a prisoner's dilemma under Cournot competition.

Perhaps more importantly, in our settings, disclosure mandates have almost no incremental effect because firms will voluntarily disclose their information anyway. However, in the Cournot setting, such disclosure results in a reduction of firms' profits but benefits consumers and society in general. Conversely, the opposite conclusion holds in the Bertrand setting. To the extent that firms' production strategies are complements in the Bertrand setting and substitutes in the Cournot setting, we conjecture that disclosure, which facilitates collusion in the strategic complementarity setting and competition in the strategic substitutability setting, may be generalized to other scenarios featuring strategic complements and substitutes.

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Appendix: Proofs

Proof of Lemma 1

Given different combinations of firms' disclosure policies, we discuss the following three cases to characterize firms' investment decisions under Bertrand competition.

Case 1: When both firms disclose cost information

When both firms disclose their cost information, depending on their respective investment decisions, we have three subgames as follows.

(i) Both firms invest. It immediately follows that both firms set equilibrium prices $p_1 = p_2 = \frac{1}{2-\theta}$ and their profits are $\pi_{1,II} = \pi_{2,II} = \frac{1}{(2-\theta)^2} - K$.

(ii) Neither firm invests. Then firms set prices $p_1 = p_2 = \frac{1+c}{2-\theta}$ and make profits $\pi_{1,NN} = \pi_{2,NN} = \frac{(1-c(1-\theta))^2}{(2-\theta)^2}$.

(iii) Only one firm invests. Without loss of generality, suppose that only firm 1 invests. Then in equilibrium the two firms' prices are $p_1 = \frac{2+\theta(1+c)}{4-\theta^2}$ and $p_2 = \frac{2(1+c)+\theta}{4-\theta^2}$. Their profits are $\pi_{1,IN} = \frac{(2+\theta(1+c))^2}{(4-\theta^2)^2} - K$ and $\pi_{2,IN} = \frac{(2+\theta-c(2-\theta^2))^2}{(4-\theta^2)^2}$.

Therefore, when $\pi_{1,II} \geq \pi_{1,NI}$ and $\pi_{1,IN} \geq \pi_{1,NN}$, or equivalently, $K \leq \underline{k}_d^B$, where $\underline{k}_d^B \equiv \frac{c(2-\theta^2)(2(2+\theta)-c(2-\theta^2))}{(4-\theta^2)^2}$, to invest is the dominant strategy for both firms and thus in equilibrium both firms invest. Alternatively, when $\pi_{1,II} \leq \pi_{1,NI}$ and $\pi_{1,IN} \leq \pi_{1,NN}$, or equivalently, $K \geq \bar{k}_d^B$, where $\bar{k}_d^B \equiv \frac{c(2-\theta^2)(2(2+\theta)-c(2-\theta(2+\theta)))}{(4-\theta^2)^2}$, not to invest is the dominant strategy for both firms and thus in equilibrium neither firm invests. Finally, when $\underline{k}_d^B < K < \bar{k}_d^B$, the two firms must adopt a mixed strategy in investment. Suppose that firm 2 invests with probability a. Then, for firm 1, if it invests, the profit is $\pi_{1,I} = a\pi_{1,II} + (1-a)\pi_{1,IN}$, whereas if it does not invest, its profit is $\pi_{1,N} = a\pi_{1,NI} + (1-a)\pi_{1,NN}$. In equilibrium, we must have $\pi_{1,I} = \pi_{1,N}$, and solving this equation yields a_d^B in Part (1) of the lemma.

