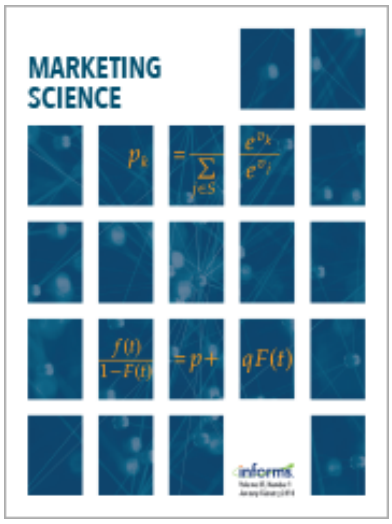

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Voluntary Quality Disclosure and Market Interaction

Liang Guo, Ying Zhao
Department of Marketing, Hong Kong University of Science and Technology,
Clear Water Bay, Kowloon, Hong Kong, China
{mkguo@ust.hk, mkyzhao@ust.hk}

Marketers disclose quality information directly to potential consumers using a variety of communication channels. This study investigates how competition may influence duopoly firms' incentive to voluntarily reveal quality information. We show that firms in competitive markets reveal less information than a monopoly firm. In addition, sequential disclosure leads to asymmetric equilibrium disclosure behavior: the disclosure leader reveals unambiguously less information than in the simultaneous disclosure case, whereas the follower ex ante reveals less (more) private information than that released by the leader or by the firms in the simultaneous case when the disclosure cost is sufficiently low (high). We also examine the equilibrium firm profits and social welfare. We demonstrate that there may be a *U-shaped* relationship between equilibrium monopoly profits (or social welfare under both monopoly and duopoly) and the disclosure cost. Moreover, in comparison to the simultaneous disclosure case, sequential disclosure can lead to increasingly softened competition, improving both firm profitability and social welfare.

Key words: communication; competition; disclosure; information transmission; quality
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1. Introduction

In many markets, sellers typically have better access to information about product quality than prospective buyers. Firms in a wide range of industries (e.g., automobiles, electronic devices, equipments, packaged goods, software, etc.) routinely invest significant resources to test the quality of new products in laboratory or field experiments. The increasing sophistication of marketing research instruments and accredited testing experts (e.g., IncoTest) has also substantially improved the scope and accuracy of quality information available to firms. On the other hand, potential buyers normally lack the resources and expertise to obtain reliable quality information. A remarkable consequence of such information asymmetry is that the buyers' willingness to pay (WTP) may be significantly undermined, probably leading to market failure (Akerlof 1970). To solve this problem, marketers disclose quality information directly to potential buyers using a variety of communication vehicles.[1] For example, retailers and cosmetics firms distribute sample products for free trial, software and electronics companies demonstrate new developments, fashion designers and PC manufacturers set up showrooms and regularly send catalogs to feature new products, and cinemas preview upcoming movies. Most firms also advertise their products through media such as newspapers and television. Third-party product reviews (e.g., *Consumer Reports*) based on independent laboratory tests or expert evaluations can be used to reveal product information to uninformed customers (Shaffer and Zettelmeyer 2002, Chen and Xie 2005). Moreover, the ubiquity of the Internet has significantly enhanced the scope and credibility of seller information disclosure (Chen and Xie 2008). Currently, many online retailers such as Amazon provide not only detailed product information, but also millions of consumer product reviews on their websites. Consumers can also share their usage experiences by posting reviews at independent third-party institutions' websites (e.g., epinions.com and consumerreview.com) in many product categories such as apparel, books, games, videos, and music. Online forums that support consumer-posted reviews represent a credible mechanism for sellers to provide truthful product information (Chen et al. 2003).

A large body of literature examines monopolistic sellers' incentives to voluntarily disclose verifiable quality information. For example, Jovanovic (1982) shows that, if disclosure is costly, favorable information would be disclosed while unfavorable information will be partially withheld. This is because a seller with a relatively high-quality product wants to reveal that information to distinguish itself from sellers of

[1] One of the main functions of marketing is to communicate product information to consumers (Anderson and Rubin 1986). See also Wernerfelt (1996) on the costs and benefits of various marketing communication channels.

lower-quality products.[2] However, there remain two under-researched issues, which we address in this paper. First, it is not clear how competition may influence sellers' incentive to disclose quality information. Would competing sellers voluntarily disclose more or less information than a monopolistic seller? Answering this question can shed light on an incumbent firm's optimal disclosure strategy in defending its business that is threatened by competitive entry (Hauser and Shugan 1983, Kalra et al. 1998). Moreover, how would competing sellers' quality disclosure strategy differ when they make their disclosure decisions simultaneously versus sequentially? This investigation may provide insight on how the order of entry may differentially influence first-moving versus later-moving entrants' disclosure strategies (Tyagi 2000).

Second, the payoff implications of voluntary quality disclosure have not been adequately studied. For example, how would the sellers' equilibrium ex ante payoffs and social welfare vary with disclosure costs and timing? Understanding the sellers' ex ante profits under voluntary quality disclosure can be important because it sheds light on the profitability of investing resources to acquire private information on quality (e.g., through product testing and/or marketing research). In addition, to the extent that later entrants can flexibly adjust information disclosure in response to those of earlier entrants, one can gain new insights on first-mover and later-mover advantages (Kerin et al. 1992, Golder and Tellis 1993). Moreover, policy makers and regulators can benefit from a better understanding of the impact of disclosure cost and disclosure timing on social welfare.

To tackle these important issues, we focus on how competition may influence equilibrium disclosure behavior, seller ex ante profits, and social welfare under voluntary quality disclosure. Following Jovanovic (1982), in the basic model we consider the disclosure behavior of two sellers who are involved in a Bertrand-style price competition. The sellers' product quality is privately and independently drawn from an identical uniform distribution. The sellers can, with a disclosure cost, credibly and truthfully disclose private quality information to a potential buyer. Both simultaneous and sequential disclosure are investigated. The buyer is rational and can make inferences about the sellers' expected quality from the sellers' strategic disclosure/withholding behavior.

In the case of simultaneous disclosure, we find that less information is revealed in equilibrium than that in the monopolistic case. This is a very interesting result because, by comparison to the single seller case, information revelation is an effective mechanism for a seller to achieve ex post quality advantage over the rival. This counterintuitive result arises because competition restricts the sellers' ability to extract surplus from the buyer, undermining their expected payoff, and hence their incentive of revealing information. We also find that sequential disclosure leads to asymmetric equilibrium disclosure behavior across the sellers. Because the disclosure follower can adjust his disclosure behavior in response to that of the disclosure leader, all else being equal, it is more likely that the follower will reveal private information when the leader remains silent than when the leader discloses. This increases the ex post differentiation and thus mitigates the competition between the sellers. As a result, in equilibrium the disclosure leader is induced to supply unambiguously less information than that provided in the simultaneous disclosure case because of the diminished need to achieve ex post differentiation through information revelation. By contrast, when the disclosure cost is sufficiently low (high), the disclosure follower ex ante reveals less (more) private information than that revealed by the disclosure leader or by the sellers in the simultaneous disclosure case. This is because the follower's disclosure behavior responds to that of the leader in an approximately opposite direction.

We obtain some interesting results on the sellers' equilibrium ex ante payoffs. A monopolistic seller can be better off as the cost of disclosure increases because a higher disclosure cost can facilitate partial information concealment and allow the seller to charge a higher price when the realized quality is relatively too low to be disclosed. However, the sellers' equilibrium ex ante payoffs under competition strictly decrease with the cost of disclosure. Moreover, in comparison to the simultaneous disclosure case, the sellers' equilibrium ex ante payoffs are asymmetric under sequential disclosure. When the cost is low (high), the leader is motivated to reveal more (less) information than the follower, leading to a lower (higher) ex ante profit for the former. Nevertheless, sequential disclosure leads to softened competition and therefore a "win-win" outcome for both sellers in comparison to the simultaneous disclosure case.

Interestingly, the equilibrium social welfare has a U-shaped relationship with the cost of disclosure. That is, the equilibrium social welfare first decreases and then increases with the disclosure cost. This is the case with either monopoly or duopoly sellers, and under either simultaneous or sequential disclosure. The mechanism underlying the positive impact of the disclosure cost on the equilibrium social welfare is the sellers' increasing incentive to conceal private information when the disclosure cost becomes higher. Nevertheless, the equilibrium social welfare is higher under duopoly than in the monopolistic case because of the increasing social efficiency brought by the

[2] Mathios (2000) finds that all firms with low-fat salad dressings disclose fat information on a nutrition label while only a negligible portion of the firms with higher-fat dressings do so.

availability of an additional purchase option. Moreover, sequential disclosure can facilitate the trade-off between achieving this social efficiency and saving the overall amount of disclosure costs incurred by increasing the ex post differentiation and thus softening the competition between the sellers. As a result, the equilibrium social welfare is higher under sequential disclosure than under simultaneous disclosure.

