Disclosing Multiple Product Attributes

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How do multiple attributes of a product jointly determine a seller's disclosure incentives? I model a monopolist whose product is characterized by vertical quality and a horizontal attribute. Contrary to the unraveling theory, the monopolist in equilibrium does not always choose disclosure. When the product's quality is common knowledge, a monopolist with higher quality is less likely to disclose the horizontal attribute. Notably, the monopolist may choose nondisclosure when his product has the highest quality. The results shed light on governments' mandatory disclosure policies and companies' marketing strategies.

1. Introduction

Product variety and complexity have both increased as the economy grows. Consumers, as a result, often have to choose among products that differ in many attributes. Although information on products' existence and prices is relatively easy to acquire, it can be hard for consumers to figure out which product provides them with the best match. Take, for example, computers, over-the-counter drugs, cars, tennis rackets, mattresses, etc.

Sellers can help consumers make more informed purchase decisions by disclosing product information. Traditionally, they may describe product attributes in advertisements, or encourage consumers to try their products by offering free samples and free returns. Recent

developments in information technology have greatly reduced the cost of information disclosure. Sellers now can easily publish online a detailed description or third-party reviews of their products.[1] Information disclosure has become much easier for sellers.

Empirical studies provide mixed evidence on sellers' disclosure incentives. Jin and Leslie (2003) find that almost all restaurants in Los Angeles County voluntarily display hygiene cards. A hygiene card shows an aggregate grade on hygiene quality: "A" (90–100%), "B" (80–89%), "C" (70–79%), or the actual score if it is less than 70%.[2] Mathios (2000), on the other hand, finds that only half of the salad dressings wear nutrition labels before the national mandate, Nutrition Labeling and Education Act. Nutrition labels, rather than showing an aggregate grade, display information on multiple nutrient contents contained in the dressing: calories, total fat, cholesterol, sodium, carbohydrate, and protein.[3]

Jin (2005) studies participation of Health Maintenance Organizations (HMOs) in two quality surveys.[4] The first survey evaluates each participating HMO's overall quality and assigns one of four possible statuses based on the extent to which it meets certain quality standards: full (valid for 3 years), 1-year, provisional and denial. The second survey evaluates and discloses each participating HMO's quality in multiple services, typically including breast cancer screening, diabetic eye exams, child immunization, and physician turnover rates.[5] The study finds that participation is not complete in either survey although the participation rate is consistently higher in the first one.[6]

Empirical evidence hence suggests that sellers do not always voluntarily disclose product information. Moreover, their disclosure incentives seem to depend on the amount and nature of the information that is being disclosed. The observations naturally lead to the following questions. Which sellers disclose product information? How do multiple product attributes *jointly* determine sellers disclosure strategy? Does mandatory disclosure always increase social welfare?

By analyzing disclosure of multiple product attributes, this paper aims to provide some insights into these questions. Although a product may have many attributes, they can often be summarized into two categories: vertical and horizontal. For example, the overall quality of

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1. See Chen and Xie (2005) for a comprehensive study of third-party product reviews.
2. See www.stanford.edu/~pleslie/restaurants for photos of hygiene cards.
3. See http://www.fda.gov/opacom/backgrounders/foodlabel/newlabel.html for a photo of the nutrition label.
4. Both surveys are conducted by the National Committee for Quality Assurance (NCQA). The first survey is NCQA accreditation program. The second survey is Health Plan Employer Data and Information Set joint with Member Satisfaction Survey.
5. See http://www.ncqa.org/Programs/HEDIS/2007/MeasuresList.pdf for the most recent list of measures.
6. See Table 1 in Jin (2005) for a comparison of participation rates.

an HMO is a vertical attribute in the sense that all consumers prefer it to be higher. The distribution of quality across different services is, on the other hand, a horizontal attribute: some consumers may prefer higher quality in eye exams whereas others care more about child care. As vertical and horizontal dimensions are general enough to cover most product attributes and easy to analyze, they have been the key elements in the literature of product differentiation.[7] In accordance with the literature, I model a fully informed monopolist whose product differs in vertical quality and a horizontal attribute. By focusing on a monopolist, the model isolates disclosure's effects on price and demand from its possible effects on competition, so that the results do not rely on a particular market structure.

In the following sections, I first assume vertical quality is common knowledge and analyze the monopolist's disclosure incentive on the horizontal attribute. The scenario best describes products that have gained some quality reputation. The monopolist's equilibrium disclosure strategy follows a certain pattern. He discloses the horizontal attribute only when it is in a central region vis-à-vis consumer tastes. Consumers, upon seeing nondisclosure, do not know at which corner of the taste space the horizontal attribute is. The information asymmetry helps the monopolist to enlarge demand. As the horizontal attribute moves away from the center of the taste space, the demand enlargement effect increases and the monopolist is more likely to choose nondisclosure.

Interestingly, the monopolist is less likely to disclose the horizontal attribute when vertical quality is known to be higher. The intuition is as follows. A low-quality monopolist can hardly make any profit without ensuring some consumers a good match. A high-quality monopolist, in contrast, aims to cover the entire market at a high price. He would have to lower the price if some consumers learn a bad match from disclosure, and hence chooses nondisclosure. Some preliminary evidence from the magazine market supports the result.