Case 2: When neither firm discloses cost information

Again, we consider symmetric equilibrium. Let p_i^H and p_i^L denote firm i's price when its cost is high ($c_i = c$) or low ($c_i = 0$), where $i \in \{1, 2\}$. Suppose that firm 2 invests with probability a. Then, the expected demand for firm 1 is $D_1 = 1 - p_1 + \theta(ap_2^L + (1-a)p_2^H)$. If firm 1 invests, its profit is $\pi_{1,I} = \max_{p_1} D_1 p_1 - K$, which yields $p_1^L = \frac{1+\theta(ap_2^L+(1-a)p_2^H)}{2}$. Alternatively, if firm 1 does not invest, its profit will be $\pi_{1,NI} = \max_{p_1} D_1(p_1 - c)$, which yields $p_1^H = \frac{1+c+\theta(ap_2^L+(1-a)p_2^H)}{2}$. There are three possible equilibria:

(i) Both firms invest. In this equilibrium we must have $p_1^L = p_2^L$, $a = 1$, and $\pi_{1,I} \geq \pi_{1,NI}$. Combined with the expressions of p_1^L and p_1^H, we know that the equilibrium can be sustained when $K \leq \underline{k}_n^B$, where $\underline{k}_n^B \equiv \frac{c}{2-\theta} - \frac{c^2}{4}$. Firms' equilibrium profits are $\pi_{1,II} = \pi_{2,II} = \frac{1}{(2-\theta)^2} - K$.

(ii) Neither firm invests. In this equilibrium we must have $p_1^H = p_2^H$, $a = 0$, and $\pi_{1,I} \leq \pi_{1,NI}$. Combined with the expressions of p_1^L and p_1^H, we know that the equilibrium can be sustained when $K \geq \bar{k}_n^B$, where $\bar{k}_n^B \equiv \frac{c(1+c)}{2-\theta} - \frac{3c^2}{4}$. Firms' equilibrium profits are $\pi_{1,NN} = \pi_{2,NN} = \frac{(1-c(1-\theta))^2}{(2-\theta)^2}$.

(iii) Both firms randomize between investing and not. In this equilibrium we must have $p_1^H = p_2^H$, $p_1^L = p_2^L$, and $\pi_{1,I} = \pi_{1,NI}$. Combined with the expressions of p_1^L and p_1^H, we can solve the mixed strategy a_n^B as given in Part (2) of the lemma. We also confirm that when $\underline{k}_n^B < K < \bar{k}_n^B$, we must have $a_n^B \in (0, 1)$. Firms' equilibrium profits are $\pi_{1,mix} = \pi_{2,mix} = \frac{(c^2-4K)^2}{16c^2}$.

Case 3: When only one firm discloses cost information

Without loss of generality, let's assume that firm 1 discloses its cost information while firm 2 withholds it. Based on equation (6), we can infer that, compared to the silent firm, the disclosing firm has a (weakly) lower incentive to invest. Therefore, when multiple equilibria exist in the subgame, we choose the one where the nondisclosing firm exhibits higher investment.

(1) Both firms invest. In equilibrium, prices set by the two firms are $p_1 = p_2 = \frac{1}{2-\theta}$ and their profits are $\pi_1 = \pi_2 = \frac{1}{(2-\theta)^2} - K$. We then check if the two firms will deviate. First, given firm 1's belief about firm 2's investment, if firm 1 deviates to not investing, this deviation will be detected by firm 2 and firm 2 will adjust its pricing strategy. Based on Case 1.(iii), from the deviation firm 1 makes profits $\pi_{1,\text{deviate}} = \frac{(2+\theta-c(2-\theta^2))^2}{(4-\theta^2)^2}$. Thus firm 1 won't deviate when $\pi_1 \geq \pi_{1,\text{deviate}}$, which is equivalent to $K \leq k_1$, where $k_1 = \underline{k}_d^B \equiv \frac{c(2-\theta^2)(2(2+\theta)-c(2-\theta^2))}{(4-\theta^2)^2}$.

Second, given firm 1's investment strategy, if firm 2 deviates to not investing, it solves $\max_{p_2}(p_2 - c)(1 - p_2 + \theta p_1)$, where firm 1's price is fixed at $p_1 = \frac{1}{2-\theta}$ because firm 1 cannot observe firm 2's deviation and thus maintains its equilibrium price. Solving this problem we can derive firm 2's profits from deviation as $\pi_{2,\text{deviate}} = \frac{(2-c(2-\theta))^2}{4(2-\theta)^2}$. Thus, firm 2 will not deviate when $\pi_2 \geq \pi_{2,\text{deviate}}$, which must hold when $K \leq k_1$. Therefore, the conjectured equilibrium can be sustained when $K \leq k_1$.