Voluntary provision of verifiable information was initially studied by Grossman and Hart (1980), Grossman (1981), and Milgrom (1981). They establish that any private information will be voluntarily unravelled as long as disclosure and verification are costless; this is further analyzed by Okuno-Fujiwara et al. (1990) in a general setting. Subsequent studies investigate the factors that may lead to partial information disclosure in a monopolistic setting, e.g., disclosure costs (Jovanovic 1982), information acquisition costs (Matthews and Postlewaite 1985, Farrell 1986, Shavell 1994), and consumers' limited understanding (Fishman and Hagerty 2003). Lizzeri (1999) investigates the role of independent certification in information disclosure. Some recent empirical studies verify that the market does respond to disclosure rules (e.g., Mathios 2000, Jin and Leslie 2003). This paper extends Jovanovic (1982) to the duopoly sellers case, and examines the effects of disclosure cost and simultaneous versus sequential disclosure on equilibrium disclosure behavior, seller ex ante profits, and social welfare.

Chen and Xie (2005) examine when and how competing firms should adapt their pricing and advertising strategies in response to the presence of third-party product reviews. In their model, consumers are uncertain about which firm fits their preferences, while their reservation prices for both preferred and nonpreferred firms are fixed and *exogenous*. The role of either advertising or third-party reviews is to change the relative mixture of consumers who prefer one firm over the other. In a related paper, Chen and Xie (2008) investigate when and how a monopolistic seller should adjust its marketing communication strategy (i.e., attribute information provision) in response to consumer reviews. They consider a setup with two-sided (symmetric) uncertainty about the fit between the seller's product and consumers' characteristics. The impact of either seller-provided or review-based information is to increase consumer heterogeneity in product valuation. As a result, the presence of either seller-supplied or consumer review information generates ex post asymmetric uncertainty on product valuation between consumers and the seller.[3] By contrast to these two studies, this paper addresses the case when sellers have ex ante information advantage over potential buyers on product quality. The disclosure of private seller information diminishes this information asymmetry, which endogenously influences buyer valuation. Moreover, we consider universally private information that can be equally unknown/disclosed to both the buyer and the rival seller, and investigate the role of disclosure cost and timing on equilibrium disclosure behavior and payoffs.

This research adds to the literature on firm communication strategies.[4] It is well known that firms can signal quality information through prices (Bagwell and Riordan 1991, Judd and Riordan 1994), advertising (Nelson 1974, Schmalensee 1978), warranties (Lutz 1989, Soberman 2003), money-back guarantees (Moorthy and Srinivasan 1995), sale signs (Anderson and Simester 1998), and umbrella branding (Wernerfelt 1988). This paper is also related to the literature on the role of advertising in informing consumers about the existence of products (e.g., Grossman and Shapiro 1984, Zhao 2000, Villas-Boas 2004). Other related studies address the optimal selling strategies for an information vendor (e.g., Sarvary and Parker 1997, Iyer and Soberman 2000).

The rest of the paper is organized as follows. Section 2 describes the model, and investigates the benchmark case with a single seller. Section 3 presents the main analysis and results. Section 4 discusses managerial and policy implications and provides some model extensions. Section 5 identifies potential directions for future research and concludes the paper.

2. The Model

Consider two sellers, $i = 1, 2$, each owning one unit of a good (service), and a buyer who wants to purchase at most one unit of the good. Both the sellers' and the buyer's utility of no trade is normalized to zero. The buyer's surplus of purchase from seller i is given by $v_i - p_i$, where v_i is the quality of the good and p_i is the price charged by seller i. Initially, the buyer does not know the quality of either seller's good. Both the sellers and the buyer are risk neutral, and all parties maintain the same prior belief that the sellers' qualities are independently, identically, and uniformly distributed between zero and one: $v_i \sim U[0, 1]$, $i = 1, 2$.[5]

[3] See Guo et al. (2009) on the impact of consumer valuation dispersion, which can be facilitated by social communication, on the profitability of firms selling durable goods.

[4] A related stream of research examines information sharing contracts in a horizontal setting among competing firms (e.g., Vives 1984, Gal-Or 1985, Shapiro 1986, Villas-Boas 1994).

[5] The independence in the sellers' qualities implies that the buyer cannot infer a seller's quality from the rival seller's disclosure decision. Relaxing this assumption will substantially sacrifice model tractability, although the main insights of the paper will hold as long as the correlation between the sellers' qualities is not perfect. Moreover, with our deliberate assumption of identical distribution

Consider the following three-stage sequence of moves. In the first stage, each seller conducts independent product testing or marketing research and thus becomes informed about respective product quality; this remains private knowledge unless disclosed. The sellers do not know each other's quality; i.e., information is universally private. Nevertheless, the sellers can credibly and truthfully disclose their private information on v_i at a cost c in the second stage of the game. For example, the sellers can demonstrate the quality of their products through free trials, showrooms, advertisements, third-party expert certifications, and/or online forums where consumer reviews on product usage experiences are posted. To rule out the trivial case when the quality information is never disclosed, we assume throughout that the disclosure cost is positive, but not too high; i.e., $0 < c < 1/2$. As will be shown, when $c \geq 1/2$, no information will be disclosed for either monopoly or duopoly sellers. If v_i is disclosed, it becomes known to both the buyer and the rival seller. We investigate two alternative scenarios when the sellers' disclosure decisions are simultaneous or sequential, respectively. Finally, the sellers in the third stage simultaneously decide on their prices p_i. The buyer then determines whether and from which seller to buy, conditional on updated belief on the sellers' (expected) qualities. In solving the game, backward induction is used to ensure subgame perfection.

As a benchmark, let us first investigate the monopolistic case when only one seller is present in the market (Jovanovic 1982).[6] Let the seller's quality be v, which is uniformly distributed between zero and one, $v \sim U[0, 1]$. The buyer's surplus of purchase is given by $v - p$, where p is the price charged by the seller. To characterize the equilibrium, we start with the last stage of the game. If the seller chooses to reveal his private information, he can optimally charge $p = v$, which will be accepted by the buyer. If the seller keeps silent, the buyer remains uninformed of the true quality, but will update her belief. We denote as $\bar{v}$ the buyer's expected value of quality conditional on the seller remaining silent. The maximum price the seller can charge, when he keeps silent, is then $\bar{v}$.

We then determine the seller's optimal disclosure strategy, conditional on $\bar{v}$. It is evident that the seller will reveal v and receive $v - c$ if $v > \hat{v}$, and will keep silent and obtain $\bar{v}$ if otherwise, where $\hat{v} = \min\{\bar{v} + c, 1\}$ is the disclosure threshold. This allows us to derive the buyer's conditional expectation $\bar{v}$, given the seller's optimal disclosure strategy:

$$\bar{v} = \mathrm{E}[v \mid v \leq \hat{v}] = \frac{\min\{\bar{v} + c, 1\}}{2}. \tag{1}$$

This leads to the buyer's equilibrium conditional expectation $\bar{v}^m = c$. The equilibrium threshold, above which the seller discloses information, is given by $\hat{v}^m = \bar{v}^m + c = 2c < 1$. This suggests that the seller in equilibrium partially reveals his private information. This partial disclosure equilibrium is sustainable because disclosure is costly. The seller chooses to reveal information if and only if the quality is above a particular threshold. The seller can credibly withhold some information because information revelation is too costly for low values of quality. Intuitively, the amount of information disclosed in equilibrium by the seller decreases with the disclosure cost; i.e., $\partial \hat{v}^m / \partial c > 0$.