I then examine the case in which both vertical quality and the horizontal attribute are known only to the monopolist. This scenario best describes new products or products that are frequently upgraded, such as computer software and skin-care products. The monopolist has the option to disclose all product information and faces a new tradeoff: the more he wants to disclose a high vertical quality and targets a bigger population, the more he wants to hide the horizontal attribute. Overall, he is more likely to choose disclosure when vertical quality is higher. Nevertheless, nondisclosure could occur even when the product has the

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7. See Becker (1965), Lancaster (1966), Muth (1966), Rosen (1974), Gorman (1980), and Tirole (1994).

highest possible vertical quality. In the context of Mathios (2000) and Jin (2005), my results suggest that when a seller's product quality is high in some dimensions and low in others, he may choose nondisclosure even with a high overall quality.

The model yields two policy implications. First, mandatory disclosure may hurt both consumer welfare and the monopolist's profit. Second, consistent with Jin and Leslie (2003) and Jin (2005), sellers are more likely to participate in quality surveys with one aggregate vertical measure than those with multiple measures. Conceptually, multiple quality measures disclose not only the overall quality but also the quality profile, a horizontal attribute. Survey designers should therefore consider the tradeoff between a survey's informativeness and its participation rate.

The current paper extends "games of persuasion" in Grossman (1981) and Milgrom (1981). Their seminal papers establish the theory of "unraveling": if quality is unknown to consumers and a seller can credibly and costlessly disclose it, he always does. The logic is as follows. The seller with the highest quality always benefits from revealing his quality. Once he reveals his quality, the seller with the second highest quality benefits from revealing *his* quality. The process continues until every quality type is revealed.

Several studies have examined the robustness of unraveling. Most of these studies, however, do not consider privately known horizontal product attributes. Instead, they often focus on incomplete product information of the seller (Shin, 1994), cost of product information acquisition and dissemination (Jovanovic, 1982; Verrecchia, 1983; Dye, 1986; Matthews and Postlewaite, 1985; Farrell, 1986; Shavell, 1994; Fishman and Hagerty, 2003; Dye and Sridhar, 1995; Stivers, 2004), or disclosure's impact on competition (Okuno-Fujiwara et al., 1990; Cheong and Kim, 2004; Board, 2009; Levin et al., 2009).

Hotz and Xiao (forthcoming) consider horizontally differentiated products, but they assume that the horizontal attributes are known to consumers. They show that quality disclosure could intensify price competition in a later stage, and therefore firms may choose nondisclosure.[8] I allow the horizontal attribute to be privately known to the monopolist and focus on the interaction of multiple product attributes in determining disclosure incentives. My results do not rely on competition.

Seidmann and Winter (1997) study unraveling in a sender–receiver framework.[9] They assume that the sender cannot take any action other

8. A similar reasoning appears in Chen and Xie (2005).
9. See Crawford and Sobel (1982)'s seminal paper on cheap talk: disclosure of payoff-relevant information in a sender–receiver framework.

than sending a message and the receiver's best response is increasing in the sender's true type. The assumptions can hardly be met in the context of product information disclosure. First, a seller sets the price besides disclosing product information. Second, a buyer's best response is not monotonic in the product's horizontal attribute.

This paper is also related to the literature of informative advertising.[10] Nelson (1974) first mentions that advertising can help match products to buyers. Subsequent studies often focus on comparing the market determined level of advertising with the socially optimal level.[11] Lewis and Sappington (1994) model quality signals that inform consumers of their match with the product. They examine how a producer chooses the precision of such signals and find that he often chooses the best available signal or the completely uninformative signal. Anderson and Renault (2006) show that a monopolist would reveal only partial information regarding consumers' match with his product. A fundamental difference between my paper and the existing informative advertising literature is that I consider horizontal attributes: consumers are affected differently by the disclosure of a particular product location. Anderson and Renault (2009) study comparative advertising and model disclosure of horizontal match information. Although they focus on a two-firm setting and discuss welfare implications of allowing versus banning comparative advertising (disclosing both own and rival's horizontal information), I have a monopoly setting in the current paper and show that horizontal information is not always revealed even when disclosure is allowed and there is no rival in the market.

The outline of the paper is the following. Section 2 introduces the model and examines the complete-information benchmark. Section 3 examines products with known vertical quality and an unknown horizontal attribute. Section 4 examines products with unknown vertical quality and horizontal attribute. Section 5 concludes. All proofs are in the Appendix.

2. A Benchmark Model: Complete Information

A profit-maximizing monopolist sells a product to many consumers. For simplicity, I assume that there is no production cost. The product is characterized by its vertical quality and horizontal attribute. For brevity, I refer to vertical quality as "quality," and the horizontal attribute as "location" hereafter. Both quality and location of the product are exogenously determined, which can be interpreted in two ways. First,

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10. See Bagwell (2007) for a comprehensive review of the advertising literature.
11. Examples include Grossman and Shapiro (1984) and Meurer and Stahl (1994).

the situation considered here represents a disclosure subgame in which quality and location are chosen in an earlier stage of an extended game. Second, quality and location are results of an R&D process that involves experiments with random outcomes.

Denote quality by v and location by l. The monopolist's product is characterized by vector (v, l). I assume that $v \geq 0$ and $0 \leq l \leq 1$. The monopolist learns (v, l) immediately after they are realized. For example, he can learn (v, l) by surveying a small group of consumers.

Utility-maximizing consumers of mass one are uniformly distributed on $[0, 1]$. If a consumer located at c purchases one unit of the product from firm[12] (v, l) at a price p, her utility is,

$$U(c; p; v, l) \equiv v - |c - l| - p.$$

That is, a consumer's utility is the product's quality less its price and her mismatch, defined as the distance between the consumer and the product. If a consumer does not buy the product, her utility is zero regardless of her location. Consumer c buys one unit of the product if $U(c; p; v, l) \geq 0$.

