COMPETITION, DISCLOSURE AND SIGNALLING*

Maarten C.W. Janssen and Santanu Roy

Competition creates strategic incentives for firms to communicate private information about product quality through signalling rather than voluntary disclosure. In a duopoly where firms may disclose quality before setting prices and prices may signal quality, non-disclosure by all firms may often be the unique symmetric outcome even if disclosure cost vanishes. A high-quality firm may not disclose even if it has strong competitive advantage over a low-quality rival. This provides an alternative explanation of infrequent voluntary disclosure. Although product information is always communicated whether or not firms disclose, signalling distortions may provide a rationale for mandatory disclosure regulation.

In a large number of markets ranging from educational and health services to consumer goods and financial assets, sellers have important information about quality attributes\(^1\) of their own products that are not publicly observable by potential buyers or even their competitors. In many of these markets, firms have the option of voluntarily disclosing this private information in a credible and verifiable manner through a variety of means such as independent third-party certification\(^2\), labelling, rating by industry associations (or, government agencies) and regulated advertising.

In practice, however, voluntary disclosure does not occur very often even when credible low cost mechanisms for facilitating such disclosure exist. Several studies report evidence that in the absence of statutory disclosure requirement, hospitals did not disclose risk-adjusted mortality, schools did not report standardised test scores, about half of health maintenance organizations did not disclose quality, restaurants almost never disclosed hygiene inspection reports and even salad dressing producers refrained from labelling fat content (see the excellent recent survey by Dranove and Jin, 2010, and also Mathios, 2000, and Jin, 2005). Evidence of inadequate voluntary disclosure is also found in the striking lack of product information in advertising\(^3\) even

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\(^*\) Corresponding author: Maarten C.W. Janssen, Department of Economics, University of Vienna, Hohenstaufengasse 9, 1010 Vienna, Austria. E-mail: maarten.janssen@univie.ac.at.

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\(^1\) Quality attributes include satisfaction from consuming the product, durability, safety, potential health hazards and environmental damage that buyers care about.

\(^2\) Third-party quality rating (such as the Leapfrog Group’s hospital rating) requires data from sellers and seller participation that imply voluntary disclosure by the sellers.

\(^3\) See, for instance, Abernethy and Butler (1992) and Abernethy and Franke (1996). There is a recent theoretical literature on the informational content of advertisements (see, among others, Anderson and Renault, 2006; Mayzlin and Shin, 2011; Renault and Koessler, 2012).

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though the penalty for false advertising (such as that under current Federal Trade Commission (FTC) regulations) could make such information credible. Indeed, the very absence of affordable mechanisms for disclosing quality credibly in many markets may be partially attributed to inadequate demand for such mechanisms and, therefore, to the unwillingness of firms to disclose voluntarily. Indirect evidence of inadequate voluntary disclosure also comes from the fact that public authorities feel the need to require mandatory disclosure, and that market outcomes do change significantly after imposition of such legal requirements (Zarkin et al., 1993; Mathios, 2000; Jin and Leslie, 2003; Dranove and Jin, 2010).

This article develops a new explanation of the observed non-disclosure of product quality attributes. A firm that does not disclose its private information about product quality directly may still communicate information about quality indirectly through signalling. In particular, the firm’s publicly observed market behaviour (such as pricing) may allow uninformed buyers to infer the firm’s product quality. Non-disclosure is not equivalent to non-revelation of information, and whether or not a firm discloses voluntarily may be seen as the outcome of a choice between alternative channels of communication.

The main result of our article is that market competition creates strong strategic incentives for firms to not disclose directly and, instead, signal their private information about quality through prices. This is true even when there are no frictions or imperfections in the voluntary disclosure process. Furthermore, non-disclosure may be preferred by all types of firms – even those with high-quality products or those that are likely to have strong competitive advantage over rivals.

We analyse a duopoly where firms engage in price competition and the products of the two firms differ only in quality; there is no other form of product differentiation. Product quality may be one of two types: high or low. Every firm produces at constant unit cost that depends on true quality. Consumers are identical with valuations depending on quality. Firms have pure private information about the qualities of their products, i.e. a firm’s product quality is unknown to its rival as well as to all buyers. After observing their product quality privately, firms first decide whether or not to disclose their private information voluntarily by incurring a fixed cost (that can be arbitrarily small). In the next stage, they decide on prices. Voluntary disclosure reveals product quality to prospective consumers as well as the rival firm and price competition takes place under the information structure generated at the voluntary disclosure stage. The model describes markets where credible voluntary disclosure and communication of the disclosed information to consumers require a longer time frame than determination of prices (or more generally, variables of short-run market competition). This is certainly true for disclosure mechanisms such as verification, certification and rating by independent agencies but may also be true for certain kinds of

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4 This article assumes that by disclosing or signalling, the firm is able to inform consumers fully about its quality. That is, we abstract from issues where observed market behaviour is only an imperfect signal, or where consumers are not able to fully understand information that is disclosed (Che, 2008).

5 Firms may not be aware of the true product quality attributes of other firms because of protection of trade secrets, zealous safeguarding of results of product quality tests, confidential settlement of consumer complaints and many other factors.

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informative product advertising that takes significant time to diffuse and reach a large section of buyers.⁶

To understand our main result note that non-disclosure implies that the rival firm remains uncertain about the true quality of the firm at the pricing stage and this modifies the nature of price competition. In particular, when a firm’s quality is not revealed through disclosure, it must think about how pricing affects consumers’ beliefs about its product quality. Reducing price to undercut a rival may induce consumers to believe that its product is of lower quality and, therefore, undercutting may not attract more buyers. These consumer beliefs discipline price competition and, in an indirect sense, non-disclosure is a way for the high-quality firm to pre-commit credibly not to undercut. Non-disclosure may also make the rival less aggressive in price competition relative to a situation where there is no uncertainty about the firm’s quality. The resulting softening of price competition allows firms to sustain higher prices. This is the strategic gain from non-disclosure. This gain is strengthened if the rival firm does not reveal any information through disclosure (as beliefs discipline the behaviour of both firms). As beliefs play an important role in our argument, we do not want our argument to depend on arbitrary out-of-equilibrium beliefs; we therefore impose a strong refinement, namely that they satisfy the D1 criterion.

The constraint imposed by beliefs of buyers under non-disclosure can, however, also be a liability for a high-quality firm if demand and cost conditions give the firm a strong competitive advantage over a low-quality rival. Such a firm may prefer to disclose its quality and use its position of strength to price aggressively and steal business from its rival without being punished by the beliefs of buyers. This is the strategic gain from disclosure. This gain is strengthened if the rival firm also reveals quality through disclosure.

If the quality premium that buyers are willing to pay is low so that the low-quality product generates higher social surplus than the high-quality product, then the unique symmetric equilibrium is one where neither firm discloses its product quality. A high-quality firm has a competitive disadvantage in such a market and, therefore, no strategic gain from disclosing. If it discloses then (independent of whether the rival firm discloses), the low-quality rival steals all business for sure and this leads to aggressive Bertrand price competition with the high-quality type of the rival that eliminates all profits.

The more interesting situation is one where the high-quality firm generates more surplus and has a competitive advantage over any low-quality rival. The strategic gain from disclosing dominates if the rival voluntarily discloses product quality. As a result, for low values of the disclosure cost, there is an equilibrium where both firms reveal quality through disclosure. We show that even in this case, an equilibrium with non-disclosure by both firms may also exist. Remarkably, if high quality is produced at lower unit cost than low quality (for instance, because low quality is subject to future liability), an equilibrium with full non-disclosure may still exist for moderate levels of disclosure cost, even though

⁶ In models of signalling quality through dissipative advertising that has no direct informational content, it is natural to model advertising and pricing decisions as being simultaneous. See, among others, Milgrom and Roberts (1986) and Hertzendorf and Overgaard (2001).

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the high-quality firm has a very strong competitive advantage. When they co-exist, the non-disclosure equilibrium may Pareto dominate the disclosure equilibrium in terms of the expected profits of both firms and both quality types.

In the full non-disclosure outcome, both firms signal quality through prices. This pricing equilibrium was characterised in Janssen and Roy (2010) where it was shown that despite Bertrand price competition and absence of any other product differentiation, firms may earn high profits and enjoy significant market power in the signalling outcome.\(^7\) It is important to clarify that what matters for our results is how the profits of the signalling equilibrium (generated after non-disclosure by both firms) are modified when a firm unilaterally deviates and discloses its type. More generally, it is the way in which price competition changes as a consequence of a firm changing its strategy from non-disclosure to disclosure (or vice versa) that is at the heart of our results.

Existing explanations of observed non-disclosure are entirely based on models that explicitly assume away the possibility of signalling so that voluntary disclosure is the only way to communicate quality and non-disclosure ensures non-revelation. Most of these explanations are based on the cost of disclosure (Grossman and Hart, 1980; Jovanovic, 1982) and other imperfections or frictions in the voluntary disclosure mechanism, such as the inability of consumers to understand the information disclosed (Fishman and Hagerty, 2003) and unawareness of consumers about disclosures made by firms (Dye and Sridhar, 1995); some of them emphasise that an increase in competition may reduce the additional rent earned by a disclosing firm to a level below the disclosure cost (Cheong and Kim, 2004; Levin et al., 2009). Recent contributions to this literature (Board, 2009; Sun, 2011; Celik, 2013; Hotz and Xiao, 2013) have argued that by not disclosing, a firm will be perceived as being the ‘average’ of non-disclosing types which may increase product differentiation with respect to a rival that discloses leading to partial non-disclosure even if there is no disclosure cost. It is important to emphasise that this argument is contingent on prices not conveying information about true product types. The argument in our article is not based on product differentiation and, in equilibrium, prices do inform consumers about exact product types.

Our results indicate that any concern about the absence of voluntary disclosure leading to consumers making uninformed decisions may be misplaced as buyers may often infer quality from the market behaviour of firms. However, from a welfare perspective consumers may still be making the ‘wrong choices’ because the prices that are set to signal quality distort the buying decisions relative to the market outcome under full information (that would result if all firms would disclose). The welfare cost of non-disclosure ought to take into account price distortions and market power. We show that when these distortions are high, there may be a case for mandatory disclosure regulation. The observation that, in some industries, the imposition of mandatory disclosure regulation is followed by consumers purchasing more high-quality products (see, for instance, Ippolito and Mathios (1990)), may simply be a consequence of correction of prior price distortions rather than better informed consumers.

\(^7\) The latter has also been noted in several other studies on signalling of quality under strategic competition (Daughety and Reinganum, 2007, 2008a). See, among others, Milgrom and Roberts (1986) and Bagwell and Riordan (1991) for signalling of quality in a monopoly framework.