It follows that the monopolistic seller's equilibrium ex ante payoff is given by

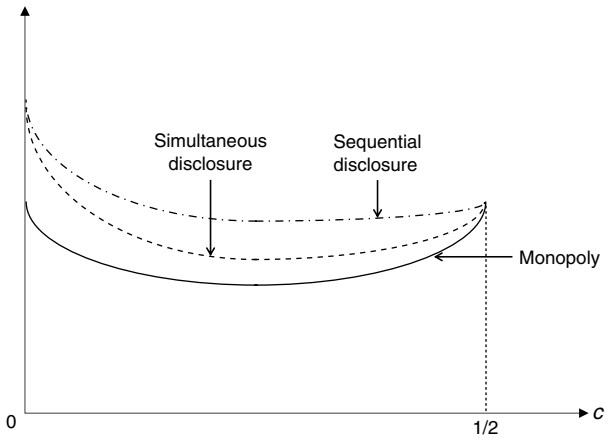
$$\pi^m = \int_0^{\hat{v}^m} \bar{v}^m \, dv + \int_{\hat{v}^m}^1 (v - c) \, dv = 1/2 - c(1 - 2c). \tag{2}$$

The seller's equilibrium ex ante payoff decreases (increases) with the disclosure cost c if the disclosure cost is low (high). Interestingly, the seller's equilibrium ex ante payoff under voluntary disclosure does not change monotonically with the cost c. This is because of the interaction of two counteracting effects that the disclosure cost c exerts on the seller's equilibrium ex ante payoff. First, the higher the disclosure cost, the more costly for the seller to disclose information when the realized quality v turns out to be relatively high. All else being equal, the seller is worse off as information disclosure becomes more costly. On the other hand, as the disclosure cost increases, it is more likely that information would be ex post withheld. This information withholding effect not only increases the likelihood that the disclosure cost would be saved, but also allows the seller to charge a higher price when the realized quality is relatively low and hence no information is revealed (i.e., $\bar{v}^m$ increases with c). As a result, the net impact of the disclosure cost on the seller's equilibrium ex ante payoff depends on the equilibrium amount of information disclosed. When c is relatively low, the seller is worse off with an increasing disclosure cost because the gain from the information withholding effect is dominated by the loss of incurring a higher per-disclosure cost. However, as the disclosure cost increases, more information would be concealed in equilibrium, in which case the information withholding effect would loom larger

we can rule out the possibility that the asymmetric equilibrium outcome under sequential disclosure stems from firm asymmetry. Nevertheless, one can readily extend the current analysis to investigate the role of asymmetric quality distribution.

[6] There are many sellers in the Jovanovic model. Nevertheless, because the number of potential buyers is sufficiently larger, each seller can charge a price that is equal to the buyers' expected value of that seller's good. This is theoretically equivalent to assuming that each of the sellers is a local monopoly.

Figure 1 Equilibrium Social Welfare



and may dominate the increasing cost of disclosing quality information. Therefore, when c becomes sufficiently high, the seller can be better off with an increasing disclosure cost.

Note that, in the monopolistic case, social welfare is equal to the seller's equilibrium ex ante profit (i.e., $SW^m = \pi^m$) because the buyer's expected surplus is completely extracted by the seller. One can then immediately obtain an interesting corollary that, as shown in Figure 1, there is a U-shaped equilibrium relationship between social welfare and the disclosure cost. To understand this, note that here information disclosure by itself does not result in any efficiency gain; it influences only the extent to which the buyer's surplus is transferred to the seller. As a result, all else being equal, social welfare is negatively affected as the cost of information disclosure increases. On the other hand, paradoxically, it is more likely that in equilibrium the cost of socially excessive information disclosure would be saved when the disclosure cost becomes higher. This explains why social welfare may first decrease and then increase with the disclosure cost.

3. The Results

We now examine the case with multiple information senders, i.e., duopoly sellers. The main objective is to assess how horizontal competition may influence equilibrium disclosure behavior, seller profitability, and social welfare, in comparison to those in the benchmark monopolistic case. We investigate and compare two alternative scenarios—when the sellers' disclosure decisions are simultaneous or sequential, respectively. We will start with the case when the sellers make their disclosure decisions simultaneously. We then investigate the case when the sellers' disclosure decisions are sequentially made such that one seller's disclosure decision is observed when the other seller makes his own disclosure decision.

To facilitate the analysis, we first investigate the sellers' equilibrium pricing decisions in the final stage of the game. Clearly, in the pricing subgame equilibrium, the seller with relatively lower (expected) quality, as compared to that of the rival seller, would charge a price equal to zero and thus have zero payoff, while the rival seller would charge a price (and earn a profit) equal to the differential between the buyer's expectations of the sellers' qualities. Note that this equilibrium result for the pricing subgame holds for either simultaneous or sequential disclosure. We then concentrate on the sellers' equilibrium disclosure decisions in the second stage of the game.

3.1. Simultaneous Disclosure

Consider first the case when the sellers' quality disclosure decisions are made simultaneously. A seller, at the time of making his disclosure decision, is uninformed of the rival seller's disclosure decision. Without loss of generality, we focus on the symmetric equilibrium.[7] Similar to the monopolistic case, we can denote as $\bar{v}$ the buyer's expectation on a seller's quality when no disclosure is observed from that seller. Let us suppose that a seller discloses if and only if his quality v_i is above a disclosure threshold $\hat{v}$. When a seller keeps silent, his expected payoff would be zero because the buyer's expected quality for the other seller cannot be lower than $\bar{v}$; the other seller would keep silent if his true quality is below $\bar{v}$, which leads the buyer to believe that the expected quality of the other seller is $\bar{v}$. When $v_i \geq \hat{v}$, the seller would disclose v_i, leading to an expected payoff equal to $\int_0^{\hat{v}} (v_i - \bar{v})\, dv + \int_{\hat{v}}^{v_i} (v_i - v)\, dv - c$. Note also that, when $v_i = \hat{v}$, the seller is indifferent between disclosure and no disclosure, which implies that $\int_0^{\hat{v}} (\hat{v} - \bar{v})\, dv - c = (\hat{v} - \bar{v})\hat{v} - c = 0$. Solving this yields the sellers' optimal disclosure threshold $\hat{v} = \min\{(\bar{v} + \sqrt{\bar{v}^2 + 4c})/2, 1\}$, conditional on $\bar{v}$. We can then readily substitute $\hat{v} = 2\bar{v}$ to obtain the buyer's equilibrium conditional expectation $\bar{v}^d = \sqrt{c/2}$, and the sellers' equilibrium disclosure threshold $\hat{v}^d = \sqrt{2c}$.

In comparison to the monopolistic case, we have the following proposition:

Proposition 1. *When the duopoly sellers disclose their private information simultaneously, less information is revealed in equilibrium than in the monopolistic case; i.e.,* $\hat{v}^d > \hat{v}^m$.

Interestingly, this proposition suggests that horizontal competition enhances the equilibrium amount of private information that is withheld by the sellers. This result is contrary to conventional wisdom. Consider the scenario when a seller chooses to conceal private information. In the case of a monopoly,

[7] It can be readily verified that the symmetric equilibrium is unique.

the seller can charge the buyer a price equal to the latter's conditional expectation $\bar{v}$. In contrast, in the presence of competition, the seller's expected payoff is only zero. Essentially, competition drives away the sellers' ability to extract surplus from the buyer when they do not reveal information; the only mechanism to achieve ex post differentiation between the sellers, and thus to earn positive profits, is to disclose the quality information. One might then be tempted to believe that the sellers should have a lower incentive not to disclose private information in the presence of competition pressure. However, this is only part of the story because competition also influences the sellers' expected payoff, and hence their incentive, of revealing information. By revealing a quality level that is above $\bar{v}$, a seller may not necessarily earn a higher profit, even gross of the disclosure cost, than when he keeps silent, unless the rival seller's quality turns out to be lower. Note that a seller can accrue a gross payoff increase of $v_i - \bar{v}$ from information revelation, with a lower probability in the presence of competition than when he is the sole seller. As a result, holding $\bar{v}$ constant, the sellers actually have a lower incentive to disclose information in the competition case. This explains why competition in the simultaneous disclosure case drives up the sellers' equilibrium information disclosure threshold and leads to less information being revealed.

Given the sellers' and the buyer's equilibrium behavior and belief, we can derive the sellers' equilibrium ex ante payoff

$$\pi^d = \int_{\hat{v}^d}^{1}\left[\int_0^{\hat{v}^d}(v_2 - \bar{v}^d)\,dv_1 + \int_{\hat{v}^d}^{v_2}(v_2 - v_1)\,dv_1 - c\right]dv_2 = \left(1 - 6c + 4\sqrt{2c^3}\right)/6. \quad (3)$$

It is evident that the sellers' equilibrium ex ante payoff π^d strictly decreases with the disclosure cost c. This result stands in contrast to that in the monopoly case in which the seller can be better off as information disclosure becomes more costly. Recall that in the single seller case, an increasing disclosure cost leads to more information concealment in equilibrium, which drives up the buyer's WTP when the seller keeps silent. This profit-enhancing effect of the disclosure cost is absent in the duopoly case, in which a seller keeping silent can earn only zero expected payoff even though the buyer's conditional expectation $\bar{v}^d$ increases with c. Actually, given that the duopoly sellers are ex ante undifferentiated from each other, a seller cannot earn positive profits unless his quality is perceived by the buyer to be higher than the rival seller's. Information disclosure is the only means to achieve ex post quality advantage over the rival seller. As a result, the disclosure cost c negatively influences the sellers' equilibrium ex ante payoff π^d.