In the complete-information benchmark, vector (v, l) is common knowledge. There is no uncertainty in the game. The monopolist chooses a price, and then each consumer decides whether to buy a unit of the product.

PROPOSITION 1: *Suppose the product's quality and location (v, l) are common knowledge. In the subgame perfect equilibrium, the monopolist's profit and demand both increase in v and decrease in $|l - 0.5|$. Equilibrium price always increases in v; it decreases in $|l - 0.5|$ if $v \geq \frac{3}{2}$, and is not monotonic in $|l - 0.5|$ otherwise.*

Intuitively, the product becomes more popular when location approaches 0.5. The monopolist can take advantage of the increased popularity, sell more units of the product, and make a higher profit. When vertical quality increases, the monopolist can take advantage of the increased willingness to pay to raise both price and demand, and hence the profit.

The pattern of price with respect to location is more complicated. If $0 \leq v < \frac{3}{2}$, the equilibrium price first increases and then decreases as location approaches 0.5. If $v \geq \frac{3}{2}$, the equilibrium price always increases as location approaches 0.5. In general, price has to be low when location is close to 0 or 1, because otherwise the monopolist barely gets any demand. As location moves away from 0 or 1 toward 0.5, more consumers become interested in the product and the monopolist raises

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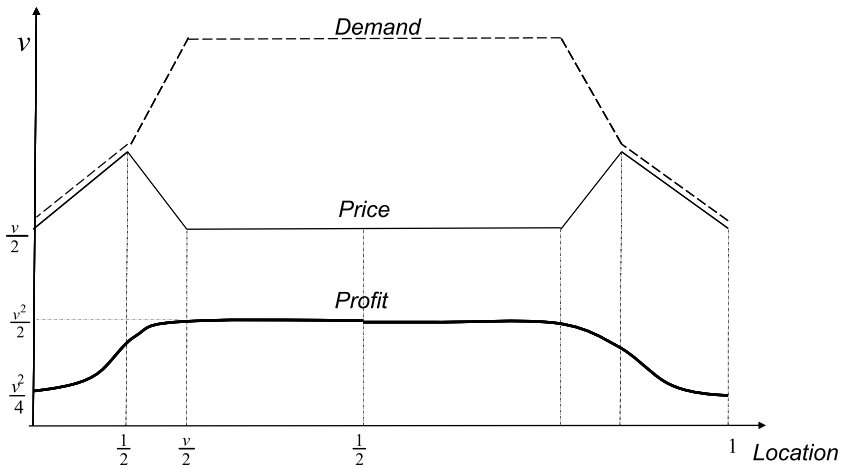12. A firm refers to a type of the monopolist.

FIGURE 1. EQUILIBRIUM PRICE, DEMAND AND PROFIT UNDER
COMPLETE INFORMATION

$v < 1$ in this figure. The x-axis represents the product's horizontal attribute space $[0, 1]$.
The thin solid line is the monopolist's equilibrium price, the dashed line equilibrium
demand, and the thickened solid line equilibrium profit. The price and demand curves
overlap when location is close to 0 or 1.

equilibrium price. When location gets close to 0.5, two possibilities arise.
If quality is high, the monopolist sells to all consumers by making the
consumer with the worst match indifferent, and therefore increases the
equilibrium price as location approaches 0.5. If quality is low, he does
not try to sell to all consumers as the price would be too low. As the
product's location gets closer to 0.5, he tries to sell more units. In order
to sell more, he lowers the equilibrium price.

Figure 1 illustrates the low quality case: it shows how equilibrium
price, demand, and profit change with location when quality is fixed
to be lower than 1. The monopolist in Figure 1 never sells to the
entire market. As explained, equilibrium price first increases and
then decreases as location approaches 0.5, although both equilibrium
demand and profit increase.

3. Known Quality, Unknown Horizontal Attribute

In this section, consumers know the product's quality, but not its
location. The monopolist has the option to disclose the location at no
cost. The scenario best describes mature products that have accumu-
lated some quality reputation. For example, when a consumer decides

whether to buy a popular digital camera, she can learn its quality reputation by reading online reviews or asking her friends. However, she can hardly find out her exact match without trying the camera. To be more specific, I assume product quality $v \geq 0$ to be common knowledge and analyze the following game.

Stage 1 Nature determines l according to a probability density function $g(l)$. The monopolist knows l; consumers know their own locations and $g(l)$, but not l.

Stage 2 The monopolist decides whether to disclose l. If he does, all consumers learn l.

Stage 3 The monopolist chooses a price. Consumers decide whether to buy the product.

If the monopolist earns the same profit whether he chooses disclosure or not, I assume that he chooses disclosure. The assumption is chosen to assure that nondisclosure behavior in equilibrium does not rely on a favorable tie-breaking rule.

I focus on perfect Bayesian equilibria (PBE) in pure strategies and categorize them into two groups. A fully revealing equilibrium is a PBE in which the monopolist always chooses disclosure. Any other PBE is a partially revealing equilibrium. I first discuss the existence of a fully revealing equilibrium.

PROPOSITION 2: *A fully revealing equilibrium always exists.*

A fully revealing equilibrium can always be supported by a pessimistic off-equilibrium-path belief: consumers assume that a firm is located as far from 0.5 as possible whenever it deviates to choose nondisclosure. Under such a belief, no firm would deviate to earn a lower profit, and hence a fully revealing equilibrium is maintained.