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Ours is the first article to study the choice between signalling and disclosure of product quality by competing firms that have (pure) private information about quality. Daughety and Reinganum (2007) argue that if competing firms can pre-commit to disclose or not disclose before knowing their own product qualities they may choose to commit to non-disclosure. In this study, we assume that firms cannot credibly pre-commit to disclosure or non-disclosure before knowing their own product quality attributes which is clearly a more natural assumption for most markets. Daughety and Reinganum (2008b, c) study the choice between voluntary disclosure and signalling of private information about product quality in a monopoly framework. The strategic gain from non-disclosure identified in our article does not arise in the absence of competition, and full disclosure occurs in their model unless disclosure is costly. Caldieraro et al. (2011) study the relation between signalling and disclosure in a duopoly, but under a different information structure from that in our model. They assume that it is common knowledge that one firm’s product is of low quality and the other’s product is of high quality and that firms know each others’ product qualities but consumers do not know which of the two products is of high quality. Their model generates full disclosure unless the cost of doing so is too high; as firms have full information about each other, the strategic advantage of competing under incomplete information that drives the main result in our article is simply ruled out.

The rest of the article is organised as follows. The next Section presents the model. Sections 2–4 present the main results on the equilibrium disclosure outcome for various cases that depend on whether or not low quality generates more surplus than high quality and whether or not low quality is supplied at lower cost. Section 5 contains a discussion of the welfare implications of our results and the effect of mandatory disclosure regulation. Section 6 concludes. Proofs of all propositions (other than Proposition 1 which is discussed in the main text) are contained in Appendix A.

1. The Model

There are two firms, \( i = 1, 2 \), in the market. Each firm’s product may be of either high (\( H \)) or low (\( L \)) quality. The true product quality is known only to the firm that supplies the product; it is not known to the rival firm or to the consumers. It is, however, common knowledge that the \textit{ex ante} probability that a firm’s product is of high quality is \( x \in (0,1) \). The products of the firms are not differentiated in any dimension other than quality. Firms produce at constant unit cost and the unit cost \( c_s \geq 0 \) of a firm depends only on its true quality \( s, s = H, L \). The unit cost subsumes both current production cost (including cost of compliance with any form of prevalent regulation) as well as the expected future costs related to the current sale of the product (such as those arising through liability, damages, legal and other costs associated with settlement of disputes and complaints).

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8 Bernhardt and Leblanc (1995) and Fishman and Hagerty (2003) also allow for both signalling and voluntary disclosure but their models are not designed to focus on the trade-off between the two.

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There is a unit mass of identical consumers in the market. Consumers have unit demand and each consumer’s valuation of a unit of quality \( s \) is given by \( V_s, s = H, L, \) where

\[
V_H > V_L, \quad V_s > c_s, \quad s = L, H.
\]

We will consider two kinds of cost regimes. In the regular cost configuration, higher quality is produced at higher unit cost, i.e.

\[
c_L \leq c_H. \tag{1}
\]

In contrast, under cost reversal, the effective cost of supplying the low-quality product is higher than that of supplying the high-quality product, i.e.

\[
c_L \geq c_H. \tag{2}
\]

Cost reversal may, in particular, arise when the expected liability damage payment associated with low quality is large enough.

Within the regular cost configuration (where (1) holds), we have two scenarios. A first scenario arises when the quality premium \( V_H - V_L \) that buyers are willing to pay for the high-quality product is lower than the cost difference:

\[
V_H - V_L \leq c_H - c_L. \tag{3}
\]

We will refer to this as the low-quality premium scenario. In this case, \( V_H - c_H \leq V_L - c_L \), so that the production and consumption of the low-quality good create more social surplus than that of the high-quality good. If the inequality in (3) holds strictly, then in price competition under complete information, the low-quality producer has a competitive advantage over a high-quality rival, reducing the latter’s market share to zero. The second scenario is one where the quality premium \( V_H - V_L \) that buyers are willing to pay for the high-quality product exceeds the cost difference:

\[
V_H - V_L > c_H - c_L. \tag{4}
\]

We will refer to this as the high-quality premium scenario. In this case, the high-quality good creates more social surplus than the low-quality good. In price competition under complete information, the high-quality producer has a competitive advantage over a low-quality rival, reducing the latter’s market share to zero.

Formally, the game proceeds in four stages. First, nature independently draws the type (or quality) \( \tau_i \) of each firm \( i \) from a distribution that assigns probabilities \( \alpha \) and \( 1 - \alpha \) to \( H \) and \( L \) respectively; the realisation of \( \tau_i \) is observed only by firm \( i \). Next, both firms (having observed their own types) simultaneously decide whether or not to voluntarily disclose their type publicly by incurring a cost \( d \geq 0 \). Disclosure is assumed to be credible and verifiable. Apart from disclosure cost, there is no other imperfection in the disclosure mechanism and the information conveyed is communicated perfectly to all consumers in the market. After observing the information disclosed in the second stage, in the third stage, firms choose their prices simultaneously. Finally, (after observing the information disclosed voluntarily and prices) consumers decide whether to buy and, if so, from which firm. The pay-off of each firm is its expected profit net of disclosure cost (if any). The pay-off of each consumer is their expected net surplus.
The solution concept used is that of perfect Bayesian equilibrium where the out-of-equilibrium beliefs satisfy the D1 criterion (Cho and Kreps, 1987) in every subgame.\(^9\) The D1 criterion is not only used to obtain a unique symmetric equilibrium in the pricing game following non-disclosure by both firms but also to characterise pricing behaviour in several subgames where only one of the firms discloses high quality.

When no information about types is revealed through disclosure in the first stage, the Bayesian–Nash equilibrium of the continuation (pricing) game is always in mixed strategies; in particular, depending on the cost configuration, either the high or the low-quality firm randomises over prices. Mixed pricing strategies can also arise as part of the equilibrium when one of the two firms reveals its type at the disclosure stage. The main results of the study are based on a careful characterisation of these pricing equilibria.

Before analysing the model, it is useful to briefly discuss the incentive to disclose product quality in the monopoly version of our model. It is easy to show that if the firm does not disclose, then the high-quality monopolist’s profit is always (strictly) lower than his optimal profit under full information.\(^10\) Therefore, as long as the disclosure cost \(d\) is below a threshold, the firm chooses to voluntarily disclose when its product is of high quality and all information is revealed through disclosure. The monopoly benchmark of our model confirms the results obtained by Daughety and Reinganum (2008\(^b\)) and indicates that the non-disclosure outcome in our model arises as a consequence of both market competition and the availability of signalling as an alternative means of communicating quality.

### 2. Low-quality Premium

In this Section, we analyse the incentives of firms to disclose their information voluntarily when the quality premium that buyers are willing to pay is relatively low: \(V_H - V_L \leq c_H - c_L\). Observe that in this case \(c_H > c_L\) (regular cost configuration holds) and that

\[
V_H - c_H \leq V_L - c_L. \tag{5}
\]

That is the low-quality product creates more surplus and therefore has a competitive advantage over the high-quality product. We argue that in this scenario, the only symmetric equilibrium is one where neither firm discloses its product quality

\(^9\) This implies that following every possible disclosure outcome in the first stage, we consider the D1 equilibrium of the pricing subgame. The D1 refinement essentially requires that after observing an out-of-equilibrium price set by a particular firm, buyers should speculate which type of the firm has greater incentive to deviate to this price (given the equilibrium strategy of the rival firm). To make this comparison of incentives, one can think about the smallest level of (expected) quantity that must be sold at that price to make the deviation gainful for one type, and compare it with that for the other type.

\(^{10}\) The argument is as follows. The full-information profit of the high-quality monopolist is \((V_H - c_H)\). To obtain the same level of expected profit under incomplete information about quality, the high-quality monopolist must charge the price \(V_H\) with probability 1 and sell to all consumers at that price. The latter requires that buyers’ equilibrium beliefs associate the price \(V_H\) with only high quality and therefore, the low-quality type must not be charging the price \(V_H\). Thus, the low-quality seller’s price must fully reveal his quality and, therefore, to be able to sell, the low-quality seller’s price is \(V_L < V_H\) and its profit are less than \((V_H - c_L)\). The low-quality seller would then always gain by deviating from such an equilibrium by charging \(V_H\) and selling to all consumers.
voluntarily (whatever its true product quality). Furthermore, this holds no matter how small the cost of voluntary disclosure is. As no information is communicated through disclosure, firms compete in prices under incomplete information about each other’s product qualities and signal their product qualities to consumers through prices.

We begin with the observation that if a high-quality firm discloses its product quality, then it earns negative net profit independent of the disclosure policy of its rival, no matter how small the disclosure cost. This reflects the competitive disadvantage of the high-quality firm; if it discloses its quality, it is fully expropriated by the rival firm when the latter is of the low-quality type. As a result, a disclosing high-quality firm can only make money in the state where the rival is of high-quality type. This, however, leads to intense price competition in the state where both firms are of high quality, thus eliminating all profits. This is easy to see if the rival high-quality firm has also revealed its type fully through disclosure but it can also be shown to hold if the rival’s type is not fully revealed. Thus, net of disclosure cost, the disclosing high-quality firm earns negative expected profit. The formal argument is contained in Appendix A (see, proof of Proposition 1). It follows that in equilibrium, a high-quality firm will never choose to disclose with positive probability.\footnote{If \(d = 0\), there is always a symmetric equilibrium where a firm discloses if, and only if, its product quality is high. The disclosing high-quality firm earns zero profit in equilibrium. By deviating to non-disclosure, it still earns zero profit (as the rival firm fully reveals its type at the disclosure stage). This equilibrium outcome is clearly not robust to positive disclosure cost.}

Next, we consider the possibility of a symmetric equilibrium where each firm discloses when its product is of low quality but not when its product is of high quality. In such an equilibrium, the types of both firms are fully revealed after the disclosure stage, so that firms engage in Bertrand-like price competition under complete information. Using (5), it is easy to check that in this equilibrium, a high-quality firm obtains zero profit independent of the type of its rival, whereas a low-quality firm earns strictly positive profit only in the state where its rival has high-quality product and its expected net profit is

\[
x[c_H - (V_H - V_L) - c_L] - d.
\]

Now, suppose that the low-quality type of firm 1 deviates from this proposed equilibrium, and does not disclose. Then, firm 2 when it sets its price, will believe that firm 1 is of high quality (as only high-quality firms do not disclose in this equilibrium). Firm 2, which reveals its type fully through disclosure in this equilibrium, will therefore set a price equal to \(c_H\) if it is of high quality, and a price equal to \(c_H - (V_H - V_L)\) if it is of low quality. Firm 1, whose true product quality is low, can now set a price just below \(c_H - (V_H - V_L)\) and sell to the entire market whatever be the type of the rival, earning an expected profit close to \([c_H - (V_H - V_L) - c_L]\), which is clearly higher than its equilibrium pay-off (6). Therefore, the deviation is gainful and there cannot be a symmetric equilibrium where low-quality firms disclose for sure.