Next, we investigate the equilibrium social welfare in the simultaneous disclosure case. To this end, we define $w \equiv \max\{v_1, v_2\}$. Given that v_1 and v_2 are independently and uniformly distributed, the probability distribution function for w is given by $F(w) = w^2$. Note that in equilibrium the buyer is indifferent between purchasing from either seller when both sellers withhold information (i.e., $w \le \hat{v}^d$). In addition, the buyer is expected to purchase in equilibrium from the seller who has a relatively higher quality than the other seller, when at least one seller discloses (i.e., $w > \hat{v}^d$). Moreover, a seller will incur the disclosure cost c if and only if $v_i > \hat{v}^d$. We can then derive the equilibrium social welfare when the sellers' disclosure is simultaneous,

$$SW^d = \int_0^{\hat{v}^d} \bar{v}^d\,dF(w) + \int_{\hat{v}^d}^{1} w\,dF(w) - 2\int_{\hat{v}^d}^{1} c\,dv = (2 - 6c + 5\sqrt{2c^3})/3. \quad (4)$$

The equilibrium social welfare in the simultaneous disclosure case is demonstrated in Figure 1. Similar to the monopolistic case, the equilibrium social welfare under simultaneous disclosure first decreases and then increases with the disclosure cost. This is also driven by the sellers' increasing incentive to conceal private information when the disclosure cost increases. Moreover, the equilibrium social welfare (i.e., SW^d) is higher than that in the monopolistic case (i.e., SW^m). This is expected because of the availability of an additional purchase option in the duopoly case: the expected value of the maximum of two goods (i.e., $w \equiv \max\{v_1, v_2\}$) is higher than that of an individual good (i.e., v_1 or v_2). Although this additional option also involves an increase in the overall cost of information disclosure—both sellers may choose to disclose and incur the disclosure cost—its net impact on social welfare is positive. Nevertheless, the difference in the social welfare, $SW^d - SW^m$, decreases with the disclosure cost c. This is because a higher disclosure cost dampens the sellers' incentive for disclosure, reducing the likelihood that the social efficiency brought up by the additional purchase option would be ex post realized. Recall that the buyer would randomly select a seller to buy when no seller discloses. As $c \to 1/2$, no information would be disclosed by any seller and as a result $SW^d \to SW^m$.

Finally, we show that the equilibrium buyer surplus is given by $BS^d = SW^d - 2\pi^d = (1 + \sqrt{2c^3})/3$, which increases with the disclosure cost c. Not surprisingly, a higher disclosure cost increases the likelihood that the sellers would not ex post reveal their private information, resulting in more intense price competition and hence improving the buyer's ex ante payoff.

3.2. Sequential Disclosure

Next, we examine the case when the sellers disclose their qualities sequentially. Each seller can choose

whether or not to disclose his private information, and the disclosure decisions are irreversible. Without loss of generality, suppose seller 1 announces his quality first (i.e., the disclosure leader), followed by seller 2 (i.e., the disclosure follower). We can think of the disclosure leader as a first-moving entrant and the disclosure follower as a later entrant to the market (Tyagi 2000). Following seller 1's disclosure decision, the buyer and the rival seller update the belief about the (expected) quality for good 1, $\tilde{v}_1$, which is equal to the true quality v_1 when seller 1 chooses to disclose, or $\bar{v}_1$ if seller 1 reveals no information. The value of $\tilde{v}_1 \in \{v_1, \bar{v}_1\}$ becomes common knowledge to all parties when seller 2 decides whether or not to disclose v_2. This setup differs from the simultaneous disclosure case in that here a seller's knowledge about the rival seller's (expected) quality is endogenously asymmetric. Then how does this influence the sellers' equilibrium information revelation strategies and payoffs?

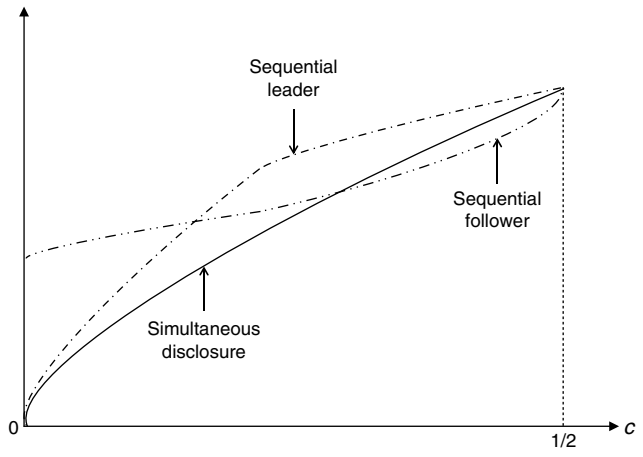
Proposition 2. *When the duopoly sellers disclose their private information sequentially*:

(1) *The disclosure leader in equilibrium discloses less private information than in the simultaneous disclosure case*;

(2) *If the disclosure cost is sufficiently low* (*high*), *the disclosure follower ex ante discloses less* (*more*) *private information than that revealed by the disclosure leader or by the sellers in the simultaneous disclosure case*; *if the disclosure cost is intermediate*, *the disclosure follower ex ante discloses more private information than the disclosure leader, but less private information than in the simultaneous disclosure case*.

The equilibrium probabilities that the sellers withhold private information are presented in Figure 2. First, the disclosure leader reveals unambiguously less private information than in the simultaneous disclosure case. This is because the disclosure follower can adjust his decision on information revelation in response to that of the disclosure leader, i.e., $\hat{v}_2^* = \min\{\tilde{v}_1 + c, 1\}$, where $\tilde{v}_1 \in \{v_1, \bar{v}_1^*\}$ is seller 1's disclosed/expected quality in equilibrium. When the disclosure leader keeps silent (i.e., $\tilde{v}_1 = \bar{v}_1^*$), it conveys the message that his expected quality is relatively low. This increases the likelihood that the disclosure follower gains an advantage in pricing through revealing his quality to the buyer. Interestingly, this increased likelihood of gaining the ex post advantage through information revelation can backfire when the disclosure follower decides to keep silent, in which case the buyer correctly infers that it is the disclosure leader who has a higher expected quality, even though both sellers keep silent (i.e., $\bar{v}_1^* > \bar{v}_2^*$), because otherwise the disclosure follower should have disclosed his quality. As a result, the expected payoff of a seller keeping silent can be positive when he acts as the leader in announcing his quality, and is zero when the sellers simultaneously make disclosure decisions. On the other hand, when the disclosure leader reveals relatively high quality levels, it is less likely that the follower will also disclose; i.e., $\hat{v}_2^*$ increases with $\tilde{v}_1 = v_1$. This drives up the expected quality of the disclosure follower when the leader discloses while the follower keeps silent. This implies that the disclosure leader has a relatively lower incentive for revealing high quality levels than in the simultaneous disclosure case. Clearly, a seller discloses undoubtedly less private information when he is the disclosure leader than when both sellers move simultaneously in quality disclosure.

Figure 2 **Equilibrium Ex Ante Information Withholding Probabilities Under Competition**



The follower's ex ante information disclosure probability is less straightforward. The follower's information disclosure, as discussed previously, responds to that of the leader in an approximately opposite fashion. This is because the leader's disclosure decision conveys information about his (expected) quality, and thus about the chance that the follower will win the pricing race. In particular, all else being equal, it is more likely that the follower will reveal his private information when the leader keeps silent than when the leader discloses. Note also that in equilibrium the leader's disclosure threshold, $\hat{v}_1^*$, increases with the disclosure cost c. As a result, as the disclosure cost decreases, the leader in equilibrium increases the amount of information disclosed. This in turn reduces the ex ante probability that the follower will disclose, which can be even lower than in the simultaneous disclosure scenario. Conversely, when the disclosure cost is high enough, the leader's disclosure threshold increases such that the follower reveals more private information than the leader. Moreover, as exhibited in Figure 2, when c is sufficiently high, the ex ante probability that the follower reveals private information

can be higher than when both sellers decide simultaneously on information disclosure. The overall message here is that the follower's quality disclosure is less responsive to the change in the cost c than that of the disclosure leader or that of the sellers under simultaneous disclosure.