In the remaining of this section, I discuss partially revealing equilibria and show that the monopolist discloses his location only when it is in a central region.

Consider any partially revealing equilibrium. The monopolist's equilibrium profit is higher at every location in a partially revealing equilibrium than in a fully revealing equilibrium, as the monopolist can always earn the complete-information equilibrium profit by choosing disclosure.

When the monopolist chooses nondisclosure, consumers may infer the product's location from the equilibrium price. For any equilibrium price p, let $L(p)$ be the set of locations at which the monopolist chooses nondisclosure and charges p. The consumer located at c, upon

observing price p, expects her utility to be

$$EU(c; p; v, l) = v - p - E(|c - l| | l \in L(p)). \tag{1}$$

The last term, $E(|c - l| | l \in L(p))$, is her expected mismatch with the product. The consumer buys one unit of the product if $EU(c; p; v, l) \geq 0$.

Let $D^p(p; v, L(p))$ denote the equilibrium demand of firm (v, l) when it chooses nondisclosure and charges equilibrium price p.

$$D^p(p; v, L(p)) = m(\{c \mid EU(c; p; v, l) \geq 0\}). \tag{2}$$

The right-hand side is the measure of the set of consumers who expect a positive utility from buying the product. The firm's corresponding equilibrium profit is, therefore,

$$\pi^p(v) = p \cdot D^p(p; v, L(p)) = p \cdot m(\{c \mid EU(c; p; v, l) \geq 0\}). \tag{3}$$

Firms with $l \in L(p)$ make the same equilibrium profit by (1)–(3). Therefore, if two nondisclosing firms make different levels of equilibrium profit, they must charge different equilibrium prices. However, there is no cost for the low profit firm to mimic the high profit one by charging the latter's equilibrium price. Consequently, I have lemma 1.

LEMMA 1: *All nondisclosing firms make the same profit in a partially revealing equilibrium.*

Lemma 1 suggests that although nondisclosing firms can charge different equilibrium prices, they must make the same equilibrium profit. Denote this profit by $\pi^p(v)$, the following lemma compares $\pi^p(v)$ with profit levels in the complete information equilibrium.

LEMMA 2: *Let $\pi^c(v, l)$ be the profit of firm (v, l) under complete information. In a partially revealing equilibrium, $\pi^c(v, 0) = \pi^c(v, 1) < \pi^p(v) \leq \pi^c(v, 0.5)$.*

Lemma 2 states that a nondisclosing firm makes more profit than when it is known to be located at 0 or 1 and less profit than when it is known to be located at 0.5. In other words, it makes the same equilibrium profit as some firm does under complete information, which leads to the following proposition.

PROPOSITION 3: *In every partially revealing equilibrium, there exists a disclosure threshold f with $0 < f \leq 0.5$ such that the monopolist discloses his location if and only if $f \leq l \leq 1 - f$. Equilibrium profit is $\pi^c(v, l)$ when he chooses disclosure, and $\pi^c(v, f)$ otherwise.*

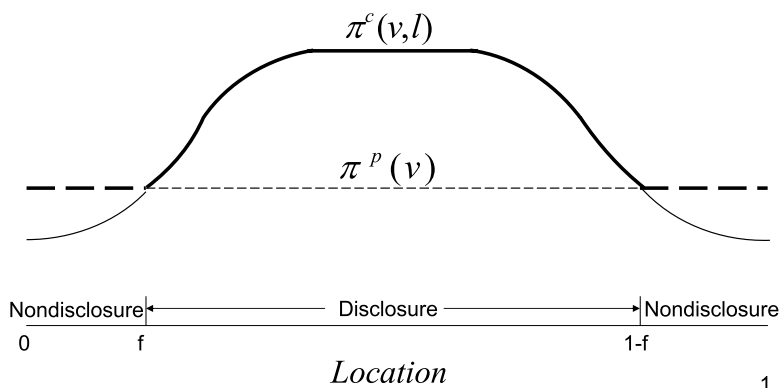See Figure 2 below for an illustration of Proposition 3.

FIGURE 2. PROFIT IN A PARTIALLY REVEALING EQUILIBRIUM

In this figure, $0 < f < 0.5$. The solid line is the monopolist's profit under complete information, $\pi^c(v, l)$. The dashed line is $\pi^p(v)$. The thickened parts of the two lines represent the monopolist's profit in the partially revealing equilibrium.

As shown in Figure 2, f is determined by $\pi^c(v, f) = \pi^p(v)$. The monopolist discloses his location in a central region: $[f, 1 - f]$. It is natural that firms located closer to 0.5 are more likely to choose disclosure as their complete-information profit is higher. However, why do not all firms choose disclosure as the unraveling result predicts? In particular, why are firms near f and $1 - f$ willing to pool with other "unpopular" firms?

Let me first use an example with uniformly distributed locations to illustrate the answers to the questions above. I will present more general results following the example. In order to discuss the example, the following lemma is needed.

LEMMA 3: *Consider partially revealing equilibria A with threshold f_A and B with threshold f_B. If $f_A > f_B$, equilibrium profit is higher at every location in A than in B.*

Lemma 3 suggests that we can rank all partially revealing equilibrium by profit, so that it is possible to focus on the "highest profit equilibrium."