The essential argument here is that by not disclosing its quality, the low-quality firm is able to change the rival firm’s belief about his type and, in particular, increase the perceived likelihood of its being a high-quality type. As the high-quality type is less competitive, this makes the rival less aggressive in price competition. This, in turn,
allows the non-disclosing low-quality firm to increase its profit by aggressively undercutting the rival at the price competition stage. Note that as the low-quality firm is not interested in communicating its type to buyers, the only advantage of disclosure for a low-quality firm would have to come from the way in which it modifies price competition; however, as the low-quality type is associated with lower marginal cost and is more competitive, disclosure of its type can only make its rival more aggressive in price competition. Of course, non-disclosure also saves the firm its disclosure cost. This general reasoning also rules out a symmetric equilibrium where every low-quality firm discloses with some positive probability; the details of this argument are contained in Appendix A (see, proof of Proposition 1).

The above discussion can be summarised as follows: there is not a symmetric equilibrium where a firm discloses with positive probability and, therefore, the only possible symmetric equilibrium outcome is non-disclosure. We now show that a full non-disclosure outcome is indeed an equilibrium.

We begin by describing this equilibrium. In this equilibrium, both low and high-quality types choose to not disclose their product quality; as a result, no additional information about the type of any firm is revealed in the disclosure stage of the game. On the equilibrium path, the price setting game is an incomplete information game where the prior beliefs assign probabilities \( \alpha \) and \( 1 - \alpha \) to high and low-quality types for each firm. This is exactly the pricing game analysed in Janssen and Roy (2010). We show there that there is a unique symmetric D1 equilibrium in the pricing game of the following kind: each firm charges a certain price \( p_H \in (c_H, V_H) \) when its product is of high quality and randomises with a continuous probability distribution over an interval \( (p_L, pH) \) when its product is of low quality, where

\[
c_L < p_L < p_H < pH.
\]

Consumers are indifferent between buying from the low-quality firm at price \( p_L \) and from a high-quality firm at price \( pH \), i.e.

\[
\overline{p}_L = pH - (V_H - V_L).
\]

In this equilibrium, consumers always buy from a low-quality firm unless both firms are of high quality. At price \( \overline{p}_L \), a low-quality firm can sell only in the state where its rival is of high quality (it is undercut for sure when its rival is of low quality) and, therefore, the low quality firm’s expected equilibrium profit is given by

\[
\alpha [p_H - (V_H - V_L)] + (1 - \alpha) [p_L - (V_H - V_L)] = \alpha (p_H - c_L).
\]

The mixed strategy followed by the low-quality firm balances its market power when the rival is of high-quality type (and charges price \( p_H \)) and its incentive to undercut the rival’s price when the latter is of low quality.

In this equilibrium of the pricing game, prices signal quality perfectly. The high-quality type of a firm charges a higher price but loses business to the rival firm with higher probability than the low-quality type. The latter plays an important role in deterring imitation of the high-quality price by the low-quality firm (which has lower marginal cost). The low-quality firm earns strictly positive expected profit – in fact, just enough profit so as to not have any incentive to imitate the high-quality type. It is easy to see from (7) that generating sufficient rent for the low-quality firm requires
that the rival firm charges a high enough price when its product is of high quality. As a result not only the low-quality firm but also the high-quality firm may choose price above marginal cost (sometimes as high as the full-information monopoly price) and earn considerable rent. More generally, signalling softens price competition to sustain rents that are important to deter imitation of higher price by low-quality firms. The reason why these rents are not dissipated through price competition has a lot to do with the beliefs of buyers. Reducing price (even slightly) to steal business from the rival may not be worthwhile for a high-quality firm, if this leads buyers to adversely revise their beliefs about the quality of its product. Therefore, incomplete information about product quality generated by non-disclosure becomes effectively a means of pre-committing to not undercut the rival’s price which, in turn, leads to a more collusive market outcome.

We now argue that neither type of a firm has any incentive to deviate from the proposed equilibrium at the disclosure stage. Earlier in this Section, we have argued that a high-quality firm that discloses earns negative expected profit whether or not its rival discloses; thus, a high-quality firm cannot gain by deviating and disclosing its type. Suppose the low-quality type of a particular firm, say firm 1, deviates and discloses its type. In this case we are in a subgame where the product quality of firm 1 is commonly known to be low quality but firm 2’s quality remains private information. The equilibrium of this price setting game with one-sided incomplete information is characterised formally in Appendix A (see, proof of Proposition 1) but the key arguments are as follows. As one would expect, the price set by the high-quality type of firm 2 (which has a competitive disadvantage vis-à-vis firm 1) would be bid down to its marginal cost $c_H$. As firm 1 faces Bertrand competition from the low-quality type of firm 2, its market power arises solely from the fact that it can charge a price $c_H - (V_H - V_L)$ and steal all business in the state where the rival firm has high quality. In equilibrium, the disclosing low-quality firm 1 earns profit only in the state where its rival is of the high-quality type and that profit is exactly equal to $[c_H - (V_H - V_L) - c_L]$. Its net expected profit is therefore $\pi[c_H - (V_H - V_L) - c_L] - d$. It is clear that this can never be larger than the equilibrium profit (7) of the low-quality firm, as $\pi_H \geq c_H$. As a result, deviation by a low-quality type from the proposed equilibrium is not gainful. Thus, full non-disclosure is an equilibrium outcome and, therefore, must be the unique symmetric equilibrium outcome. In fact, non-disclosure remains an equilibrium if $d = 0$ but the uniqueness result does not hold. The following Proposition summarises our discussion in this Section.

**Proposition 1.** Suppose that (5) holds, i.e. the quality premium is relatively low. Then, for all $d > 0$, i.e. no matter how small the cost of disclosure, the unique symmetric equilibrium outcome is one where, independent of true product quality, neither firm discloses voluntarily; firms communicate private quality information only by signalling through prices.

3. High-quality Premium

In this Section, we consider the scenario where the quality premium that buyers are willing to pay is relatively high; in particular, $V_H - V_L > c_H - c_L$ so that
which implies that the high-quality product generates higher surplus and has a competitive advantage over the low-quality product. Furthermore, in this Section, we will assume that the regular cost configuration obtains, i.e.

\[ c_H \geq c_L. \] (9)

The case of cost reversal is analysed in the next Section.

The competitive advantage of the high-quality seller leads to a strong incentive to disclose if the rival firm also behaves similarly. We show that if the disclosure cost is below a critical level, there is always an equilibrium with full disclosure where high-quality firms disclose voluntarily and types are fully revealed prior to price competition. However, despite its competitive advantage, a high-quality firm may not disclose its type if the rival firm also hides its type. We show that under certain conditions, there is an equilibrium where neither firm discloses voluntarily; such an equilibrium may exist even if the cost of disclosure is arbitrarily small. When both the full-disclosure and the full–non-disclosure equilibria co-exist, the latter may yield higher pay-off for both firms of both types, i.e. non-disclosure is the Pareto-dominant outcome.

We begin with what is probably the most interesting result: the existence of an equilibrium with full non-disclosure. Suppose that both firms of both types choose not to disclose. The continuation pricing game is one of two-sided incomplete information where each firm’s product is of high quality with probability \( \pi \). As shown in Janssen and Roy (2010), the unique symmetric D1 equilibrium of this game is identical to the one broadly described in the previous Section. In this equilibrium, a high-quality firm charges a high price and loses the entire market to its rival when the latter has low quality. When (8) holds, for the low-quality firm to earn sufficient rent so as not to imitate the higher price it must be able to attract buyers at a price above its marginal cost and thus the high-quality firm must charge a price sufficiently higher than \( c_H \). High-quality firms can sustain such high prices despite price competition because the out-of-equilibrium beliefs of buyers punish deviation to any lower price.

Now, suppose that a high-quality firm unilaterally deviates from the full non-disclosure equilibrium and discloses its type. This firm is no longer constrained by the beliefs of buyers and can reduce its price freely; this implies that it no longer loses business to its rival in the state where the latter has low quality. Even if the low-quality rival charges its marginal cost, the firm can earn positive profit and the size of this profit depends on the extent of competitive advantage that the high-quality type has over a low-quality rival. The downside is that in the state where the rival has high quality, competition is much more aggressive. If \( \pi \) is large enough, and/or the

\[ V_H - c_H > V_L - c_L, \] (8)

Note that in a full-disclosure equilibrium only one of the types needs to disclose its quality formally and pay the disclosure cost. If, in such an equilibrium, consumers observe a firm not disclosing quality, they will infer its type anyway, and it does not have an incentive to disclose.

\[ \text{Although Janssen and Roy (2010) do not formally analyse the case where } c_H = c_L, \text{ the limit of the unique symmetric D1 equilibrium for } c_H > c_L \text{ as } (c_H - c_L) \to 0 \text{ continues to be a D1 signalling equilibrium when } c_H = c_L \text{ and has qualitatively similar properties. However, there are other pooling equilibria that meet the D1 criterion in this case.} \]
competitive advantage of the high-quality firm over the low quality firm is small, the deviation from full non-disclosure may not be gainful. Under such conditions, full non-disclosure is an equilibrium.

Let \( \hat{d} \) be defined by

\[
\hat{d} = (1 - \alpha)[(V_H - c_H) - (V_L - c_L)] - \frac{\alpha}{2} (c_H - c_L), \quad \text{if} \quad \frac{V_L - c_L}{V_H - c_L} \geq \frac{1}{2},
\]

\[
= [(V_H - c_H) - (V_L - c_L)] - \frac{\alpha}{2} \left( \frac{V_H - c_H}{V_H - c_L} \right) (V_L - c_L), \quad \text{if} \quad \frac{V_L - c_L}{V_H - c_L} < \frac{1}{2}.
\]

(10)

**Proposition 2.** Suppose that (8) and (9) hold. If the disclosure cost

\[
d \geq \max\{0, \hat{d}\}
\]

(where \( \hat{d} \) is as defined in (10)), then a symmetric equilibrium with full non-disclosure exists where neither firm discloses voluntarily, whatever their true product qualities are, and firms signal quality to consumers through prices. Furthermore, (11) is necessary for such an equilibrium if \( c_H > c_L \), i.e. (9) holds as a strict inequality.