Moreover, as shown in the appendix, seller 2's optimal disclosure strategy $\hat{v}_2^* = \min\{\tilde{v}_1 + c, 1\}$ in equilibrium leads to $\bar{v}_2^* < \tilde{v}_1 < \hat{v}_2^*$, which always holds for any $\tilde{v}_1 \in \{v_1, \bar{v}_1^*\}$. This suggests that seller 1's expected gross payoff is positive when and only when in equilibrium seller 2 decides to withhold v_2, which is given by $\int_0^{\hat{v}_2^*} (\tilde{v}_1 - \bar{v}_2^*)\, dv_2 = \max\{(\tilde{v}_1^2 - c^2)/2, \tilde{v}_1 - 1/2\}$. Similarly, seller 2's expected gross payoff is positive when and only when in equilibrium it decides to disclose its private information, which is given by $v_2 - \tilde{v}_1$. Recall also that $\tilde{v}_1 = v_1$ if $v_1 \geq \hat{v}_1^*$, and $\tilde{v}_1 = \bar{v}_1^*$ if otherwise. The sellers' equilibrium ex ante payoffs are then given by, respectively,

$$\pi_1^* = \int_0^{\hat{v}_1^*} (\bar{v}_1^{*2} - c^2)/2\, dv_1 + \int_{\hat{v}_1^*}^1 [\max\{(v_1^2 - c^2)/2, v_1 - 1/2\} - c]\, dv_1, \quad (5)$$

$$\pi_2^* = \int_0^{\hat{v}_1^*} \int_{\bar{v}_1^* + c}^1 (v_2 - \bar{v}_1^* - c)\, dv_2\, dv_1 + \int_{\hat{v}_1^*}^{1-c} \int_{v_1 + c}^1 \max\{v_2 - v_1 - c, 0\}\, dv_2\, dv_1, \quad (6)$$

which can be readily simplified to yield the following proposition.

Proposition 3. *When the duopoly sellers disclose their private information sequentially*:

(1) *If the disclosure cost is sufficiently low* (*high*), *the disclosure leader's equilibrium ex ante payoff is lower* (*higher*) *than that of the follower*;

(2) *Both the leader's and the follower's equilibrium ex ante payoffs are higher than in the simultaneous disclosure case*.

The sellers' profitability in the sequential disclosure scenario is asymmetric, thanks to the asymmetry at the time of disclosure in their information about the rival's (expected) quality. Note that the follower can improve his knowledge about the leader's quality from the latter's disclosure decision, but not vice versa. Although this disclosure asymmetry gives the follower a higher flexibility in the disclosure decision, the follower may benefit only when his quality turns out to be relatively high and is thus disclosed in equilibrium. By contrast, it is the leader who benefits from the follower's disclosure flexibility when the follower decides to keep silent. This can be seen from the equilibrium outcome $\bar{v}_2^* < \tilde{v}_1 < \hat{v}_2^*$. Furthermore, all else being equal, it is more likely that the sellers disclose private information when the disclosure cost c is relatively low. As a result, when c is sufficiently low (high), the follower (leader) benefits more from the disclosure asymmetry between the sellers than the rival seller. This implies that when the disclosure cost is low, it pays to be strategically patient and adjust one's quality disclosure in response to what the rival does. Conversely, when the disclosure cost is high, a seller can be better off moving quickly and ahead of the rival seller in making disclosure decisions.

Despite the asymmetry in the sellers' profitability, it turns out that sequential disclosure leads to a "win-win" outcome for both sellers in comparison to the simultaneous disclosure case. This is because sequential disclosure can increase the ex post differentiation and thus soften competition between the sellers who are ex ante identical from the buyer's perspective. Recall that in the simultaneous disclosure case, both sellers end up with zero payoffs when they both keep silent. In contrast, when the sellers make disclosure decisions sequentially, there is always one seller who ex post earns positive profits, i.e., the leader (the follower) when the follower in equilibrium decides to (not to) keep silent. As a result, both sellers are better off under sequential disclosure.

The equilibrium social welfare when the sellers' disclosure is sequential is given by

$$SW^* = \int_0^{\hat{v}_1^*} \left[\int_0^{\bar{v}_1^* + c} \bar{v}_1^*\, dv_2 + \int_{\bar{v}_1^* + c}^1 (v_2 - c)\, dv_2 \right] dv_1 + \int_{\hat{v}_1^*}^1 \left[\int_0^1 \max\{v_1, v_2 - c\}\, dv_2 - c \right] dv_1. \quad (7)$$

As shown in Figure 1, the equilibrium social welfare under sequential disclosure, similar to that under simultaneous disclosure, first decreases and then increases as the disclosure cost c becomes higher. The driving force is also the negative impact of the disclosure cost on the sellers' incentive to disclose information. Nevertheless, in comparison to the simultaneous disclosure case, we have:

Proposition 4. *The equilibrium social welfare is higher under sequential disclosure than under simultaneous disclosure*; *i.e.*, $SW^* > SW^d$. *The difference in social welfare*, $SW^* - SW^d$, *increases* (*decreases*) *with the disclosure cost c when the disclosure cost is low* (*high*).

This suggests that both the sellers' equilibrium ex ante payoffs and the social welfare can be improved when the sellers disclose information sequentially. Intuitively, sequential disclosure can, from a social planning perspective, facilitate the trade-off between informing the buyer of the seller with a relatively higher quality and saving the overall disclosure costs that may be incurred by the sellers. Recall first that the disclosure leader has an unambiguously higher

equilibrium disclosure threshold and hence a lower disclosure cost on average, than when disclosure is simultaneous. The disclosure follower may also incur on average a lower disclosure cost than under simultaneous disclosure, especially when the leader has chosen to disclose in which case the follower's disclosure threshold increases (i.e., $\hat{v}_2^* = v_1 + c$). The savings in the follower's overall disclosure cost is particularly prominent when c is relatively low, in which case the follower discloses less information on expectation than when disclosure is simultaneous. Conversely, when c becomes sufficiently high, the equilibrium ex ante probability that the disclosure follower reveals his quality is higher than under simultaneous disclosure, leading to a higher disclosure cost incurred on expectation. This explains why the difference in the equilibrium social welfare, $SW^* - SW^d$, becomes larger (smaller) with an increasing disclosure cost c when the disclosure cost is low (high).

Finally, the equilibrium buyer surplus is given by $BS^* = SW^* - \pi_1^* - \pi_2^*$. Akin to the simultaneous disclosure case, BS^* increases with the disclosure cost c. Moreover, one can readily verify that $BS^* < BS^d$. This suggests that the flexibility in the follower's disclosure decision can increase ex post differentiation and alleviate price competition between the sellers, improving the sellers' equilibrium ex ante payoffs at the expense of the buyer's.

4. Implications and Extensions

In the previous section, we examine the influences of disclosure cost and disclosure timing (i.e., simultaneous versus sequential) on the equilibrium disclosure behavior of duopoly sellers and on the equilibrium payoffs, as compared with those in the monopolistic seller case. Several intriguing findings emerge from our analysis, providing remarkable insights into voluntary quality disclosure in markets characterized by significant information asymmetry between sellers and potential buyers. We now discuss the managerial/policy implications of our study and provide some model extensions.

This paper sheds light on the disclosure strategy of firms in competitive markets, demonstrating that quality disclosure can be used as a strategic tool to soften competition pressure. This suggests that competing firms should facilitate communication about product quality with potential consumers. As discussed in §1, there are a wide range of strategies/vehicles through which a firm's quality can be truthfully demonstrated/communicated, including free product trials, product demonstration, advertising, expert certification, and/or online consumer reviews, etc. Nevertheless, firms should disclose their quality only when it is sufficiently high. Interestingly, this paper suggests that the disclosure threshold for competing firms should be higher than that for their monopolistic counterpart; this contradicts the intuition that competition leads to more information disclosure. However, this result offers a rationale for the puzzling empirical evidence that health maintenance organizations (HMOs) in relatively more competitive areas are less likely to disclose quality (Jin 2005).

This result also has interesting managerial implications about strategic reaction to competitive entry. For example, consider an incumbent firm that is facing encroachment from a new entrant. How should the incumbent firm adjust its quality disclosure strategy in response to the competitive entry? We suggest that one effective defensive strategy in the post-entry period is to adjust upward the information disclosure threshold, revealing less product quality information to consumers, e.g., cutting back investments in free product trials and/or advertisements.