EXAMPLE 1: *Suppose location is uniformly distributed, $g(l) = 1$ for $0 \leq l \leq 1$. There exists a partially revealing equilibrium in which all nondisclosing firms charge the same profit-maximizing price when $v \geq 0.584$.*

By focusing on uniformly distributed locations, we can compute the expected mismatch of consumers when a firm chooses not to disclose
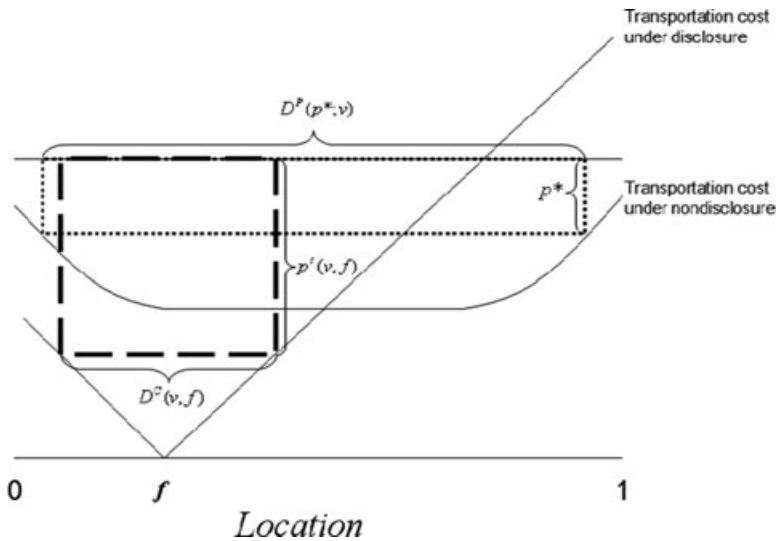
FIGURE 3. PROFIT COMPARISON

In this figure, $0 < f < 0.5$. The solid line is the monopolist's profit under complete information, $\pi^c(v, l)$. The dashed line is $\pi^p(v)$. The thickened parts of the two lines represent the monopolist's profit in the partially revealing equilibrium.

its location. Under the assumption that all nondisclosing firms charge the same profit-maximizing price, we can also solve for the pooling profit of the nondisclosing firms. Compare the pooling profit with the complete-information profit, we can find the disclosure threshold f for each level of quality v. Figure 3 illustrates the demand, price, and profit comparisons of the indifferent firm (v, f).

Under complete information, the location of firm (v, f) is known and consumers compute their mismatch as reflected by "transportation cost under disclosure." The firm charges the profit-maximizing price $p^c(v, f)$, and generates the corresponding demand, $D^c(v, f)$. As a result, its profit would equal the area within the dash-line box.

On the other hand, when firms located in $[0, f)$ and $(1 - f, 1]$ pool together, they do not disclose their locations and charge the same price. Consumers in this case expect their mismatch as reflected by "transportation cost under nondisclosure." Nondisclosing firms charge the profit-maximizing price, p^*, and generate the corresponding demand, $D^p(p^*; v, L(p^*))$. A partially revealing equilibrium exists when the two boxes, the dotted-line box and the dash-line box, have the same area.

The intuition why partially revealing equilibria exist can be seen from two important features of Figure 3. First, for consumers

located close to the firm, expected mismatch is lower under complete information, whereas for consumers located far from the firm, expected mismatch is lower under nondisclosure. By not revealing its location, firm (v, f) can pool with other firms located near the two ends, and attract the central consumers. Second, demand under complete information is less sensitive to price changes than the demand under nondisclosure.[13] The nondisclosure is sending an unfavorable signal that the firms are far from the center. On the other hand, because they can be located near either of the two corners, many consumers expect a positive utility from buying when the price is low enough. A more elastic demand combined with a lower price yields a higher profit for the nondisclosing firms, compared with what they would earn under complete information.

Let us now turn to more general conditions under which a partially revealing equilibrium exists. As our goal here is to demonstrate that product location does not always unravel in the same way as quality, I offer here a sufficient condition.[14]

To keep the analysis tractable, I assume for the rest of this section that the location distribution is symmetric for the next two propositions: $g(l) = g(1 - l)$, $\forall l \in [0, 1]$. The assumption simplifies the quality threshold characterized below, but is not necessary to the existence of partially revealing equilibrium.[15]

PROPOSITION 4: *A partially revealing equilibrium exists if $v > 2 - \sqrt{2}$ and $g(0) > 0$. When $v \geq 1$, there exists a partially revealing equilibrium with $f = 0.5$.*

Proposition 4 suggests that partial revelation occurs for high levels of quality. If quality is too low, the monopolist can hardly get any demand unless he attracts nearby consumers by disclosure his location. When quality is high, the monopolist can get away with enough demand even when consumers are unsure of their match with the product. Once quality exceeds a certain threshold, the monopolist always prefers nondisclosure.

As Proposition 4 points to the direction that the level of quality has a great influence on equilibrium disclosure, I explore this relationship

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13. In the proof of Example 1, I derive the explicit functional form of the demand for nondisclosing firms given any quality v, threshold f, and nondisclosing firms' price p. It is straightforward that the magnitude of the partial derivative of this demand with respect to price is always higher than 2, and the magnitude of the partial derivative of the complete information demand is always lower than 2.

14. For a discussion on the necessary condition see Section 5.1.

15. See a more detailed discussion of the symmetry assumption in Section 5.1.

formally. In order to do so, we need to introduce the following definition.

DEFINITION 1: *The Highest Profit Symmetric Equilibrium (HPSE) is the partially revealing equilibrium in which (1) for any equilibrium price p charged by some nondisclosing firms, $l \in L(p)$ implies $1 - l \in L(p)$, and (2) the equilibrium profit for every firm is the highest among all partially revealing equilibria that satisfy (1).*

This definition relaxes assumptions in Example 1 in two ways. First, location does not have to be uniformly distributed. Second, nondisclosing firms do not have to charge the same price. In a symmetric equilibrium, the monopolist only has to charge the same price for pairs of locations with the same distance from 0.5.