Observe that a lower value of \( \hat{d} \) implies that the full–non-disclosure outcome occurs for more parameter values. \( \hat{d} \) is decreasing in \( \alpha \) and increasing in \( [(V_H - c_H) - (V_L - c_L)] \), the competitive advantage of the high-quality firm. If \( \hat{d} < 0 \), then there is an equilibrium with full non-disclosure no matter how small the disclosure cost. It is easy to check (using Propositions 2 and (10)) that:

**Corollary 1.** If (8) and (9) hold, then there exists a critical \( \bar{\alpha} \in (0,1) \) such that if \( \alpha > \bar{\alpha} \), there exists a symmetric equilibrium with full non-disclosure no matter how small the disclosure cost. The same conclusion holds if \( (V_H - c_H) - (V_L - c_L) \) is small enough.

Next, we turn to the existence of an equilibrium with full disclosure where each firm discloses voluntarily if, and only if, its product is of high quality. In such an equilibrium, types are fully revealed and the pricing outcome is identical to that under full information. In particular, the low-quality firm earns zero profit in equilibrium. The high-quality firm makes profit only in the state where the rival is of low-quality type, and its profit depends on its competitive advantage. We show that a high-quality firm that deviates unilaterally and does not disclose will be perceived as a low-quality firm and, furthermore, will not be able to change this perception through pricing because buyers know that the low-quality type (with zero equilibrium profit) has at least as much incentive to deviate to any out-of-equilibrium price above \( c_{HF} \); as a result, a high-quality firm that unilaterally deviates from disclosure cannot make any profit. The disclosure equilibrium is sustained as long as the high-quality type’s equilibrium profit (net of disclosure cost) is non-negative.

**Proposition 3.** Suppose that (8) and (9) hold, i.e. the buyers’ quality premium is relatively high and the marginal cost of supplying the high-quality product is at least as large as that of the low-quality product. Let \( d > 0 \) be defined by

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\[ \dd = (1 - x)[(V_H - c_H) - (V_L - c_L)]. \]

There exists a symmetric equilibrium where high-quality firms disclose their product quality with probability 1 and low-quality firms do not disclose if, and only if, \( d \leq \dd \).

A lower value of \( \dd \) implies that the disclosure equilibrium occurs for a smaller set of parameter values. Note that \( \dd \) is decreasing in \( x \), and in \( [(V_H - c_H) - (V_L - c_L)] \); as discussed above, these are the factors that increase the equilibrium profit of a high-quality firm. We have noted earlier in this Section that the parameter region where an equilibrium with full non-disclosure exists becomes larger with higher values of \( x \) and smaller values of the competitive advantage of the high-quality firm; we can see now that they also make the parameter region where an equilibrium with full disclosure exists smaller.

Both full disclosure and full non-disclosure can co-exist as symmetric equilibrium outcomes. The range of parameter values for which this occurs is characterised in Proposition A.1 in Appendix A. Proposition A.1 also indicates that high-quality firms may randomise between disclosure and non-disclosure, i.e. partial disclosure may occur.

When both full disclosure and full non-disclosure co-exist as equilibrium outcomes, low-quality firms always prefer the non-disclosure equilibrium as they make positive profit in any such equilibrium, whereas their profits are equal to zero in the disclosure equilibrium. Interestingly, high-quality firms may also prefer the non-disclosure equilibrium. In the disclosure equilibrium, a high quality firm earns profit only in the case where the other firm has low-quality product and, if this probability is small, i.e. \( x \) is large, then high-quality firms make low profits in a disclosure equilibrium. On the other hand, the profits of high-quality firms are increasing in \( x \) in the no disclosure equilibrium. The next Proposition shows that there is a set of parameter values such that both types of firm are better off in the non-disclosure equilibrium.

**Proposition 4.** Suppose that (8) and (9) hold and, furthermore, both full non-disclosure and full disclosure by high-quality types co-exist as equilibrium outcomes. Then, a critical value \( x^* < 1 \) exists, such that for all \( x > x^* \) the non-disclosure equilibrium yields higher pay-off to both low and high-quality firms. In particular, if \( (V_L - c_L)/(V_H - c_L) \geq \frac{1}{2} \), then \( x^* < 1/2 \).

Thus, when both disclosure and non-disclosure are equilibrium outcomes, under certain conditions, the latter may be preferred by all players (of all types) so that they are likely to focus on the non-disclosure equilibrium. Furthermore, the fact that the non-disclosure equilibrium provides higher pay-off to both low and high-quality firms implies that both types of firms may be worse off under a mandatory disclosure regulation. In particular, when \( x \) is relatively large, even a high-quality firm may oppose mandatory disclosure. We return to the effects of mandatory disclosure in a later Section.

**4. Cost Reversal**

In this Section, we analyse the situation where the effective marginal cost of supplying the low-quality product exceeds that of supplying high quality:
Such a cost configuration may arise in situations when the low-quality product is associated with health, environmental or other hazards that make the expected liability and therefore, the effective expected marginal cost, higher for the low-quality product. Note that (12) implies that \( V_H - c_H > V_L - c_L \), so that, as in the previous Section, the high-quality firm has a competitive advantage. Indeed, the relative disadvantage of the low-quality firm is now much more pronounced: it produces a worse product at higher cost than the high-quality firm. The high-quality firm’s incentive to disclose should then be higher than in the case of regular cost configuration discussed in the previous Section. For the latter case, we have shown that there is always an equilibrium with full disclosure if the disclosure cost is small. Somewhat surprisingly, this is no longer true with cost reversal. There may be no equilibrium with full disclosure even if disclosure is costless; the market outcome is then characterised by either partial or full non-disclosure. If the disclosure cost is moderately high, there is an equilibrium with full non-disclosure.

It is intuitive that under (12), a low-quality firm can never earn positive profit whether or not its quality is revealed at the disclosure stage. One implication of this is that if a firm’s type is not revealed at the disclosure stage, then the low-quality type of the firm will gain by imitating any price above \( c_L \) at which the high-quality type sells. As a result, if a high-quality firm does not disclose, it is constrained to price below \( c_L \) which restricts its profitability. This, in turn, ought to create a strong incentive for disclosure by the high-quality firm. However, by deviating from an equilibrium where it is supposed to disclose, a high-quality firm can make its rival believe that it is a low-quality (higher marginal cost) firm. This makes the rival much less aggressive in price competition (particularly when the rival is of high-quality type). After softening its rival, the deviating high-quality firm can reveal its true type to buyers by charging a price below the marginal cost of the low-quality type and eventually earn high profit. We show that under certain conditions, the latter effect may dominate and rule out an equilibrium with full disclosure.

**Proposition 5.** Assume (12). There is no equilibrium where the product qualities of both firms are fully revealed through voluntary disclosure if

\[
d > (1 - \alpha)(V_H - V_L) - \alpha(c_L - c_H).
\]

Furthermore, this holds for all \( d > 0 \), i.e. no matter how small the cost of disclosure, if

\[
\alpha > \frac{V_H - V_L}{(V_H - V_L) + (c_L - c_H)}.
\]

If, on the other hand,

\[
(1 - \alpha)(V_H - V_L) - \alpha(c_L - c_H) \geq d,
\]

then there is a symmetric equilibrium where each firm voluntarily discloses quality if, and only if, it is of high-quality type.

---

14 In this Section, when \( c_L = c_H \) and neither firm discloses, we choose the D1 pooling equilibrium where both firms set price equal to marginal cost. This is the limit as \( c_L - c_H \to 0 \) of the signalling equilibrium when \( c_H < c_L \).

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Proposition 5 provides a necessary and sufficient condition (13) under which there is no symmetric equilibrium with disclosure. Observe that (13) does not require the disclosure cost to be prohibitive. Indeed, under restriction (14), the disclosure cost may be arbitrarily small, even zero. As the discussion above indicates, the incentive to deviate from disclosure increases with \( z \). If this probability exceeds a threshold indicated in (14), disclosure does not occur no matter how small the disclosure cost. An increase in \((c_L - c_H)\), the cost advantage of the high-quality producer, leads to an increase in the profit that the high-quality firm can make by hiding its type while still revealing its type to consumers (by pricing just below \( c_L \)) and, therefore, reduces the possibility of disclosure. Finally, an increase in \((V_H - V_L)\), the buyers' quality premium increases the incentive for disclosure because the disclosing high-quality firm can charge a high enough price.

When condition (13) holds, a symmetric equilibrium can be of only two possible types: neither type of any firm discloses (signalling outcome in the market), or high-quality firms randomise between disclosure and non-disclosure. Our last Proposition provides necessary and sufficient conditions for these outcomes.

**Proposition 6.** Assume (12).

(i) There is a symmetric equilibrium with full non-disclosure where neither firm of any type discloses its product quality voluntarily if

\[
d \geq (1 - z)(V_H - V_L). \tag{16}
\]

(ii) If

\[
\max\{0, (1 - z)(V_H - V_L) - z(c_L - c_H)\} < d < (1 - z)(V_H - V_L), \tag{17}
\]

there is a symmetric equilibrium with partial non-disclosure where each high-quality firm randomises between disclosure and non-disclosure while low-quality firms do not disclose.

Observe that conditions (15), (16) and (17) are mutually exclusive and exhaust the parameter space. It is easy to check from (16) that an increase in \( z \) and a decrease in \((V_H - V_L)\) increase the parameter region where an equilibrium with full non-disclosure exists.

5. **Discussion: Effect of Mandatory Disclosure**

In this Section, we informally discuss the welfare effects of mandatory disclosure regulation. This is of interest as we have shown that in the absence of such regulation, voluntary disclosure may not occur. It is generally presumed that the purpose of mandatory disclosure regulation is to provide more information to consumers in markets where firms do not disclose voluntarily. However, when firms signal their product quality through prices, consumers are fully informed before making their purchase decisions even if firms do not disclose voluntarily. This raises the question about whether there is any other rationale for mandatory disclosure rules.

Our analysis indicates that mandatory disclosure can change the information structure of firms and their need to signal product quality through prices. This, in turn, affects the strategic interaction of firms, the resulting prices and quantities sold, as well

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as the composition of goods sold. In particular, as goods of different qualities differ in the social surplus they create, changes in the quality composition of goods bought by consumers may increase total social surplus. Of course, one must also take into account the disclosure cost incurred as a consequence of the regulation. We comment on this trade-off by looking at specific cases. Note that given the unit demand structure of our model, the possible welfare loss of high prices in terms of reduced quantity is ignored in our model.

We first consider the scenario analysed in Section 2 where low quality generates higher social surplus than high quality. The unique symmetric equilibrium is one where no firm discloses. In the pricing game that follows full non-disclosure, firms signal quality through prices and all consumers buy the low-quality product if it is available. It is clear that the total surplus cannot be larger than that generated in this outcome: the quality that generates higher surplus is consumed whenever it is available and no disclosure cost is incurred. Thus, mandatory disclosure can only reduce total surplus.