(2) Firm 1 does not invest and firm 2 invests. Based on Case 1.(iii) we know that in equilibrium the two firms' prices are $p_1 = \frac{2(1+c)+\theta}{4-\theta^2}$ and $p_2 = \frac{2+\theta(1+c)}{4-\theta^2}$. Their profits are $\pi_1 = \frac{(2+\theta-c(2-\theta^2))^2}{(4-\theta^2)^2}$ and $\pi_2 = \frac{(2+\theta(1+c))^2}{(4-\theta^2)^2} - K$. We then check the two firms' possible deviation. First, if firm 1 deviates to investing, firm 2 will adjust its pricing strategy accordingly, and firm 1 makes profits $\pi_{1,\text{deviate}} = \frac{1}{(2-\theta)^2} - K$. As discussed in (1), when $K > k_1$, firm 1 will not deviate to investing. Second, if firm 2 deviates to not investing, without observing the deviation firm 1 will maintain its equilibrium price, and firm 2 makes profits $\pi_{2,\text{deviate}} = \frac{\left(2(2+\theta)+c(\theta^2+2\theta-4)\right)^2}{4(4-\theta^2)^2}$. Solving $\pi_2 \geq \pi_{2,\text{deviate}}$ yields $K \leq k_2$, where $k_2 \equiv \frac{c\left(4(2+\theta)+c(\theta^2+4\theta-4)\right)}{4(4-\theta^2)}$. Straightforward comparison yields $k_2 > k_1$. Therefore, when $k_1 < K \leq k_2$, the conjectured equilibrium can be sustained.

(3) Firm 1 does not invest whereas firm 2 mixes. Then firm 1 maximizes profit $\pi_{1,NI} = \max_{p_1}(p_1 - c)(1 - p_1 + \theta E[p_2])$, which yields $\hat{p}_1 = \frac{1+c+\theta E[p_2]}{2}$. For firm 2, if it does invest, it max-

imizes $\pi_{2,I} = p_2(1 - p_2 + \theta\hat{p}_1) - K$ and its optimal price is $p_{2,I} = \frac{2+\theta+c\theta+\theta^2 E[p_2]}{4}$; if it does not invest, it maximizes $\pi_{2,NI} = (p_2 - c)(1 - p_2 + \theta\hat{p}_1)$, which yields its optimal price as $p_{2,NI} = \frac{2+\theta+c(2+\theta+\theta^2 E[p_2])}{4}$. Combined with $E[p_2] = ap_{2,I} + (1-a)p_{2,NI}$, we can derive $p_{2,I} = \frac{4+2(1+c)\theta+c\theta^2(1-a)}{2(4-\theta^2)}$ and $p_{2,NI} = \frac{2(1+c)(\theta+2)-ca\theta^2}{2(4-\theta^2)}$. Inserting $p_{2,I}$ and $p_{2,NI}$ into firm 2's profit function and letting $\pi_{2,I} = \pi_{2,NI}$ yields the mixed strategy $a = \frac{(2+\theta)\left(4c-c^2(2-3\theta)-4(2-\theta)K\right)}{2c^2\theta^2}$. Only when $k_2 < K < k_3$, where $k_3 = \bar{k}_n^B \equiv \frac{c(1+c)}{2-\theta} - \frac{3c^2}{4}$, can firm 2's mixed strategy be sustained. In equilibrium, firms set prices $p_1 = \frac{c^2-2c+4K}{2c\theta}$, $p_{2,I} = \frac{c}{4} + \frac{K}{c}$, and $p_{2,NI} = \frac{K}{c} + \frac{3c}{4}$. The profits are $\pi_1 = \frac{\left(2c-c^2(1-2\theta)-4K\right)^2}{4c^2\theta^2}$ and $\pi_2 = \frac{(c^2-4K)^2}{16c^2}$. Again, we check if the two firms will deviate. First, firm 2 will not deviate because given firm 1's investment strategy, firm 2 has been indifferent between investing and not. So we only consider firm 1's possible deviation given its belief about firm 2's mixed investment strategy. If firm 1 deviates to investing, when firm 2 invests, firm 1 makes profits $\pi_{1I,\text{deviate}} = \frac{1}{(2-\theta)^2} - K$, whereas when firm 2 does not invest, firm 1 makes profits $\pi_{1NI,\text{deviate}} = \frac{(2+\theta(1+c))^2}{(4-\theta^2)^2} - K$. Given firm 1's belief about firm 2's equilibrium investment strategy a, its expected profit from deviation is $\pi_{1,\text{deviate}} = a\pi_{1I,\text{deviate}} + (1-a)\pi_{1NI,\text{deviate}}$. We can check that for $k_2 < K < k_3$, $\pi_1 \geq \pi_{1,\text{deviate}}$ always holds. Therefore, the conjectured equilibrium can be sustained when $k_2 < K < k_3$.