The HPSE is the symmetric equilibrium with the highest equilibrium profit. By Lemma 3, the HPSE is also the symmetric equilibrium with the highest disclosure threshold and the lowest number of disclosing firms. Focusing on the HPSE makes it possible to discuss how disclosure incentives change with quality in general.

PROPOSITION 5: *The disclosure threshold in the HPSE weakly increases with v.*

Proposition 5 indicates that the higher is the product's quality, the *less* likely the monopolist chooses disclosure. To the monopolist, disclosure always has the benefit of attracting consumers nearby at the cost of deterring consumers far away. When quality is low, the benefit is crucial and outweighs the cost. As quality becomes higher, consumers are more likely to buy the product without disclosure. When quality is high enough, the monopolist tries to cover the entire market at a high price. Disclosure in this case would lower marginal consumers' willingness to pay: the cost of disclosure starts to outweigh its benefit.

Some preliminary evidence from the magazine market provides support for Proposition 5. Among the 100 best-selling magazines on Amazon.com as of November 9, 2006, 49 (49%) offer free trials through electronic pages or paper issues. Out of the 100 magazines, 13 won the National Magazine Award in General Excellence during 2000–2006. Among the 13 magazines, only 4 (31%) offer free trials.[16] That is, the

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16. Award is given by the American Society of Magazine Editors. The General Excellence category recognizes overall excellence in magazines. Other prestigious awards such as the Investigative Reporters and Editors Award and the Pulitzer Prize often focus on individual articles rather than the overall quality of the magazines. Award winners (2000–2006) are: Wired, Time, Popular Science*, National Geographic, Newsweek, Esquire, Gourmet, Entertainment Weekly*, National Geographic Adventure, The New Yorker, Harpers Magazine, Dwell*, and Saveur*. Magazines with * offer free trials.

	No. of Mags	No. of Mags with Trials	% of Mags with Trials
Amazon.com	100	49	49
2000–2006 Award	13	4	31
2001–2006 Award	11	3	27
2003–2006 Award	9	2	22
2005–2006 Award	6	1	17

percentage of award-winning magazines that offer free trials is lower than that of general top selling magazines. Furthermore, the more recently a magazine won the award, the less likely it offers free trials. See Table I for a more detailed comparison of the trial-offering behavior.

Free trials would disclose a magazine's horizontal attributes such as the text-graphics ratio. Under the interpretation that the award signals strong quality reputation among consumers, Proposition 5 is consistent with the fact that award-winning magazines are less likely to offer free trials. If we assume that a more recent award may carry more weight in consumers' quality evaluation, the proposition is also consistent with the fact that the more recent the award is, the less likely the magazine offers free trials.[17]

To finish the section, I discuss some welfare implications of mandatory disclosure policies. Due to the existence of multiple equilibria, it is infeasible to characterize general conditions under which mandatory disclosure worsens consumer welfare. The following example shows, nevertheless, that mandating disclosure in the HPSE may indeed hurt both expected consumer welfare and the monopolist's profit.

EXAMPLE 2: *Suppose $v = 1$ and l equals a and $1 - a$ with probability 0.5 each, with $0 \leq a < 0.5$. In the HPSE, the monopolist never chooses disclosure. Mandating disclosure reduces expected consumer welfare when $3 - 2\sqrt{2} < a < \frac{1}{2}$ and increases expected consumer welfare otherwise.*

Mandating disclosure forces the monopolist into the complete-information benchmark and hence lowers his equilibrium profit no matter where he is located. Regarding expected consumer welfare, there are two opposing effects. First, compared with the complete-information benchmark, demand in the HPSE is higher and more

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17. Past winners are eligible for the same award. For instance, National Geographic has won the General Excellence award four times since 1984.

consumers expect a positive surplus. Second, consumers near the product expect a higher surplus under mandatory disclosure than in the HPSE. When a is close to 0 in this example, consumes in the HPSE expect a small surplus as their expected mismatch is high, and the second effect dominates. When a is close to 0.5, the HPSE price is much lower than the complete-information price, and the first effect dominates.

4. UNKNOWN QUALITY, UNKNOWN HORIZONTAL ATTRIBUTE

In the real world, consumers may not know anything about the product. Many new products come into the market every day and firms upgrade their products all the time. For new or upgraded products, sellers often have to disclose all product information if any.[18] For example, consumers would learn almost all aspects of the product once the seller offers free trials or publishes consumer reviews of the product. Given that it is hard to separately disclose quality and location, how does the monopolist choose his disclosure strategy? I try to answer the question by analyzing the following game.

Stage 1 Nature determines the value of v and l with $v \geq 0$ and $0 \leq l \leq 1$. The monopolist knows both v and l. Consumers know their own locations and the joint distribution $h(v, l)$, but they do not know v or l.

Stage 2 The monopolist decides whether to choose disclosure. If he does, every consumer learns both v and l.

Stage 3 The monopolist chooses a price. Consumers decide whether to buy the product.

   A fully revealing equilibrium in which the monopolist always chooses disclosure still always exists. It can be supported by the following off-equilibrium-path belief: whenever a firm deviates to nondisclosure, consumers believe that its product quality and location are such that they generate the lowest possible profit under complete information. A similar off-equilibrium-path belief supports any possible partially revealing equilibrium. If a firm deviates to nondisclosure and an off-equilibrium-path price, consumers believe that the its product quality and location are such that they generate the lowest possible profit under complete information. The following proposition discusses the monopolist's disclosure behavior in the partially revealing equilibria.