Next, we consider the case analysed in Section 3 where (8) and (9) hold. Here, the high-quality good creates higher social surplus. Our analysis indicates that depending on parameter values, the symmetric equilibrium outcome may be one with voluntary disclosure or one with full non-disclosure, or both. It is easy to see that imposition of mandatory disclosure cannot lead to any improvement over the voluntary disclosure equilibrium outcome; if anything, there is a welfare loss as both types of firms must incur the disclosure cost to attain the same market outcome. So, consider the full non-disclosure equilibrium, where prices signal product quality. The outcome is similar to that described in the previous paragraph: consumers buy low quality when it is available, resulting in a surplus of

\[ a^2(V_H - c_H) + (1 - a^2)(V_L - c_L). \]  

(18)

Now, consider the outcome under mandatory disclosure regulation. At the pricing stage, firms engage in Bertrand competition under complete information; the high-quality sellers, if any, serve the market and all consumers buy the high-quality product if it is available. Thus, mandatory disclosure regulation corrects the signalling distortion in prices that makes consumers buy the low-quality good even when the high-quality product is available. The expected total surplus generated under mandatory disclosure is

\[ a(2 - a)(V_H - c_H) + (1 - a)^2(V_L - c_L) - 2d. \]  

(19)

Comparing (18) and (19), it is obvious that mandatory disclosure improves total surplus over a non-disclosure equilibrium if, and only if,

\[ d < 2a(1 - a)\left[ (V_H - c_H) - (V_L - c_L) \right]. \]

Thus, in this case, mandatory disclosure is likely to improve welfare (over an outcome where no firm discloses voluntarily) if disclosure cost is small, if there is considerable uncertainty about product quality \((a(1 - a)\) is high) and if the additional surplus generated by the high-quality good (over the low quality good) is large.\(^{15}\)

\(^{15}\) Note that if \(a\) is high enough (for instance, close to 1), or if the surplus difference between low and high-quality goods is small, then (as indicated in Section 3), the non-disclosure outcome is more likely; however, in those situations, mandatory disclosure regulation is unlikely to be welfare improving.

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Finally, it is worth noting that the sharpening of competition between firms after imposition of mandatory disclosure regulation may lead to either the high or the low-quality firms (depending on which type generates smaller surplus) exiting the market if market profit does not cover the disclosure cost. This may lead to higher market power and concentration in the future. A proper analysis of the dynamic benefits and costs of mandatory disclosure rules should be an interesting topic for future research.

6. Conclusion

We analyse a simple model of strategic voluntary disclosure in a market where firms have private information about their own product quality, and can signal their product quality through prices when they do not disclose voluntarily. Voluntary disclosure of product quality is modelled as a (relatively long-term) decision that is made prior to (short-run) price competition. We show that competition between firms and the possibility of signalling may together create strong incentives to not disclose product quality and instead, signal quality through prices. Non-disclosure inhibits sharp price undercutting by high-quality firms, as they take into account how pricing affects the beliefs of buyers about product quality, and leads to a signalling outcome characterised by sufficient market power.

We show that no matter how small the disclosure cost, non-disclosure by all firms is the unique symmetric equilibrium outcome when the quality premium that buyers are willing pay is relatively low so that the low-quality product generates more social surplus. When the high quality product generates more surplus, for small disclosure cost there is an equilibrium where high-quality firms disclose their product quality. However, non-disclosure by all firms may still be an equilibrium. In fact, an equilibrium with full non-disclosure can exist even if the low-quality product has higher effective marginal cost than the high-quality product. When both kinds of equilibrium co-exist, the non-disclosure equilibrium may generate higher profits for firms of all quality than the disclosure equilibrium. In general, non-disclosure occurs for a larger set of parameter values if the likelihood of being a high-quality producer and the competitive disadvantage of the low-quality seller are higher. If the latter are sufficiently high, then (at least in the case where the cost of supplying high quality is greater than that of low quality) non-disclosure is an equilibrium even if disclosure cost vanishes.

Our results provide a new explanation of the observed reluctance of firms to disclose quality attributes. This explanation is based on the availability of an alternative channel of communicating quality, namely signalling, and the existence of sufficiently strong market competition. Furthermore, we can explain full non-disclosure by all firms even when disclosure frictions are small or non-existent. Our analysis indicates that the social cost of non-disclosure is not the consumers’ inability to make informed decisions; indeed, in our framework, consumers can infer private information of firms from prices. Rather it is related to the distortions in prices and market shares of producers of different qualities when they signal their private quality through prices. In some cases, this may create some limited role for mandatory disclosure regulation.

The limitations of our analysis arise from the simplicity of our model. Our model ignores imperfections in both signalling and voluntary disclosure as modes of communicating private information. We do not deal with the situation where product
quality is multi-dimensional. In a more general model, signalling may be imperfect and noisy. At the same time, (as some of the literature on voluntary disclosure has emphasised) it may be difficult to communicate voluntarily disclosed information to all buyers; for instance, the latter may not be able to absorb all the information communicated. Some of these imperfections may soften competition and others may have the reverse effect. It is difficult to say which imperfections are more important and ought to be incorporated.

The assumption that disclosure decisions are made prior to price competition, i.e. voluntary disclosure is a relatively long-term decision, plays an important role in our results. As mentioned in the Introduction, this is motivated by the fact that mechanisms of communicating through voluntary disclosure (which includes both the disclosure process as well as the process of information reaching consumers) often require significant amount of time. However, this is not a good assumption for markets where credible disclosure may occur through certain forms of product advertising that reach many consumers very fast. Disclosure is probably much more likely in those markets.

We have restricted our analysis to the case where consumers are homogeneous in their preferences for the products and the case of only two types of quality. We also abstained from considering repeated price competition. In a dynamic setting if qualities remain unchanged over time, future price competition takes place under full information in later periods independent of whether information is revealed through signalling or disclosure. While a full analysis of this kind of dynamic game is complex, it appears that the trade-off between signalling and disclosure may remain qualitatively unaffected. A proper analysis of such a dynamic model, however, ought to also take into account the possibility that quality may change and firms may acquire new private information over time; the latter is likely to reinforce the effects on the choice between disclosure and signalling uncovered by our current analysis. The simplifying assumptions of our analysis are made to bring out the implications of competition in its starkest form and to ensure a clean characterisation of the signalling outcome. Follow-up research on the relation between competition, disclosure and signalling ought to consider relaxing these assumptions.

Appendix A

This Appendix contains proofs of all results in the text.

Proof of Proposition 1. (remaining details from Section 2). Much of the proof has been outlined in the main text of Section 2. Three parts of the proof were left out; these are as follows:

(i) showing that there is no equilibrium where a high-quality firm discloses with positive probability;
(ii) showing that there is no symmetric equilibrium where low-quality firms randomise between disclosure and non-disclosure (and high-quality firms do not disclose); and
(iii) showing that the low-quality firm has no incentive to deviate from the equilibrium with full non-disclosure.

We begin with (i). Suppose there is an equilibrium where firm 1 of H type discloses with strictly positive probability. Consider the price competition that follows disclosure of high quality...
by this firm. It is obvious that firm 1 can never earn strictly positive profit in the state of the world where firm 2 is of \( L \) type. This is because (using (5)) the latter will always undercut any price above \( c_L \) charged by firm 1 by a sufficient amount so as to steal all business. This occurs independent of whether or not firm 2’s type is revealed at the disclosure stage. To earn strictly positive expected profit, firm 1 must sell at a price above \( c_H \) when firm 2 is of \( H \) type. Hence, consider the situation where firm 2 is also of \( H \) type. If firm 2’s type is fully revealed at the end of the disclosure stage, then it is obvious that the two firms will engage in Bertrand price competition leading to marginal cost pricing. What if firm 2’s type is not fully revealed at the end of the disclosure stage? As firm 1 has revealed its product quality to be high, it will be uninhibited in undercutting firm 2. As a result, firm 2 must earn zero expected profit in equilibrium; if it charges price above \( c_H \) it is undercut by firm 1 with probability 1 at the upper bound of its (possibly mixed) price distribution. As firm 2 earns positive profit when it is of \( L \) type, \( H \) type of firm 2 has greater incentive to charge any out-of-equilibrium price that undercut a price above marginal cost charged by firm 1. The D1 criterion suggests that following any such price undercutting by firm 2, buyers should believe that firm 2’s product is of high quality. Therefore, firm 2 will be uninhibited in undercutting firm 1. In particular, if firm 1 charges a price above marginal cost, it is undercut by firm 2 with probability 1 at the upper bound of its (possibly mixed) price distribution, leading to zero expected profit for firm 1. Thus following disclosure, firm 1 of \( H \) type earns negative net profit (taking into account disclosure cost \( d > 0 \)).

Next, we prove (iii). Consider the pricing subgame after the low-quality type of firm 1 deviates and discloses. In equilibrium, firm 1’s expected profit (ignoring any disclosure cost) is

\[
\geq \pi(c_H - (V_H - V_L) - c_L) \text{ as it can set a price just below } c_H - (V_H - V_L) \text{ and sell in the case that firm 2 is of } H \text{ type. Suppose that (5) holds with strict inequality. In that case, } c_H - (V_H - V_L) - c_L > 0 \text{ which means that firm 1’s expected profit }\pi > 0 \\
\text{Let us denote by } \pi_1 \text{ the upper bound of the support of the possibly mixed price strategy firm 1 chooses. Then, price } \pi_1 > c_L \text{ and at this price, firm 1 is undercut by firm 2 with probability 1 if the latter is of } L \text{ type. So, at price } \pi_1, \text{ firm 1 sells only in the state where firm 2 is of } H \text{ type. If } \pi_1 > c_H - (V_H - V_L), \text{ then at price } \pi_1, \text{ firm 1 is undercut with probability 1 by a margin of more than } (V_H - V_L) \text{ in the state where firm 2 is of type } H \text{ so that it sells zero at price } \pi_1. \text{ Therefore, } \pi_1 \leq c_H - (V_H - V_L) \text{ so that the only way for firm 1 to earn at least } \pi(c_H - (V_H - V_L) - c_L) \text{ as profit in the equilibrium of this subgame is that it sets } \pi_1 = c_H - (V_H - V_L), \text{ obtains equilibrium profit equal to } \pi(c_H - (V_H - V_L) - c_L) \text{ while firm 2 of } H \text{ type earns zero profit; all consumers buy from firm 1 when firm 2 is of } H \text{ type. In particular, firm 2 of } H \text{ type charges a price equal to } c_H \text{ in equilibrium. The other details of the mixed strategy equilibrium are easily derived. Firm 1’s profit at price } p \leq \pi_1 \text{ is given by}
\]

\[
\{x + (1 - x)[1 - F^L_1(p)]\} (p - c_L)
\]

where \( F^L_1(p) \) is the mixed strategy chosen by the \( L \) type of firm 2. Setting this expression equal to \( \pi(c_H - c_L - (V_H - V_L)) \), the equilibrium pay-off of firm 1 gives us a continuous mixed strategy distribution of firm 2 of type \( L \) on \( \{x[c_H - (V_H - V_L)] + (1 - x)c_L - (V_H - V_L)\} \). A similar consideration for the low type of firm 2 makes clear that firm 1 should choose a similar mixed strategy but with a mass point at price \( \pi_1 = c_H - (V_H - V_L) \) of probability \( x \). Consumers buy at the lowest price when both firms are of \( L \) type. Next, suppose that (5) holds with equality. In that case, neither firm has any market power. The unique equilibrium outcome is that firm 1 charges its marginal cost \( c_L \) and each type of firm 2 charges its marginal cost; all firms earn zero profit. Thus, we have that if the low-quality type of firm 1 deviates and discloses, its net profit in the D1 equilibrium of the continuation pricing game is \( \pi(c_H - (V_H - V_L) - c_L) - d \leq [p_H - (V_H - V_L) - c_L], \text{ the pay-off of the low quality firm if it does not deviate (as indicated in (7)), where } p_H \geq c_H \)