We also provide insights into how the competing firms' disclosure strategy may differ when they make disclosure decisions simultaneously versus sequentially. We have shown that the disclosure leader in equilibrium reveals less information than in the simultaneous disclosure case, whereas the disclosure follower may disclose less (more) information than that revealed by the leader or by the firms in the simultaneous case, when disclosure cost is sufficiently low (high). This result sheds light on how firms' order of entry may differentially influence their quality disclosure strategy. To the extent that firms enter and disclose product quality sequentially, a first-moving entrant may want to plan its quality disclosure strategically to influence the later entrant's disclosure decision. We suggest that this foresight should lead the first mover to reveal less information to consumers than when the firms enter/disclose simultaneously. By comparison, the later entrant may wish to adjust its disclosure strategy in response to the first-moving entrant's disclosure strategy. We suggest that this response should be approximately the reverse of that of the first-moving entrant, i.e., reveal more (less) information when the first mover keeps silent (discloses). This also implies that the later entrant's disclosure strategy should be less responsive to the change in the disclosure cost.

We also investigate the sellers' equilibrium ex ante profits under voluntary quality disclosure. Firms normally invest significant resources and time to improve their knowledge about the quality of their products (e.g., through product testing and/or marketing research). Investigation of the firms' ex ante payoffs can help to gauge the potential profitability of their information-acquisition investments/activities. We show that a monopolistic firm can benefit from an increasing cost of disclosing quality information

because a higher disclosure cost can facilitate partial information concealment and increase the consumers' WTP when the realized quality is relatively low and is thus not revealed. By contrast, in the presence of competition, the firms' equilibrium ex ante payoffs strictly decrease with the cost of disclosure.

In addition, this paper demonstrates that the disclosure leader in a sequential disclosure scenario can earn lower (higher) profits than its rival (i.e., the disclosure follower) when the disclosure cost is low (high). This asymmetry in the firms' profitability provides a rationale for when a firm should strategically lead or delay the revelation of quality information in interacting with other competing firms. To the extent that a remarkable consequence of later entry is the increasing flexibility in information disclosure, this result also provides new insights on first-moving versus later-moving advantages. We suggest that this disclosure flexibility can benefit (hurt) the later entrant when the disclosure cost is relatively low (high), leading to a scenario of later-mover (first-mover) advantage. Nevertheless, we show that the firms are both better off when they sequentially decide on quality disclosure than when they do so simultaneously. This "win-win" outcome implies that competing firms may have an incentive to coordinate their entry/disclosure timing to enhance mutual benefits.[8] For example, when it is individually advantageous to be the first mover, firms may want to cooperate to avoid concurrent entry, because, otherwise, neither firm can realize the benefits of sequential disclosure. Conversely, when later-mover advantage is present, it is collectively desirable to have some firm move first. Paradoxically, the first-mover (later-mover) advantage will not arise unless it is not pursued by all firms. This raises an interesting issue for future investigation on how sequential disclosure can be practically implemented, given that strategic delay can be confounded with strategic silence in voluntary quality disclosure. One possible solution might be to delegate disclosure decisions to third parties (i.e., *Consumer Reports*, independent evaluators, etc.) who provide quality certifications on a regular basis (e.g., quarterly). Future research can look at this interesting issue, preferably in a dynamic setting where strategic delay can be disentangled from strategic silence.

In our paper, we obtain two results on equilibrium social welfare that could be potentially interesting for policy makers and regulators. The first is that there is a U-shaped equilibrium relationship between social welfare and the cost of disclosure, which persists with either monopoly or duopoly firms and under either simultaneous or sequential disclosure. This suggests that there may exist circumstances under which it is socially desirable to impose a tax on quality disclosure, particularly when the cost of disclosure is high. The second result we obtain is that equilibrium social welfare is higher under sequential disclosure than under simultaneous disclosure. This implies that it may be socially efficient to induce competing firms to make their quality disclosure decisions sequentially. For instance, heterogeneous deadlines can be regulated for different firms in a market, by which time they must decide whether to disclose their quality to consumers. Market entry licenses can also be issued sequentially. These arrangements could be feasible, especially when the actual quality must be verified by third-party agencies (e.g., *Consumer Reports*) or industrial trade groups (e.g., the National Sporting Goods Association). Implementation friction is likely to be low because the social preference for sequential quality disclosure, as we show, can be aligned with the firms' private interests.

4.1. Distribution Support

To facilitate exposition, in the basic model the distribution of the quality of the sellers' good is bounded between zero and one. The derived insights can be readily extended to more general distribution support, e.g., $v_i \sim U[0, u]$, $i = 1, 2$. Next, we present the results in the monopoly and the simultaneous duopoly scenarios under this extension; the sequential disclosure case can be similarly analyzed. We will concentrate on the interesting case $0 < c < u/2$ to ensure that information is disclosed in equilibrium with positive probability.

Note first that the monopoly seller's equilibrium disclosure threshold is still given by $\hat{v}^m = 2c$, yielding an ex ante probability of information concealment that is equal to $\hat{v}^m/u = 2c/u$. Moreover, the monopoly's equilibrium ex ante payoff is $\pi^m = \int_0^{\hat{v}^m} \overline{v}^m/u\,dv + \int_{\hat{v}^m}^{u} (v - c)/u\,dv = u[1/2 - c(1 - 2c/u)/u]$. In the duopoly case under simultaneous disclosure, the indifference condition for disclosure becomes $\int_0^{\hat{v}} (\hat{v} - \overline{v})/u\,dv - c = (\hat{v} - \overline{v})\hat{v}/u - c = 0$. Substituting $\hat{v} = 2\overline{v}$, this yields the equilibrium disclosure threshold $\hat{v}^d = \sqrt{2uc}$, which is higher than that of the monopoly seller (i.e., $\hat{v}^m = 2c$) for any $0 < c < u/2$. Similarly, the duopoly sellers' equilibrium ex ante payoff is given by

$$\pi^d = \int_{\hat{v}^d}^{u} \frac{\int_0^{\hat{v}^d} (v_2 - \overline{v}^d)/u\,dv_1 + \int_{\hat{v}^d}^{v_2} (v_2 - v_1)u\,dv_1 - c}{u\,dv_2}$$
$$= u\left[1 - 6c/u + 4\sqrt{2(c/u)^3}\right]/6,$$

[8] There is a literature on sequential product introduction. For example, Moorthy and Png (1992) show that a firm can benefit from strategically delaying the release of a low-quality product, which could cannibalize sales of a high-quality product if introduced simultaneously. Padmanabhan et al. (1997) demonstrate that sequential product provision and upgrading can be used as an effective signal about market potential and thus about network externality. By contrast, sequential quality disclosure in this paper occurs between duopoly firms each carrying only one product.

and the equilibrium social welfare is

$$SW^d = \int_0^{\hat{v}^d} \frac{\bar{v}^d\, d(w/u)^2 + \int_{\hat{v}^d}^u w\, d(w/u)^2 - 2\int_{\hat{v}^d}^u c}{u\, dv} = u\left[2 - 6c/u + 5\sqrt{2(c/u)^3}\right]/3.$$

Clearly, with the reparametrization $\check{c} \equiv c/u \in (0, 1/2)$, the above results are qualitatively similar to those in the basic model. Intuitively, what matters is only the ratio of the disclosure cost c to the mean quality (i.e., $u/2$).

4.2. Buyer Heterogeneity

The basic model assumes buyer homogeneity and thus perfect competition in that the sellers' demand is either one or zero. We now examine the robustness of the assumption by allowing for buyer heterogeneity. Consider a market in which each of the duopoly sellers has a loyal buyer segment of size $\alpha \in (0, 1)$. These buyers consider purchasing only from the seller to which they are loyal. There is another segment of buyers, of size $1 - \alpha$, that purchase from the option with the highest expected payoff. All buyers have the same information/belief on the sellers' quality. We maintain the other assumptions in the basic model. Note that this modified model collapses to the case of perfect competition when $\alpha \to 0$, and the sellers are local monopolies when $\alpha \to 1$.

We begin by characterizing the sellers' equilibrium payoffs in the third stage of the game, conditional on the disclosed/expected quality $\tilde{v}_1$ and $\tilde{v}_2$, where $\tilde{v}_i \in \{v_i, \bar{v}_i\}$. Without loss of generality, suppose $\tilde{v}_1 \geq \tilde{v}_2$. Given this setup, one can readily follow Narasimhan (1988) to obtain the firms' equilibrium conditional payoffs, given by $\pi_1 = \alpha\tilde{v}_1 + (1-\alpha)(\tilde{v}_1 - \tilde{v}_2)$ and $\pi_2 = \alpha\tilde{v}_2$.