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18. See Section 5.3 for a discussion on alternative disclosure formats.

PROPOSITION 6: *In every partially revealing equilibrium, there exists a decreasing function $f(v)$ such that the monopolist chooses disclosure if and only if $l \in [f(v), 1 - f(v)]$.*

Figure 4 illustrates this proposition.

As shown in the figure, the monopolist chooses disclosure when location is in a central region. The region enlarges as quality becomes higher, which reflects the monopolist's incentive to reveal a high quality. The result implies that a higher quality firm is more likely to choose disclosure. One can still show, however, that partially revealing equilibria exist in many cases.

PROPOSITION 7: *Suppose $v \geq \underline{v}$ and $h(v, l) = h(v, 1 - l), \forall v \geq 0, \forall l \in [0, 1]$. There exists a partially revealing equilibrium if $\underline{v} \geq 2 - \sqrt{2}$ and $h(\underline{v}, 0) > 0$.*

The logic is similar to that of Proposition 4. When the perceived quality is high enough, the monopolist can get enough demand without disclosure. Taking it to the extreme, a highest-quality firm may also choose nondisclosure when its location is far enough from 0.5. The following example demonstrates how this occurs.

EXAMPLE 3: *Suppose quality v equals v_H or v_L with probability 0.5 each and $0 \leq v_L < v_H$. Location l equals 0 or 1 with probability 0.5 each. There exists an equilibrium in which no firm chooses disclosure if (1) $0 \leq v_H < 2$ and $v_L \geq \frac{v_H^2}{2} - v_H + 1$ or (2) $v_H \geq 2$ and $v_L \geq v_H - 1$.*
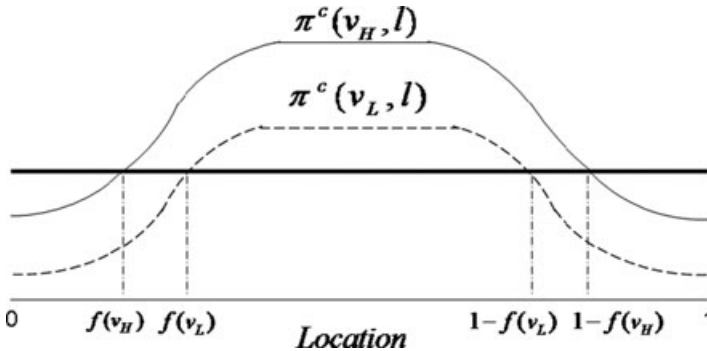

FIGURE 4. *EQUILIBRIUM PROFIT WITH UNKNOWN QUALITY AND LOCATION*

In this figure, $0 < v_L < v_H$ and $0 < f(v_H) < f(v_L) < 0.5$. The solid curve is the complete-information equilibrium profit for quality v_H, and the dashed curve for quality v_L. The thickened straight line is the monopolist's profit when he chooses nondisclosure in equilibrium.

In this example, the monopolist with quality v_H chooses nondisclosure when the difference between v_L and v_H is small. In general, for all firms to choose nondisclosure in equilibrium, it is sufficient that the highest possible complete-information profit is strictly lower than $E(v) - \frac{1}{2}$.[19] This is more likely to happen when the distribution of quality is not widely dispersed.

The results in this section provide possible explanations for firms' nondisclosure behavior in Mathios (2000) and Jin (2005). First, the higher is the average quality, the more likely the firm discloses the quality profile. Second, a firm is more likely to choose disclosure when its quality profile is well balanced across different quality dimensions. Third, disclosing firms do not necessarily have higher average quality than nondisclosing firms. It may be the case that a disclosing firm has lower average quality, but a more balanced quality profile, than a nondisclosing firm. Finally, more firms choose disclosure when the dispersion in average quality is large.

5. Discussion

In essence, introducing an horizontal product attribute opens up the possibility of partial revelation. In both information scenarios above, partially revealing equilibria arise from the monopolist's incentive to hide an unfavorable horizontal attribute. In another possible scenario, consumers know the location of the product but not the vertical quality. The model then is the same as in Grossman (1981) and Milgrom (1981). The monopolist would always choose disclosure as in the standard argument of unraveling.

In this section, I discuss some assumptions and implications of the model, and conclude with thoughts on future research.

5.1 Robustness and Completeness of Results

Alternative Cost Structures

The literature on horizontal product differentiation sometimes uses a quadratic mismatch function (Tirole 1994). Incorporating this feature into the current model does not change the main results qualitatively. When quality is common knowledge but location is unknown to consumers, the monopolist's profit under complete information still increases as the product's location approaches 0.5. As a result, any partially revealing equilibrium still features a central region of disclosing

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19. Under the assumption $h(v, l) = h(v, 1 - l)$, $\forall v \geq 0$, $\forall l \in [0, 1]$, if all firms choose nondisclosure and charge $E(v) - \frac{1}{2}$, all consumers would purchase the product.

firms. Along the line of Proposition 4, one can still show that a partially revealing equilibrium exists when $v > 0.75$. When both quality and location of the product are unknown to consumers, higher quality firms are more likely to reveal the quality–location pair.

A more general production cost structure can also be incorporated. For example, suppose both the fixed and marginal cost increase in product quality. The monopolist's profit under complete information would still increase as the product's location approaches 0.5. As a result, Proposition 3 would hold. Propositions 4 and 7 would hold with modified thresholds. As long as marginal cost increases slowly enough in the product's quality, complete-information equilibrium profit increases in product quality and Propositions 5 and 6 hold.