Finally, we return to the proof of (ii). Suppose there is a symmetric equilibrium where each firm discloses with positive probability \( x \in (0,1) \) if it is of \( L \) type and discloses with probability \( 0 \) when it is of \( H \) type. We show that given the proposed equilibrium strategy of firm 1, firm 2 of \( L \) type must earn strictly higher net expected profit from non-disclosure than from disclosure so that it would never randomise between them in equilibrium. There are two possibilities:
(a) firm 1 discloses and
(b) firm 1 does not disclose.

Given its equilibrium strategy, (a) occurs with probability \( x(1 - z) \) and (b) with probability \( 1 - x \).

We will show that non-disclosure is better for firm 2 of \( L \) type in both situations (a) and (b).

Suppose (a) occurs; in that case firm 1 is known to be of \( L \) type. If firm 2 of \( L \) type discloses in the first stage, Bertrand competition leads to a net profit of \(-d\). As the firm can guarantee itself at least zero net expected profit under non-disclosure, disclosure leads to lower pay-off in the event that (a) occurs. So, suppose that (b) occurs. In this case, the pricing game is one where firm 1’s type is \( H \) with (updated) probability \( \hat{x} = x/[1 - x(1 - z)] \) and \( L \) with probability \( 1 - \hat{x} \). If firm 2 of \( L \) type has not disclosed, it is a symmetric pricing game of incomplete information virtually identical to the one (characterised in Janssen and Roy, 2010; and described in Section 2) when both firms do not disclose for sure in the first stage, except that we replace \( x \), the probability of being \( H \) type, by \( \hat{x} \). As indicated in the text in Section 2, the pay-off of firm 2 (which is of \( L \) type) is (using (7)):

$$\hat{x}[p_H - (V_H - V_L) - \epsilon_L].$$

On the other hand, if firm 2 (which is of \( L \) type) discloses the pricing game is a game of one-sided incomplete information where firm 1 is of type \( H \) with probability \( \hat{x} \in (0, 1) \) and firm 2 is of \( L \) type for sure. Using the characterisation of the equilibrium of this pricing game in the proof of (iii) above, we have that the pay-off to firm 2 from disclosure is

$$\hat{x}[\epsilon_H - (V_H - V_L) - \epsilon_L] - d.$$ 

As \( p_H \geq \epsilon_H \) and \( d > 0 \), disclosure yields strictly higher net expected profit for firm 2.

Proof of Proposition 2. In the full non-disclosure outcome, the pricing strategies in the unique symmetric D1 equilibrium of the pricing game characterised by Janssen and Roy (2010) depend on whether or not the condition \( (V_L - \epsilon_L)/(V_H - \epsilon_L) \geq 1/2 \) holds. If \( (V_L - \epsilon_L)/(V_H - \epsilon_L) \leq 1/2 \), then the high-quality price satisfies \( p_H = \max\{\epsilon_H, \epsilon_L + 2(V_H - V_L)\} \) and the equilibrium is one where all consumers buy with probability 1. If \( (V_L - \epsilon_L)/(V_H - \epsilon_L) > 1/2 \), then \( p_H = V_H \) and the equilibrium is one where some consumers do not buy in the state where both firms are of high quality. Although Janssen and Roy (2010) do not formally analyse the case, the unique symmetric D1 equilibrium derived in that study continues to be a D1 signalling equilibrium when \( \epsilon_H = \epsilon_L \), although it is not the unique symmetric D1 equilibrium in this case; in what follows we will choose this as the equilibrium of the continuation pricing game for \( \epsilon_H = \epsilon_L \).

First consider the case where \( (V_L - \epsilon_L)/(V_H - \epsilon_L) \geq 1/2 \). When both firms do not disclose information with probability 1, the equilibrium of the pricing game is one where the high-quality firm sets a price \( p_H = \epsilon_L + 2(V_H - V_L) \), the low-quality firms choose a mixed pricing strategy over the interval \( [\epsilon_L + x(V_H - V_L), \epsilon_L + (V_H - V_L)] \) and the consumers buy at the lowest low-quality price if at least one of the firms is of low quality and otherwise randomly buys at one of the two shops. The equilibrium profits of the high-quality firm are given by \( x/2[2(V_H - V_L) - (\epsilon_H - \epsilon_L)]. \)

We will now show that under the conditions specified in the Proposition, no type has an incentive to deviate. It is easy to see that if the \( L \) type of any firm deviates and discloses, then it must lose all market to the rival in the state where the latter is of type \( H \). As the disclosing low-quality firm only makes profits in the state where the rival is also of type \( L \), Bertrand competition drives the price charged by firm 1 of type \( L \) to \( \epsilon_L \). The deviating firm makes a negative net profit of \(-d\) by disclosing; making the deviation not profitable.

Next, consider the case where the \( H \) type of a firm, say firm 1, deviates and discloses its type. This leads to a subgame where firm 1 is known to be of \( H \) type and firm 2’s type remains private information. In this subgame, it is easy to see that if firm 1 charges any price above \( \epsilon_L + (V_H - V_L) \), it is undercut with probability 1 by its rival of both types. Therefore, the highest price of firm 1 of type \( H \) after disclosure will not be larger than \( \epsilon_L + (V_H - V_L) \). Moreover, it is

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clear that the low type of firm 2 has to set a price equal to \( c_L \). As the low type of firm 2 cannot make any profit, the high type of firm 2 can also not make any profit in equilibrium, as otherwise the low type of firm 2 would have an incentive to deviate and imitate its high type’s price. The equilibrium then is one where both firm 1 (which is of high type) and the high type of firm 2 set a price equal to \( c_L + (V_H - V_L) \) and all consumers buy from firm 1 (which has disclosed its information). The high type of firm 2 cannot profitably undercut as consumers believe him to be of low type and will not buy at a deviating price. These consumers’ beliefs are consistent with the D1 requirement (note that this is the only subgame where a firm benefits from disclosing its information).

Therefore, the net profit of firm 1 of type \( H \) after disclosure is equal to 
\[
\frac{c_L}{C_0} + \frac{(V_H - V_L)}{C_0} \frac{V_H}{C_0} \frac{VL}{c_L} \frac{C_0}{C_0} - d.
\]

Comparing this to the profit of a \( H \) type firm in the candidate equilibrium shows that the deviation is not gainful if 
\[
d \geq (1 - \alpha)(V_H - V_L) - (1 - \alpha/2)(\epsilon_H - \epsilon_L) = \hat{d}.
\]

Now, consider the case where \((V_L - \epsilon_L)/(V_H - \epsilon_L) < 1/2\). In this case Janssen and Roy (2010) show that in case firms never disclose information, a unique D1 equilibrium exists where the high-quality firm sets a price \( p_H = V_H \), the low quality firms choose a mixed pricing strategy over the interval \([\epsilon_L + \alpha(V_L - \epsilon_L), V_L]\) and the consumers buy at the lowest low-quality price if at least one of the firms is of low quality and otherwise buys with a probability \( \eta = 2[(V_L - \epsilon_L)/(V_H - \epsilon_L)] \) and, if she buys, she randomly does so from one of the two firms. The equilibrium profits of the high-quality firm in this case are given by 
\[
\frac{c_L}{C_0} + \frac{(V_H - V_L)}{C_0} \frac{V_H}{C_0} \frac{VL}{c_L} \frac{C_0}{C_0} - d.
\]

This can be re-written as 
\[
d \geq (V_H - V_L) - (\epsilon_H - \epsilon_L) - \frac{(V_H - \epsilon_H)(V_L - \epsilon_L)}{V_H - \epsilon_L} = \hat{d}.
\]

Proof of Proposition 3. As the candidate equilibrium is fully revealing, in the price competition game, firms make no profit when both firms are of the same type. In the case where the firms are of different types, the high-quality firm wins the competition and sets a price equal to \( \epsilon_L + (V_H - V_L) \), which is larger than \( \epsilon_H \) under (8). The ex ante equilibrium profit of a high-quality firm in this case is therefore equal to 
\[
(1 - \alpha)[\epsilon_L + (V_H - V_L) - \epsilon_H] - d,
\]

whereas the low-quality firms earn zero profits. A necessary condition for this to be an equilibrium is that the net profit of the high-quality firm given by (A.1) should be non-negative, i.e.
\[
d \leq (1 - \alpha)[\epsilon_L + (V_H - V_L) - \epsilon_L].
\]

Note that if \((V_L - \epsilon_L)/(V_H - \epsilon_L) = 1/2\), \( \epsilon_L + 2(V_H - V_L) = V_H \)

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If this is satisfied, the only reason why this would not be an equilibrium outcome is if the high-quality firm has an incentive not to disclose. Suppose that the high-quality type of firm 1 deviates and does not disclose. Given that we consider an equilibrium where (only) the low quality type does not disclose, firm 2 now believes that firm 1 is of low-quality type and, therefore, sets a price equal to $c_L$ if it is itself of low-quality type and $c_L + (V_H - V_L)$ if it is of high-quality type. To determine the optimal pricing strategy of firm 1 in the pricing game, the out-of-equilibrium beliefs of consumers at price $p > c_H$ are important. As the equilibrium profit of a low-quality firm is 0, this type has a greater incentive to deviate to any such price (deviation is gainful for this type as long as it can expect to sell any strictly positive amount but that is not true for the high-quality type). Therefore, the D1 criterion implies that consumers should believe that any $p > c_H$ charged by firm 1 is actually set by a low-quality type and no consumer should buy at such price. Thus, the high-quality firm cannot gain by deviating and not disclosing its quality. Thus, (A.2) is necessary and sufficient for existence of this equilibrium.