Consider first the simultaneous disclosure case. A seller is indifferent between disclosing $\hat{v}$ or not disclosing, if and only if $\alpha\hat{v} + \int_0^{\hat{v}}(1-\alpha)(\hat{v} - \bar{v})\, dv - c = \alpha\hat{v} + (1-\alpha)(\hat{v} - \bar{v})\hat{v} - c = \alpha\bar{v}$. Substituting $\hat{v} = 2\bar{v}$, we obtain the equilibrium disclosure threshold $\hat{v}^d = (\sqrt{\alpha^2 + 8(1-\alpha)c} - \alpha)/2(1-\alpha)$. One can then readily verify that $\partial\hat{v}^d/\partial\alpha < 0$; i.e., less information is disclosed in equilibrium as competition intensifies.

We now investigate the sequential disclosure case. As shown in the appendix, the economic mechanism underlying the sellers' disclosure strategy, i.e., the ex post-mitigated competition resulting from the flexibility in the follower's disclosure decision in response to that of the leader, remains effective. For example, the disclosure leader enjoys an ex post advantage over the disclosure follower when both keep silent (i.e., $\bar{v}_1^* > \bar{v}_2^*$). This implies that the leader has a less compelling incentive for information revelation in comparison to the simultaneous case. In addition, the follower's equilibrium disclosure decision responds to that of the leader in an approximately reverse manner: $\hat{v}_2^* = \min\{2[(1-\alpha)\tilde{v}_1 + c]/(2-\alpha), 1\}$, where $\tilde{v}_1 \in \{v_1, \bar{v}_1^*\}$. That is, all else being equal, the follower will reveal more private information when the leader keeps silent than when the leader discloses. This suggests that, similar to the homogeneous case, the follower's ex ante probability of information disclosure is less responsive to the change in the disclosure cost c. As a result, although the reduced-form derivation of the equilibrium disclosure strategies and payoffs becomes somewhat tangled, the main insights in the basic model are expected to hold.

We can then suggest that the qualitative results in the basic model are robust to allowing for buyer heterogeneity. Intuitively, the introduction of the loyal buyers to the model exerts the same increase in a seller's expected payoff independent of his disclosure decision; the driving force underlying disclosure is instead the ex post differential in the sellers' (expected) quality (i.e., $\tilde{v}_1 - \tilde{v}_2$).

5. Concluding Remarks

The primary objective of this paper is to investigate the role of competition and disclosure timing in voluntary quality disclosure. A pivotal assumption in the model is that information disclosure is truthful. This would hold if buyer verification costs are negligible, false claims are legally prohibited (e.g., by advertising laws) or can be sufficiently punished in long-term interactions, and/or certifications can be provided by reputed third-party experts. Moreover, as we discuss previously, this truth-telling assumption is reasonable for a number of widely used practices to demonstrate quality (e.g., free product trial, online consumer reviews). Nevertheless, if information cannot be credibly conveyed, communication would be uninformative. Firms then have to resort to alternative information transmission mechanisms, e.g., signaling.

A few interesting issues that result from relaxing some of the model assumptions can be examined in future research. First, we consider universally private information in this paper. Should we allow the firms to know each other's quality, the possibility would arise that a firm might try to disclose the rival's quality (e.g., by comparative advertising). This incentive would increase as the quality differential between the firms increases. It would be interesting to investigate how this will influence the firms' disclosure of own quality. Our model also assumes that quality is exogenously determined and beyond the control of firms. If we relaxed this assumption and made quality a decision variable, quality disclosure would become an irrelevant issue because in equilibrium consumers will correctly infer the firms' chosen quality levels. To overcome this difficulty, one could consider a setup

where the buyer's valuation v is stochastic and positively related to quality q, e.g., $v = q + \epsilon$, where q is chosen by the firms, and ϵ is random and can be disclosed. An alternative remedy would be to allow for some degree of consumer irrationality such that the firms' chosen quality cannot be correctly inferred by all consumers or with full certainty.

Another premise in the paper is that the disclosure cost is known and exogenous. However, if quality disclosure has to go through third parties (e.g., certification institutions, advertising firms), then disclosure costs would be endogenous and may not be directly observable to consumers. Moreover, if disclosure costs are uncertain for consumers, one may wonder whether a firm would strategically disclose or conceal private information to manipulate consumers' belief on the firm's future information disclosure ability/credibility.

The current research can be extended in a number of other directions. In the current model, product quality information influences only the buyer's WTP. One might consider cases with heterogenous buyers in which information may affect their willingness to buy and the total size of demand. In this paper we concentrate on the effect of the order of entry/disclosure. Future research can consider the firms' entry decisions, and investigate how quality disclosure can be used strategically for entry deterrence/accomadation (e.g., Judd 1985). In addition, one may consider information acquisition along with information disclosure. Although the main implications from this study are expected to hold under these extensions, it would be of interest to explore whether additional insights may arise.

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Appendix

Proof of Proposition 2. We begin by characterizing the follower's equilibrium disclosure strategy, conditional on $\tilde{v}_1 \in \{v_1, \bar{v}_1\}$. If seller 2 chooses not to reveal v_2, suppose the buyer believes that the expected quality for good 2 is $\bar{v}_2$. Seller 2's payoff is then equal to $\max\{\bar{v}_2 - \tilde{v}_1, 0\}$ if he keeps silent. It follows that seller 2 discloses his private information if and only if $v_2 - \tilde{v}_1 - c \geq \max\{\bar{v}_2 - \tilde{v}_1, 0\}$. This leads to seller 2's disclosure threshold, conditional on both $\bar{v}_2$ and $\tilde{v}_1$, i.e., $\hat{v}_2 = \min\{\max\{\bar{v}_2 + c, \tilde{v}_1 + c\}, 1\}$. Substituting $\bar{v}_2 = \hat{v}_2/2$, we can solve for seller 2's optimal disclosure threshold, $\hat{v}_2 = \min\{\max\{2c, \tilde{v}_1 + c\}, 1\}$, conditional on $\tilde{v}_1$.

Given seller 2's optimal disclosure strategy, we can then investigate the leader's equilibrium disclosure decision. To this end, we first derive seller 1's expected payoff (gross of disclosure cost), conditional on $\tilde{v}_1 \in \{v_1, \bar{v}_1\}$ and taking into account seller 2's subsequent optimal response. When $\tilde{v}_1 \leq c$, it is obvious that seller 1's expected payoff is zero, since $\tilde{v}_1 \leq \bar{v}_2 = c$. When $c < \tilde{v}_1 \leq 1 - c$, we have $\bar{v}_2 = (\tilde{v}_1 + c)/2 < \tilde{v}_1 < \hat{v}_2 = \tilde{v}_1 + c$, which implies that seller 1's expected payoff is given by $\int_0^{\hat{v}_2} (\tilde{v}_1 - \bar{v}_2)\, dv_2 = (\tilde{v}_1^2 - c^2)/2$. When $\tilde{v}_1 > 1 - c$, we have $\bar{v}_2 = 1/2$ and $\hat{v}_2 = 1$, which suggests that seller 1's expected payoff is given by $\int_0^{\hat{v}_2} (\tilde{v}_1 - \bar{v}_2)\, dv_2 = \tilde{v}_1 - 1/2$. To summarize, seller 1's expected conditional gross payoff is equal to $\max\{0, (\tilde{v}_1^2 - c^2)/2, \tilde{v}_1 - 1/2\}$.

To derive seller 1's equilibrium disclosure strategy, suppose first $\bar{v}_1 \leq c$. It follows that if seller 1 keeps silent, his expected payoff would be zero. As a result, seller 1 chooses to disclose v_1 if and only if $\max\{(v_1^2 - c^2)/2, v_1 - 1/2\} - c \geq 0$. This yields seller 1's optimal disclosure threshold $\hat{v}_1 = \min\{\sqrt{2c + c^2}, c + 1/2\}$. But then we have $\bar{v}_1 = \hat{v}_1/2 > c$, which is a contradiction. Suppose then $\bar{v}_1 \geq 1 - c$. If seller 1 does not disclose, his expected payoff would be $\bar{v}_1 - 1/2$. Seller 1 would choose to disclose v_1 if and only if $v_1 - 1/2 - c \geq \bar{v}_1 - 1/2$. This implies that seller 1's disclosure threshold is $\hat{v}_1 = \bar{v}_1 + c$. Substituting $\hat{v}_1 = 2\bar{v}_1$, we obtain $\bar{v}_1 = c$, which is again a contradiction.