(4) Neither firm invests. Based on Case 1.(ii), in equilibrium the two firms set prices $p_1 = p_2 = \frac{1+c}{2-\theta}$ and their profits are $\pi_1 = \pi_2 = \frac{(1-c(1-\theta))^2}{(2-\theta)^2}$. Then, if firm 1 deviates to investing, based on Case 1.(iii), it makes profits $\pi_{1,\text{deviate}} = \frac{(2+\theta(1+c))^2}{(4-\theta^2)^2} - K$. Solving $\pi_1 \geq \pi_{1,\text{deviate}}$ yields $K \geq \bar{k}_d^B$. For firm 2, if it deviates to investing, we can derive that it makes profits $\pi_{2,\text{deviate}} = \frac{(2+c\theta)^2}{4(2-\theta)^2} - K$. Thus firm 2 will not deviate when $\pi_2 \geq \pi_{2,\text{deviate}}$, which always holds when $K \geq \bar{k}_d^B$. Therefore, when $\bar{k}_d^B < K < k_3$, the conjectured equilibrium can co-exist with equilibrium 3.(2) and 3.(3), we select the one that features less investment for the disclosing firm. Consequently, the conjectured equilibrium can be sustained when $K > k_3$.

To sum up, under Bertrand competition, the equilibrium when only firm 1 discloses cost information is as follows (note that $k_1 = \underline{k}_d^B$, $k_3 = \bar{k}_n^B$, $k_2 > \bar{k}_d^B$, and $k_2 > \underline{k}_n^B$): (a) When $K \leq k_1$, both firms invest; (b) when $k_1 < K \leq k_2$, firm 1 does not invest but firm 2 invests; (c) when $k_2 < K < k_3$, firm 1 does not invest whereas firm 2 mixes; and (d) when $K \geq k_3$, neither firm invests.

Proof of Proposition 1

Comparing the three cases in Lemma 1, we know that when the investment cost is too low (i.e., $K < k_1$), both firms invest in the cost-reduction technology regardless of the disclosure decisions. Similarly, both firms refrain from investment when the investment cost is too high, i.e., $K > k_3$. We thus focus on the more interesting case in which $k_1 < K < k_3$.

(1) Suppose that $k_1 < K < \min\{\underline{k}_n^B, \bar{k}_n^B\}$. Since $\pi_{1,NI}^{DN} > \pi_{1,II}^{NN}$, (nondisclosure, nondisclosure) can not be sustained in equilibrium, where the superscript indicates the firms' disclosure decisions and the subscript indicates the two firms' investment decisions (for instance, $\pi_{1,NI}^{DN}$ means firm 1's expected profit when only firm 1 discloses cost information, whereas firm 1 does not invest but firm 2 invests). Furthermore, when $K < \min\{\underline{k}_n^B, \bar{k}_n^B\}$, we can show that $\pi_{1,mix}^{DD} < \pi_{1,IN}^{ND}$. Therefore, (disclosure, nondisclosure) and (nondisclosure, disclosure) coexist in equilibrium.