**Proof of Proposition 4.** We know that in the disclosure equilibrium the $L$ type makes zero profits, whereas the $L$ type makes positive profits in the non-disclosure equilibrium. We therefore only need to check the profits of the $H$ type firms in the different equilibria. In the disclosure equilibrium, the $H$ type makes an *ex ante* profit of $(1 - x)(c_H + V_H - V_L - c_H) - d$. As indicated above, if $(V_L - c_L)/(V_H - c_L) \geq 1/2$, in the non-disclosure equilibrium where the $H$ type charges a price $p_H < V_H$ and it makes a net profit of $x(V_H - V_L) - x/2(c_H - c_L)$. Straightforward calculations show that the latter expression is larger than the former if

$$x > \frac{(V_H - V_L) - (c_H - c_L) - d}{2(V_H - V_L) - 3/2(c_H - c_L)}.$$ 

Denote the RHS of this inequality by $x^*$ if $(V_L - c_L)/(V_H - c_L) \geq 1/2$. It is easy to see that $x^* < [(V_H - V_L) - (c_H - c_L)]/[2(V_H - V_L) - 3/2(c_H - c_L)] < 1/2$.

If $(V_L - c_L)/(V_H - c_L) < 1/2$, the non-disclosure equilibrium is one where $H$ type firms charge a price $p_H = V_H$ and, as indicated above, each $H$ type firm makes a profit of $x[(V_H - c_H)(V_L - c_L)]/(V_H - c_L)$. Straightforward calculations show that this profit expression is larger than its net profit $(1 - x)(c_L + V_H - V_L - c_H) - d$ in the disclosure equilibrium if

$$x > \frac{(V_H - V_L) - (c_H - c_L) - d}{(V_H - c_H)(V_L - c_L) + (V_H - V_L) - (c_H - c_L)}.$$ 

Denote the RHS of this inequality by $x^*$ in case $(V_L - c_L)/(V_H - c_L) \leq 1/2$. Thus if both disclosure and full non-disclosure equilibrium co-exist, then for all $x > x^*$ both types of firms make more profit in the non-disclosure equilibrium.

**Proposition A.1.** Suppose that (8) and (9) hold. If either,

$$\frac{V_L - c_L}{V_H - c_L} \geq \frac{1}{2}$$  \hspace{1cm} (A.3)

or

$$\frac{1}{V_H - c_L} + \frac{1}{V_H - c_H} < \frac{1}{V_L - c_L},$$  \hspace{1cm} (A.4)

then $\hat{d} < d$ and both the full non-disclosure and the disclosure equilibrium (with only high-quality firms disclosing) co-exist if (and only if) $\hat{d} < d \leq \bar{d}$. If neither (A.3) nor (A.4) holds, then $\hat{d} \leq d$ and the two kinds of equilibrium do not co-exist for any value of the disclosure cost $d$; furthermore, for $d \in [\hat{d}, \bar{d}]$ there is no symmetric equilibrium where both quality types choose pure strategies at the disclosure stage but there is a symmetric equilibrium with partial disclosure where each high-quality firm discloses with probability $q \in (0, 1)$ and low-quality firms do not disclose.

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Proof of Proposition A.1. It is straightforward to see that \( \hat{d} < \bar{d} \) if \( (V_L - c_L)/(V_H - c_L) \geq 1/2 \). In the case, \( (V_L - c_L)/(V_H - c_L) < 1/2 \), straightforward algebra shows that \( \hat{d} < \bar{d} \), if and only if, \( 1/(V_H - c_L) + 1/(V_H - c_L) \geq 1/(V_L - c_L) \). In these cases, the statements of the Proposition on the necessary and sufficient conditions of the co-existence of a disclosure and non-disclosure equilibrium immediately follow. On the other hand, in the case, \( (V_L - c_L)/(V_H - c_L) < 1/2 \), it may be that \( \hat{d} < \bar{d} \) and then there is a region of disclosure cost \( d \) such that no pure strategy equilibrium exists. The proof concludes by showing that in this case there is a mixed strategy equilibrium where the high-quality firm randomises between disclosing and not disclosing and the low-quality type chooses not to disclose.

Hence, suppose that \( \hat{d} < d < \bar{d} \) and that a high-quality firm chooses to disclose with probability \( q \). In this case three possible pricing subgames can arise in equilibrium. First, if both firms disclose that they are of high quality, there will be Bertrand competition resulting in no profits for either firm. Second, if one firm discloses it is of high quality and the other firm does not disclose, we are in the pricing game analysed in Proposition 2 so that the high-profits for either firm. Third, if no firm discloses we are in the pricing game analysed in Janssen and Roy (2010) with the exception that now the firms believe their rival is of low quality with probability \( 1/2 \) and \( 1/2 \).

\[ \pi^*_H = \frac{\alpha(1-q)(V_H - c_H)(V_L - c_L)}{1-\alpha q} \frac{V_H - c_L}{V_H - c_L} \]

For a high-quality type to be indifferent between disclosing and not-disclosing, it therefore has to be the case that

\[ \alpha q \cdot 0 + (1-\alpha q)[c_L + (V_H - V_L) - c_H] - d = \alpha q \cdot 0 + \alpha(1-q) \frac{(V_H - c_H)(V_L - c_L)}{V_H - c_L} \]

where the two terms on both sides of the expression reflect the pay-off of disclosing (respectively, not disclosing) in case the other firm discloses and does not disclose. This can be re-written as

\[ (1-\alpha q)[(V_H - c_H) - (V_L - c_L)] - \alpha(1-q) \frac{(V_H - c_H)(V_L - c_L)}{V_H - c_L} - d = 0 \]

It is easy to see that the LHS of this equation is decreasing in \( q \), it equals \( \hat{d} - \bar{d} > 0 \) if \( q = 0 \) and it equals \( \hat{d} - \bar{d} < 0 \) if \( q = 1 \). Thus, there must be a unique value of \( q \) with \( 0 < q < 1 \) such that the indifference equation holds. As the argument showing that the low-quality type does not have an incentive to deviate is the same as before, we conclude that in the case \( (V_L - c_L)/(V_H - c_L) < 1/2 \) and \( d_2 < d < d_2 \) a mixed strategy equilibrium exists where the high-quality firm randomises between disclosing and not disclosing.

In the proofs of Propositions 5 and 6 we use the following Lemma A.1, determining equilibrium pricing strategies of the different pricing subgames when \( c_L \geq c_H \).

**Lemma A.1.** Assume (12). Consider the game of price setting that follows the voluntary disclosure stage.

(i) Suppose that the types of both firms are fully revealed at the disclosure stage. Then, both firms charge price equal to marginal cost earning zero (gross) profit when they have identical types, and if their types differ, the L type firm charges its marginal cost selling zero output while the H type firm sells to the entire market charging price equal to \( V_H - (V_L - c_L) \) and earning (gross) profit equal to \( [(V_H - c_H) - (V_L - c_L)] \).

(ii) Suppose that the type of only one firm (say, firm 1) is fully revealed at the end of the disclosure stage. Let \( x \in (0,1) \) denote the probability that the other firm (firm 2) is of H type assigned by the updated posterior belief after the disclosure stage.
Suppose the revealed type of firm 1 is $H$. Suppose further that

\[
\frac{V_H - V_L}{c_L - c_H} \geq \frac{x}{1-x}.
\]  

(A.5)

Then, firm 1 charges $[c_L + (V_H - V_L)]$, sells only in the state where rival is of type $L$ and earns gross expected profit $(1 - x)(c_L + V_H - V_L - c_H)$. Firm 2 of type $L$ sells zero with probability 1 and follows a mixed strategy; firm 2 of type $H$ charges $c_L$, sells to all consumers and earns gross profit equal to $(c_L - c_H)$. Next, suppose that (A.5) does not hold. Then, firm 1 follows a mixed strategy that has a mass point at $(c_L + V_H - V_L)$ and a continuous distribution on an interval $[p, c_L]$, where $p < c_L$, whereas firm 2 of type $H$ follows a mixed strategy that has a mass point at $c_L$ and whose support is the interval $[p, c_L]$; the equilibrium (gross) profits of both firms are equal to $(1 - x)(c_L + V_H - V_L - c_H)$. Firm 2 of type $L$ follows a mixed strategy and sells zero, earning zero gross profit.

(ii.) Suppose the revealed type of firm 1 is $L$. Then, firm 1 as well as both types of firm 2 charge a common price $c_L$ and all consumers buy from firm 2 with probability 1; firm 1 as well as firm 2 of type $L$ type earn zero gross profit while firm 2 of type $H$ type earns gross profit equal to $(c_L - c_H)$.

(iii) Suppose that neither firm’s type is revealed fully at the end of the disclosure stage. In particular, consider the symmetric situation where the updated posterior belief assigns identical probability $\beta \in (0,1)$ to the event that either firm is of $H$ type. The unique symmetric equilibrium is one where both firms of type $L$ charge price $c_L$ earning zero (gross) profit, whereas each firm of type $H$ follows a mixed strategy with continuous distribution on support $[(1 - \beta)c_L + \beta c_H, c_L]$ earning (gross) expected profit equal to $(1 - x)(c_L - c_H)$.