It follows that in equilibrium we must have $c < \bar{v}_1 < 1 - c$. This suggests that if seller 1 keeps silent, his expected payoff would be $(\bar{v}_1^2 - c^2)/2$. Moreover, seller 1 chooses to disclose v_1 if and only if $\max\{(v_1^2 - c^2)/2, v_1 - 1/2\} - c \geq (\bar{v}_1^2 - c^2)/2$. This yields seller 1's disclosure threshold,

$$\hat{v}_1 = \begin{cases} \sqrt{\bar{v}_1^2 + 2c}, & \text{if } c < \bar{v}_1 \leq \sqrt{1 - 4c + c^2}; \\ (\bar{v}_1^2 - c^2 + 2c + 1)/2, & \\ & \text{if } \max\{c, \sqrt{1 - 4c + c^2}\} < \bar{v}_1 < 1 - c. \end{cases}$$

Noting that $\bar{v}_1 = \hat{v}_1/2$, we can then solve for seller 1's equilibrium disclosure threshold.

$$\hat{v}_1^* = \begin{cases} 2\sqrt{2c/3}, & \text{if } c \leq (7 - 2\sqrt{10})/3; \\ 4 - 2\sqrt{2 + (1 - c)^2}, & \text{if otherwise,} \end{cases} \tag{8}$$

which is higher than the equilibrium disclosure threshold in the simultaneous disclosure case (i.e., $\hat{v}^d = \sqrt{2c}$).

Note that seller 2's disclosure decision responds to that of seller 1; i.e., $\hat{v}_2^* = \min\{\tilde{v}_1 + c, 1\}$. In particular, when $v_1 \leq \hat{v}_1^*$, seller 1 would keep silent (i.e., $\tilde{v}_1 = \bar{v}_1^*$), in which case seller 2's equilibrium disclosure threshold is $\hat{v}_2^* = \bar{v}_1^* + c$. When $v_1 > \hat{v}_1^*$, seller 1 would reveal v_1 (i.e., $\tilde{v}_1 = v_1$). There are two scenarios to consider: (1) if $\hat{v}_1^* \leq 1 - c$ (i.e., $c \leq (7 - 2\sqrt{10})/3$), then $\hat{v}_2^* = \min\{v_1 + c, 1\}$; and (2) if $\hat{v}_1^* > 1 - c$ (i.e., $c > (7 - 2\sqrt{10})/3$), then $\hat{v}_2^* = 1$. Integrating over v_1, the ex ante probability that seller 2 conceals private information is given by

$$\int_0^{\hat{v}_1^*} (\bar{v}_1^* + c)\, dv_1 + \int_{\hat{v}_1^*}^1 \min\{v_1 + c, 1\}\, dv_1$$

$$= \begin{cases} (1 + 2c - c^2)/2, & \text{if } c \leq (7 - 2\sqrt{10})/3; \\ 11 + 2c^2 - 2(3 + c)\sqrt{2 + (1 - c)^2}, & \text{if otherwise.} \end{cases}$$

The proposition follows immediately. This completes the proof. Q.E.D.

Sequential Disclosure with Buyer Heterogeneity

We begin by characterizing the follower's equilibrium disclosure strategy, conditional on $\tilde{v}_1 \in \{v_1, \bar{v}_1\}$. If seller 2 keeps silent, its expected payoff is equal to $\max\{\alpha\bar{v}_2 + (1-\alpha)(\bar{v}_2 - \tilde{v}_1), \alpha\bar{v}_2\}$. If seller 2 discloses, its expected payoff is $\alpha v_2 + (1-\alpha)(v_2 - \tilde{v}_1) - c$. This leads to seller 2's disclosure threshold, conditional on both $\bar{v}_2$ and $\tilde{v}_1$; i.e., $\hat{v}_2 = \min\{\max\{\bar{v}_2 + c, \alpha\bar{v}_2 + (1-\alpha)\tilde{v}_1 + c\}, 1\}$. Substituting $\bar{v}_2 = \hat{v}_2/2$, we can solve for seller 2's optimal disclosure threshold, $\hat{v}_2 = \min\{\max\{2c, 2[(1-\alpha)\tilde{v}_1 + c]/(2-\alpha)\}, 1\}$, conditional on $\tilde{v}_1$.

Next, we derive seller 1's expected payoff (gross of disclosure cost), conditional on $\tilde{v}_1 \in \{v_1, \bar{v}_1\}$ and taking into account seller 2's subsequent optimal response. When $\tilde{v}_1 \le c$, it is obvious that seller 1's expected payoff is given by $\pi_1(\tilde{v}_1) = \alpha\tilde{v}_1$, since $\tilde{v}_1 \le \bar{v}_2 = c$. When $c < \tilde{v}_1 \le \min\{(2-\alpha-2c)/2(1-\alpha), 2c/\alpha\}$, we have $\bar{v}_2 = ((1-\alpha)\tilde{v}_1 + c)/(2-\alpha)\tilde{v}_1 < \hat{v}_2 = 2[(1-\alpha)\tilde{v}_1 + c]/(2-\alpha)$, which suggests that seller 1's expected payoff is given by $\pi_1(\tilde{v}_1) = \alpha\tilde{v}_1 + \int_0^{\hat{v}_2}(1-\alpha)(\tilde{v}_1 - \bar{v}_2)\,dv_2 = \alpha\tilde{v}_1 + 2(1-\alpha)(\tilde{v}_1 - c)[(1-\alpha)\tilde{v}_1 + c]/(2-\alpha)^2$. When $\tilde{v}_1 > \min\{(2-\alpha-2c)/2(1-\alpha), 2c/\alpha\}$, there are two scenarios to consider: (1) if $\alpha \le 2c$, then we have $\bar{v}_2 = 1/2$ and $\hat{v}_2 = 1$, which suggests that seller 1's expected payoff is given by $\pi_1(\tilde{v}_1) = \alpha\tilde{v}_1 + (1-\alpha)(\tilde{v}_1 - 1/2) = \tilde{v}_1 - (1-\alpha)/2$; and (2) if $\alpha > 2c$, then we have $\tilde{v}_1 > \hat{v}_2$, which implies that seller 1's expected payoff is equal to $\pi_1(\tilde{v}_1) = \alpha\tilde{v}_1 + (1-\alpha)[\int_0^{\hat{v}_2}(\tilde{v}_1 - \bar{v}_2)\,dv_2 + \int_{\hat{v}_2}^{\tilde{v}_1}(\tilde{v}_1 - v_2)\,dv_2] = \alpha\tilde{v}_1 + (1-\alpha)\tilde{v}_1^2/2$.

To characterize seller 1's equilibrium disclosure strategy, suppose first $\bar{v}_1 \le c$. It follows that seller 1's optimal disclosure threshold must satisfy that $\pi_1(\hat{v}_1) - c - \alpha\hat{v}_1/2 = 0$. However, it can be verified that $\pi_1(\hat{v}_1) - c - \alpha\hat{v}_1/2$ is negative when evaluated at $\hat{v}_1 = 2c$. This implies that in equilibrium we must have $\hat{v}_1 > 2c$, which is a contradiction. Suppose then $\bar{v}_1 \ge \min\{(2-\alpha-2c)/2(1-\alpha), 2c/\alpha\}$. If $\alpha \le 2c$, seller 1 would choose to disclose v_1 when and only when $v_1 - (1-\alpha)/2 - c \ge \bar{v}_1 - (1-\alpha)/2$. This implies that seller 1's disclosure threshold is $\hat{v}_1 = 2c$, which is also a contradiction. If $\alpha > 2c$, seller 1 would choose to disclose v_1 when and only when $\alpha v_1 + (1-\alpha)v_1^2/2 - c \ge \alpha\bar{v}_1 + (1-\alpha)\bar{v}_1^2/2$. This suggests that $\hat{v}_1 = 2[\sqrt{\alpha^2 + 6(1-\alpha)c} - \alpha]/3(1-\alpha)$, which again contracts $\bar{v}_1 \ge \min\{(2-\alpha-2c)/2(1-\alpha), 2c/\alpha\}$.

It follows that in equilibrium we must have $c < \bar{v}_1^* < \min\{(2-\alpha-2c)/2(1-\alpha), 2c/\alpha\}$, which also implies that $\bar{v}_2^* < \bar{v}_1^* < \hat{v}_2^*$. Moreover, seller 2's equilibrium disclosure decision is characterized by $\hat{v}_2^* = \min\{2[(1-\alpha)\tilde{v}_1 + c]/(2-\alpha), 1\}$.

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