(2) Suppose that $\min\{\underline{k}_n^B, \bar{k}_d^B\} < K < \max\{\underline{k}_n^B, \bar{k}_d^B\}$. If $\underline{k}_n^B < K < \bar{k}_d^B$, since $\pi_{1,mix}^{DD} > \pi_{1,IN}^{ND}$ and $\pi_{1,NI}^{DN} > \pi_{1,mix}^{NN}$, to disclose is the dominant strategy for firm 1 (and similar for firm 2). Thus, (disclosure, disclosure) is the unique equilibrium. In contrast, if $\bar{k}_n^B < K < \underline{k}_n^B$, because $\pi_{1,NN}^{DD} > \pi_{1,IN}^{ND}$ and $\pi_{1,NI}^{DN} > \pi_{1,II}^{NN}$, to disclose is again a dominant strategy and hence (disclosure, disclosure) is the unique equilibrium.

(3) Suppose that $\max\{\underline{k}_n^B, \bar{k}_d^B\} < K < k_2$. Since $\pi_{1,NN}^{DD} > \pi_{1,IN}^{ND}$, (disclosure, disclosure) can be sustained as an equilibrium. Furthermore, $\pi_{1,NI}^{DN} - \pi_{1,mix}^{NN} = \frac{\left(c\left(\theta^2-2\right)+\theta+2\right)^2}{\left(\theta^2-4\right)^2} - \frac{\left(c^2-4K\right)^2}{16c^2}$, which is a decreasing function of K when $\max\{\underline{k}_n^B, \bar{k}_d^B\} < K < k_2$. Define $\bar{K} = \frac{c\left(3c\theta^2-4c+4\theta+8\right)}{4(4-\theta^2)}$. We can show that when $\max\{\underline{k}_n^B, \bar{k}_d^B\} < K < \bar{K}$, $\pi_{1,NI}^{DN} > \pi_{1,mix}^{NN}$;

that is, to disclose is the dominant strategy and thus (disclosure, disclosure) is the unique equilibrium. When $\bar{K} < K < k_2$, $\pi^{DN}_{1,NI} < \pi^{NN}_{1,mix}$. So there co-exist two equilibria: (disclosure, disclosure) and (nondisclosure, nondisclosure).

(4) Suppose that $k_2 < K < k_3$. Since $\pi^{DD}_{1,NN} > \pi^{ND}_{1,mix\ N}$ and $\pi^{NN}_{1,mix} > \pi^{DN}_{1,N\ mix}$, there coexist two equilibria: (disclosure, disclosure) and (nondisclosure, nondisclosure).

Proof of Lemma 2

As in the proof of Lemma 1, we discuss three cases to characterize firms' equilibrium investment decisions under Cournot competition.

Case 1: When both firms disclose cost information

When both firms disclose their cost information, depending on their respective investment decisions, we have three subgames and consider them as follows.

(i) Both firms invest. It immediately follows that both firms produce $Q_1 = Q_2 = \frac{1}{2+\theta}$ and firms' equilibrium profits are $\pi_{1,II} = \pi_{2,II} = \frac{1}{(2+\theta)^2} - K$.

(ii) Neither firm invests. Then firms produce $Q_1 = Q_2 = \frac{1-c}{2+\theta}$ and make profits $\pi_{1,NN} = \pi_{2,NN} = \frac{(1-c)^2}{(2+\theta)^2}$.

(iii) Only one firm invests. Without loss of generality, suppose that only firm 1 invests. Then in equilibrium the two firms produce $Q_1 = \frac{2-\theta(1-c)}{4-\theta^2}$ and $Q_2 = \frac{2(1-c)-\theta}{4-\theta^2}$. Their profits are $\pi_{1,IN} = \frac{(2+\theta(1-c))^2}{(4-\theta^2)^2} - K$ and $\pi_{2,IN} = \frac{(2(1-c)-\theta)^2}{(4-\theta^2)^2}$.

Therefore, we have the following results: (a) When $K \leq \underline{k}^C_d$, both firms invest, where $\underline{k}^C_d \equiv \frac{4c(2-c-\theta)}{(4-\theta^2)^2}$; (b) when $K \geq \bar{k}^C_d$, neither firm invests, where $\bar{k}^C_d \equiv \frac{4c(2-\theta-c(1-\theta))}{(4-\theta^2)^2}$; (c) when $\underline{k}^C_d < K < \bar{k}^C_d$, firms randomize between investing and not investing with probability a^C_d, where a^C_d is given in Part (1) of the lemma.