**Proof of Lemma A1.** The proof of part (i) is obvious. Consider (ii.a). In the event that firm 2 is of type $L$, firm 1 can sell to the entire market at price $c_L + (V_H - V_L) > c_H$ and therefore its equilibrium expected (gross) profit $\geq (1 - x)(c_L + V_H - V_L - c_H) > 0$. If firm 1 sells only in the state where rival is of $H$ type, price competition would drive its profit to zero. Therefore, it must sell in the state where rival is of $L$ type and thus firm 2 of type $L$ must earn zero gross profit in equilibrium. If firm 2 of type $H$ sells at any price above $c_L$ with positive probability, it will be imitated by firm 2 of type $L$. Therefore, in equilibrium, the price charged by firm 2 of type $H$ does not exceed $c_L$. The decision problem for firm 1 (which is of type $H$) is then whether to forsake the market in the state where firm 2 is of type $H$ and sell only in the state where the latter is of type $L$ charging a deterministic price $c_L + V_H - V_L$, or to compete for the market even when its rival is of type $H$. First, suppose (A.5) holds. It is optimal for firm 1 to forsake the market when its rival is of type $H$ and, therefore, charge $c_L + (V_H - V_L)$ with probability 1. Firm 2 of type $L$ sells zero with probability 1 and follows a mixed strategy whose distribution function $\phi$ is continuous with support $[c_L, \infty)$, where

\[
\phi(p) = 1 - \frac{c_L + V_H - V_L - c_H}{p + V_H - V_L - c_H}, \quad p > c_L.
\]

This distribution function makes firm 1 of type $H$ indifferent between charging $c_L + (V_H - V_L)$ and any price above that. Firm 2 of type $H$ charges $c_H$ with probability 1. Next, suppose that (A.5) does not hold, i.e. $(V_H - V_L)/(c_L - c_H) < x/(1 - x)$. In this case, firm 1 follows a mixed strategy that has a mass point at $(c_L + V_H - V_L)$ and a continuous distribution on the interval $[p, c_L]$, where $p$ is given by

\[
p - c_H = (c_L + V_H - V_L - c_H)(1 - x).
\]

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Note that \( p < c_L \). The distribution function \( F^H(p) \) followed by firm 1 is given by:

\[
F^H(p) = \begin{cases} 
0, & p \leq x \frac{c_L + V_H - V_L - c_H}{p - c_H}, \quad p \in [p, c_L] \\
1 - (1 - x) \frac{c_L + V_H - V_L - c_H}{p - c_H}, \quad p \in [c_L, c_L + V_H - V_L] \\
1, & p \geq c_L + V_H - V_L.
\end{cases}
\]

Firm 2 of type \( H \) follows the distribution function \( \Gamma^H(p) \) where

\[
\Gamma^H(p) = \begin{cases} 
0, & p \leq x \frac{c_L + V_H - V_L - c_H}{p - c_H}, \quad p \in [p, c_L] \\
1 - \left(1 - \frac{x}{c_L} - 1\right), \quad p \in [p, c_L] \\
1, & p \geq c_L.
\end{cases}
\]

Note that firm 2 puts probability mass \( (1 - x/c_L) (V_H - V_L - c_H) \in (0, 1) \) on price equal to \( c_L \).

Finally, firm 2 of type \( L \) follows a mixed strategy with the distribution function \( \phi \) as outlined in above which makes firm 1 of type \( H \) indifferent between charging \( c_L + (V_H - V_L) \) and any price above that. It is easy to check that given the strategy of firm 2, firm 1 of type \( H \) is indifferent between charging \( c_L + V_H - V_L \) and any price in \( [p, c_L] \) and is strictly worse off charging a price in \( (c_L, c_L + V_H - V_L) \). On the other hand, given the equilibrium strategy of firm 1, firm 2 of type \( L \) can never make strictly positive profit and, therefore, has no incentive to deviate from its prescribed strategy; firm 2 of type \( H \) is indifferent between all prices in the interval \( [p, c_L] \) and strictly prefers to not set a price below \( p \).

Next, consider (ii.b). As firm 1 is known to be of type \( L \), it can never sell in the state where the rival firm is of type \( H \) which leads to severe competition between \( L \) type firms and an outcome where both \( L \) types charge their marginal cost while firm 2 of type \( H \) sells to all consumers though the latter cannot charge a price above of \( c_H \) without being imitated by its own \( L \) type; therefore, both types of firm 2 charge price equal to \( c_L \). All consumers (strictly prefer to) buy from firm 2. The out-of-equilibrium beliefs assign probability 1 to the event that firm 2 is of type \( L \), if it charges a price above \( c_L \).

Finally, consider (iii). If a firm is of \( H \) type, it can always charge a price just below \( c_L \) and guarantee itself profit arbitrarily close to \( (c_L - c_H) \) in the state where the rival firm is of \( L \). Therefore, the equilibrium profit of the \( H \) type firm must be strictly positive which also implies that in any symmetric equilibrium, a firm of \( H \) type must sell in the state where the rival is of \( L \) type (if \( H \) type firms sell only in the state where both firms are of \( H \) type, Bertrand price competition will lead to zero profit). This, in turn, implies that \( L \) type firms must sell zero in the state where rival is \( H \) type and therefore Bertrand competition between \( L \) type firms leads to marginal cost pricing for those firms. Even though consumers would prefer to buy high quality at a price slightly above \( c_H \) rather than buy low quality at price \( c_L \), a type \( H \) firm cannot charge a price above of \( c_H \) without being imitated by its own \( L \) type (that earns zero profit in equilibrium). The unique symmetric (D1) equilibrium of this game is one where both firms of type \( L \) charge price \( c_L \) while each firm of type \( H \) follows a mixed strategy with distribution function \( \Psi \) and support \( [(1 - x) c_L + x c_H, c_L] \) where

\[
\Psi(p) = 1 - \left(\frac{1 - x}{x} - 1\right), \quad p \in [(1 - x) c_L + x c_H, c_L].
\]

The out-of-equilibrium beliefs assign probability 1 to the event that firm 2 is of type \( L \) if it charges a price above \( c_L \).

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Proof of Proposition 5. Suppose that (13) holds and that, contrary to the Proposition, there exists \( d < 0 \) and an equilibrium where the types of both firms are fully revealed with probability 1 at the voluntary disclosure stage. In any such equilibrium, the market outcome is identical to the full-information outcome (except for the disclosure cost being incurred) and therefore the equilibrium profit (gross of any disclosure cost) of each firm of \( L \) type is 0 and that of each firm of \( H \) type is at most \((1 - z)(\epsilon_L + V_H - V_L - \epsilon_H)\) as such a firm can make money only if its rival is of \( L \) type. The equilibrium strategy of firm 1 at the voluntary disclosure stage can be one of three kinds:

(i) Disclose if, and only if, realised type is \( H \);

(ii) disclose if, and only if, realised type is \( L \); and

(iii) disclose independent of realised type.

Consider case (i). Suppose firm 2 of type \( H \) deviates and does not disclose its type. Given the equilibrium strategy of firm 2, firm 1 must then infer that firm 2 is of type \( L \) with probability 1. It would then be rational for firm 1 to believe that firm 2 would never charge a price lower than \( \epsilon_L \), which means that independent of firm 2’s type, it would never charge a price strictly less than \( \epsilon_L \). The deviation strategy of firm 2 of type \( H \) would then be to charge a price \( \epsilon_L - \epsilon_H - e \) for \( e > 0 \) arbitrarily small. Upon observing this out-of-equilibrium price set by firm 2, consumers must charge price \( \epsilon_L \) and only a type \( L \) firm can make money only if its rival is of \( H \) type.

Next, consider cases (ii) and (iii). Here, firm 1 of type \( L \) earns negative pay-off after disclosure (it makes zero profit under full information) while it can certainly ensure zero pay-off by not disclosing (and charging \( \epsilon_L \) in the continuation game).

Proof of Proposition 6.

(i) In an equilibrium where both firms disclose with probability 0, the equilibrium path at the pricing stage is one where firms signal quality through prices, as described in part (iii) of Lemma A.1. In particular, a firm charges \( \epsilon_L \) for sure if it is of \( L \) type and earns zero profit. If a firm is of \( H \) type it follows a mixed strategy with no mass point whose support is an interval \([\bar{p}_L, \epsilon_L]\) where \( \epsilon_L < \bar{p}_L \) and earns equilibrium pay-off \((\epsilon_L - \epsilon_H)(1 - z)\). The out-of-equilibrium consumer beliefs are that a firm charging price \( \epsilon_L \) is of low quality with probability 1. Clearly, a low-quality firm has no incentive to deviate.
and disclose quality. Suppose a firm, say firm 2, of type $H$ deviates and discloses its true quality. The continuation pricing game is as described in part (ii) of Lemma A.1, firm 2 charges $c_L + (V_H - V_L)$ with positive probability and, at that price, sells to all consumers only when its rival is of type $L$ and the deviation profit of firm 2 is

$$(1 - x)(c_L + V_H - V_L - c_H) - d \leq (c_L - c_H)(1 - x),$$

using (16).

(ii) We begin defining the equilibrium strategies. At the disclosure stage, each firm of type $L$ chooses not to disclose while each firm of type $H$ discloses with probability $p \in (0,1)$. We will show later how this probability is determined. At the pricing stage, the strategies of firms on the equilibrium path are as follows. If both firms disclose their types, they are both of type $H$ and both firms charge $c_H$ and earn net profit (net of disclosure cost 0). If firm 2 discloses, but not firm 1, then the firms’ pricing strategies are as indicated in part (ii) of Lemma A.1 where the posterior belief assigns probability $x = \frac{a(1 - p)}{(1 - x)}$, $1 - x = \frac{a}{1 - x}$, so that the expected net profit from disclosure is

$$\pi^H_2(D) = (1 - x)(c_L + V_H - V_L - c_H)(1 - x) - d$$

On the other hand, the reduced-form expected profit of firm 2 of type $H$ when it does not disclose but its rival does disclose (which occurs with probability $1 - x$), firm 2’s expected profit is $(1 - x)(c_L - c_H)$. The expected net profit of firm 2 of type $H$ from non-disclosure can be written as

$$\pi^H_2(ND) = [1 - (1 - p)x](c_L - c_H), \text{ if } p \geq 1 - \frac{1 - x V_H - V_L}{x c_L - c_H}$$

$$= \frac{1 - x}{1 - x} \left[ p x (V_H - V_L) + (c_L - c_H) \right], \text{ if } p < 1 - \frac{1 - x V_H - V_L}{x c_L - c_H},$$

where the second line is valid only if $(V_H - V_L)/(c_L - c_H) < x/(1 - x)$. It is easy to check that

$$\frac{1 - x}{1 - x} \left[ p x (V_H - V_L) + (c_L - c_H) \right] - [1 - (1 - p)x](c_L - c_H) \to 0,$$

as $p \to 1 - \frac{1 - x}{x}[(V_H - V_L)/(c_L - c_H)]$. Thus, $\pi^H_2(ND)$ is continuous in $p$ on $[0,1]$. As $p \to 0, \pi^H_2(ND) \to (1 - x)(c_L - c_H)$ so that, using (17), $\pi^H_2(D) - \pi^H_2(ND) \to (1 - x)(V_H - V_L) - d > 0$. On the other hand, $\lim_{p \to 1} \pi^H_2(ND) \geq (c_L - c_H)$ so that, using (17),
\[
\lim_{\hat{p} \to 1} [\pi_1^H(D) - \pi_1^L(ND)] \leq (1 - \alpha)(V_H - V_L) - \alpha(c_L - c_H) - d < 0.
\]

From the intermediate value theorem, there exists \( \hat{p} \in (0, 1) \) such that \( \pi_1^H(D) = \pi_1^L(ND) \) for \( p = \hat{p} \). This completes the construction of the equilibrium.

University of Vienna and Higher School of Economics
Southern Methodist University

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References

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