Case 2: When neither firm discloses cost information

Again, we consider symmetric equilibrium. Let Q_i^L and Q_i^H denote firm i's production when its cost is high ($c_i = c$) or low ($c_i = 0$), where $i \in \{1, 2\}$. Suppose that firm 2 invests with probability a. Then, the expected price for firm 1's product is $p_1 = 1 - Q_1 + \theta(aQ_2^H + (1-a)Q_2^L)$. If firm 1 invests, its profit is $\pi_{1,I} = \max_{Q_1} Q_1 p_1 - K$, which yields $Q_1^H = \frac{1+\theta(aQ_2^H+(1-a)Q_2^L)}{2}$. Alternatively, if firm 1 does not invest, its profit will be $\pi_{1,NI} = \max_{Q_1} Q_1(p_1 - c)$, which yields $Q_1^L = \frac{1-c+\theta(aQ_2^H+(1-a)Q_2^L)}{2}$. There are three possible equilibria:

(i) Both firms invest. This equilibrium can be sustained when $K \leq \underline{k}_n^C$, where $\underline{k}_n^C \equiv \frac{c}{2+\theta} - \frac{c^2}{4}$. Firms' equilibrium profits are $\pi_{1,II} = \pi_{2,II} = \frac{1}{(2+\theta)^2} - K$.

(ii) Neither firm invests. This equilibrium can be sustained when $K \geq \bar{k}_n^C$, where $\bar{k}_n^C \equiv \frac{c(4-c(2-\theta))}{4(2+\theta)}$. Firms' equilibrium profits are $\pi_{1,NN} = \pi_{2,NN} = \frac{(1-c)^2}{(2+\theta)^2}$.

(iii) Both firms randomize between investing and not investing. This equilibrium can be sustained when $\underline{k}_n^C < K < \bar{k}_n^C$ and firms' equilibrium profits are $\pi_1 = \pi_2 = \frac{(c^2-4K)^2}{16c^2}$.

Case 3: When only one firm discloses cost information

We assume without loss of generality that firm 1 discloses its cost information. Based on equation (11), we learn that relative to the silent firm, the disclosing firm has a weakly stronger incentive to invest. Thus, when multiple equilibria exist in the subgame, we choose the one in which the nondisclosing firm exhibits lower investment.

(1) <u>Both firms invest</u>. In equilibrium, the two firms produce $Q_1 = Q_2 = \frac{1}{2+\theta}$ and their profits are $\pi_1 = \pi_2 = \frac{1}{(2+\theta)^2} - K$. We then check if the two firms will deviate. First, given firm 1's belief about firm 2's investment, if firm 1 deviates to not investing, this deviation will be detected by firm 2 and firm 2 will adjust its production strategy accordingly. Based on Case 1.(iii), from the deviation firm 1 makes profits $\pi_{1,\text{deviate}} = \frac{(2(1-c)-\theta)^2}{(4-\theta^2)^2}$. Thus firm 1 won't deviate when $\pi_1 \geq \pi_{1,\text{deviate}}$, which is equivalent to $K \leq \frac{4c(2-c-\theta)}{(4-\theta^2)^2}$.

Second, given firm 1's investment strategy, if firm 2 deviates to not investing, it solves $\max_{Q_2} Q_2(1 - Q_2 - \theta Q_1 - c)$, where $Q_1 = \frac{1}{2+\theta}$ because firm 1 cannot observe firm 2's deviation and thus keeps the equilibrium production intact. Solving this problem we can derive firm 2's profits from deviation as $\pi_{2,\text{deviate}} = \frac{(2-c(2+\theta))^2}{4(2+\theta)^2}$. Thus, firm 2 will not deviate when $\pi_2 \geq \pi_{2,\text{deviate}}$, which must hold when $K \leq k_0^C$, where $k_0^C = \underline{k}_n^C \equiv \frac{c}{2+\theta} - \frac{c^2}{4}$. We further show that $k_0^C < \frac{4c(2-c-\theta)}{(4-\theta^2)^2}$, where the inequality follows because $\theta \in (0,1)$ and as shown in Case 1.(iii), for $Q_2 > 0$ we need $c < 1 - \frac{\theta}{2}$. Therefore, the conjectured equilibrium can be sustained when $K \leq k_0^C$.

(2) Firm 1 invests and firm 2 does not invest. In equilibrium, the two firms produce $Q_1 = \frac{2-\theta(1-c)}{4-\theta^2}$ and $Q_2 = \frac{2(1-c)-\theta}{4-\theta^2}$, and their profits are $\pi_1 = \frac{(2+\theta(1-c))^2}{(4-\theta^2)^2} - K$ and $\pi_2 = \frac{(2(1-c)-\theta)^2}{(4-\theta^2)^2}$. As usual, we consider the two firms' possible deviations. First, if firm 1 deviates to not investing, based on Case 1.(ii), it makes profits $\pi_{1,\text{deviate}} = \frac{(1-c)^2}{(2+\theta)^2}$. Solving $\pi_1 \geq \pi_{1,\text{deviate}}$ yields $K \leq k_2^C$, where $k_2^C = \bar{k}_d^C \equiv \frac{4c(2-\theta-c(1-\theta))}{(4-\theta^2)^2}$.

Second, if firm 2 deviates to investing, since this deviation cannot be detected by firm 1, firm 2 makes profits $\pi_{2,\text{deviate}} = \frac{2-\theta-c\theta^2}{(2+\theta)^2(2-\theta)} - K$. Thus firm 2 will not deviate when $\pi_2 \geq \pi_{2,\text{deviate}}$, which is equivalent to $K \geq k_1^C \equiv \frac{c\left(4(2-\theta)-c(4+\theta^2)\right)}{4(4-\theta^2)^2}$. Note that $k_1^C < k_0^C < k_2^C$. Therefore, when $k_1^C < K < k_0^C$, the conjectured equilibrium coexist with (Invest, Invest) and we select the one that features lower investment for the nondisclosing firm. Thus, when $k_1^C \leq K \leq k_2^C$, the conjectured equilibrium can be sustained.

(3) Neither firm invests. In equilibrium, the two firms produce $Q_1 = Q_2 = \frac{1-c}{2+\theta}$ and make profits $\pi_1 = \pi_2 = \frac{(1-c)^2}{(2+\theta)^2}$. If firm 1 deviates to investing, it can make profits $\pi_{1,\text{deviate}} = \frac{(2+\theta(1-c))^2}{(4-\theta^2)^2} - K$. Solving $\pi_1 \geq \pi_{1,\text{deviate}}$ yields $K \geq k_2^C$. Next, if firm 2 deviates to investing, it can make profits $\pi_{2,\text{deviate}} = \frac{(2+c\theta)^2}{4(2+\theta)^2} - K$. And we can check that firm 2 will not deviate only if $\pi_2 \geq \pi_{2,\text{deviate}}$, which must hold if $K \geq k_2^C$. Therefore, the conjectured equilibrium can be sustained when $K \geq k_2^C$.

To sum up, under Cournot competition, the equilibrium when only firm 1 discloses cost information is as follows: (a) when $K \leq k_1^C$, both firms invest; (b) when $k_1^C < K \leq k_2^C$, firm 1 invests whereas firm 2 does not; and (c) when $K > k_2^C$, neither firm invests.

Proof of Proposition 2

As in the Bertrand economy, we focus on the more interesting case in which $k_1^C < K < k_2^C$.

(1) Suppose that $k_1^C < K < \underline{k}_n^C$. Since $\pi_{1,II}^{DD} > \pi_{1,NI}^{ND}$ and $\pi_{1,IN}^{DN} > \pi_{1,II}^{NN}$, to disclose is the dominant strategy for firms. So, (disclosure, disclosure) is the unique equilibrium.

(2) Suppose that $\underline{k}_n^C < K < \min\{\underline{k}_d^C, \bar{k}_n^C\}$. Since $\pi_{1,II}^{DD} > \pi_{1,NI}^{ND}$ and $\pi_{1,IN}^{DN} > \pi_{1,mix}^{NN}$, to disclose is the dominant strategy. Thus, (disclosure, disclosure) is the unique equilibrium.

(3) If $\underline{k}_d^C < \bar{k}_n^C$, suppose that $\underline{k}_d^C < K < \bar{k}_n^C$. Since $\pi_{1,mix}^{DD} > \pi_{1,NI}^{ND}$ and $\pi_{1,IN}^{DN} > \pi_{1,mix}^{NN}$, (disclosure, disclosure) is the unique equilibrium. If $\underline{k}_d^C > \bar{k}_n^C$, suppose that $\bar{k}_n^C < K < \underline{k}_d^C$. It is straightforward that $\pi_{1,II}^{DD} > \pi_{1,NI}^{ND}$ and $\pi_{1,IN}^{DN} > \pi_{1,NN}^{NN}$. So, again, (disclosure, disclosure) is the unique equilibrium.

(4) Suppose that $\max\{\underline{k}_d^C, \bar{k}_n^C\} < K < k_2^C$. Since $\pi_{1,mix}^{DD} > \pi_{1,NI}^{ND}$ and $\pi_{1,IN}^{DN} > \pi_{1,NN}^{NN}$, to disclose is the dominant strategy. Thus, (disclosure, disclosure) is the unique equilibrium.

Overall, (disclosure, disclosure) is the unique equilibrium.

Proof of Corollary 1

To demonstrate the prisoner's dilemma, we must establish that the two firms achieve higher profits when they conceal their cost information compared to when they disclose it. As discussed in Section 3.2.1, the investments made by the two firms in Cournot competition are strategic substitutes, meaning that one firm's aggressive investment will diminish the rival firm's profit. Consequently, the proof hinges on demonstrating that the likelihood of investment is higher when both firms disclose cost information than when both firms conceal it. Denote the investment likelihood when both disclose information as a_d and that when neither discloses information as a_n. We here show that $a_d > a_n$ when $\underline{k}_n^C < K < \bar{k}_d^C$.

(1) Suppose $\underline{k}_n^C < K < \min\{\underline{k}_d^C, \bar{k}_n^C\}$. Then, $a_d = 1$ and $0 < a_n < 1$.

(2) Suppose $\min\{\underline{k}_d^C, \bar{k}_n^C\} < K < \max\{\underline{k}_d^C, \bar{k}_n^C\}$. If $\underline{k}_d^C > \bar{k}_n^C$, then $a_d = 1$ and $a_n = 0$. If $\underline{k}_d^C < \bar{k}_n^C$, then based on Lemma 2,

$$a_d - a_n = \frac{2c^2 - 4c + (-\theta^3 + 8\theta + 8)\,K}{4c^2} > \frac{\theta\,(c\,(\theta^2 - 8) - 4\theta + 8)}{2c(\theta - 2)^2(\theta + 2)} > \frac{2\theta}{c\,(4 - \theta^2)} > 0,$$

where the first inequality follows $K > \underline{k}_d^C$ and the second inequality follows $c > 0$.

(3) Suppose $\max\{\underline{k}_d^C, \bar{k}_n^C\} < K < \bar{k}_d^C$. Then, $0 < a_d < 1$ and $a_n = 0$.

Overall, we show that $a_d > a_n$.

Proof of Corollary 2

Based on Lemma 1, $\frac{\partial(k_3 - k_1)}{\partial\theta} = \frac{c\left(c\left(-\theta^4 + 4\theta^3 + 16\right) + \theta\left(\theta^3 + 4\theta^2 + 12\theta + 16\right)\right)}{(4-\theta^2)^3} > 0$. Based on Lemma 2, $\frac{\partial(k_2^C - k_1^C)}{\partial\theta} = \frac{c\left(\theta\left(\theta^3 - 4\theta^2 + 12\theta - 16\right) - 4c\left(3\theta^2 - 4\theta + 4\right)\right)}{(4-\theta^2)^3} > 0$.