The assumption that disclosure cost is zero can be relaxed as well. As long as disclosure cost is low and does not change with product location, Proposition 3 still holds. Propositions 4 and 7 hold with modified thresholds. Proposition 6, however, needs not hold when disclosure cost increases in the product's vertical quality.

NECESSARY CONDITION FOR THE EXISTENCE OF PARTIALLY REVEALING EQUILIBRIA

It would be ideal to characterize a necessary condition for the existence of partially revealing equilibria. This is feasible, however, only when we impose further restrictions on the equilibrium. The idea is that for a partially revealing equilibrium to exist, quality has to exceed the expected mismatch of the best-matched consumer. It is impossible to calculate this expected mismatch in general as nondisclosing firms can partition themselves arbitrarily into multiple subsets by charging different equilibrium prices. If we knew enough properties of the partition, we could calculate the lowest mismatch for each subset and then take minimum across subsets. Unfortunately, the fact that nondisclosing firms have to make the same level of equilibrium profit does not impose enough regularity on the partition.

Therefore, we focus on partially revealing equilibria in which all nondisclosing firms charge the same price. Discussing the existence of such an equilibrium is worthwhile as one could potentially argue that the monopolist does not want to signal his product location when he chooses not to disclose it. To derive the necessary condition for the existence of a uniform-price partially revealing equilibrium, realize that in any such equilibrium, the consumer at 0.5 has the lowest expected mismatch among all consumers.[20]

The lowest mismatch in a uniform-price partially revealing equilibrium with threshold f is therefore:

---

20. See proof of Proposition 4.

$$\int_0^f \left(\frac{1}{2} - l\right) \frac{g(l)}{G} dl + \int_{1-f}^1 \left(l - \frac{1}{2}\right) \frac{g(l)}{G} dl$$

$$= 1 - 2E\left(l \mid l \in [0, f]\right) \geq 1 - 2E\left(l \mid l \in \left[0, \frac{1}{2}\right]\right),$$

where $G = 2\int_0^f g(l)dl$. Hence, a necessary condition for a uniform-price partially revealing equilibrium to exist is:

$$v \geq 1 - 2E\left(l \mid l \in \left[0, \frac{1}{2}\right]\right).$$

ASYMMETRIC LOCATION DISTRIBUTION

I have assumed a symmetric distribution to simplify the quality threshold when characterizing the sufficient condition for the existence of a partially revealing equilibrium. I show next that symmetry in the location distribution is not crucial to the existence itself. In particular, I characterize a sufficient condition for the existence of a uniform-price partially revealing equilibrium with an arbitrary location distribution. In such equilibria, the consumer located at 0 or 1 always has the highest mismatch, which is bounded from above by

$$h = \max_f \{E(l \mid l \in [0, f) \cup (1 - f, 1]), 1 - E(l \mid l \in [0, f) \cup (1 - f, 1])\}.$$

If all nondisclosing firms charge $v - h$, demand is 1 and the corresponding profit is $v - h$. This profit level is higher than the complete information profit of the firm located at 0 whenever $v > 2 - 2\sqrt{1 - h}$. Therefore, a sufficient condition for a partially revealing equilibrium to exist is $v > 2 - 2\sqrt{1 - h}$ and $g(0) > 0$.

5.2 DISCLOSURE DYNAMICS

One can learn some disclosure dynamics by linking the two different information scenarios studied in this paper. In the product's early age, it has no quality reputation. Results from Section 4 suggest that the higher the product's quality is, the more likely the monopolist chooses disclosure. Once the product has become familiar to consumers and earned some quality reputation, results from Section 3 suggest that the higher the product's quality, the less likely the monopolist chooses disclosure.

As a result, a high-quality monopolist may choose disclosure in the beginning but not afterwards. He earns more profit later by exploiting his reputation of high quality. On the other hand, a low quality monopolist may choose nondisclosure in the beginning but

switch to disclosure afterwards. He earns more in the beginning by not revealing the true quality of his product.

5.3 Future Research

I conclude by discussing two natural extensions of the paper. Each extension introduces new strategic actions for consumers or the monopolist. Although they are not analyzed in the current paper, both extensions have great potential for future research, and I offer some conjectures for each of them.

Cost of Information Acquisition

I have assumed that a consumer has no cost to acquire information disclosed by the monopolist. In reality, consumers are more likely to decide rationally whether they want to pay the attention and time to obtain such information. What would happen if we introduce a positive cost of information acquisition into the model? Some results would still hold: nondisclosing firms earn the same profit and a disclosing firm must be making more than that profit. We can expect that there is still a central region of disclosing firms in any equilibrium: when a firm earns a strictly higher profit in equilibrium by disclosing location, there must be some consumers who acquire the disclosed information. If this is the case, then consumers close to 0 or 1 have a higher incentive to acquire location information than centrally located consumers. The nonacquiring consumers would rely on the acquiring ones and use equilibrium price as a signal of the location. It would be interesting for future research to explore whether the disclosing firms would still earn the complete information profit, which consumers would choose to acquire information, and how their acquisition incentives change with product quality.[21]

Disclosure Formats

So far I have assumed that the monopolist discloses both attributes or neither. For some products, e.g., magazines, this might be realistic as all attributes can be inferred from a simple trial. For other products, the monopolist may have the option of disclosing certain product attributes while holding others back. What would happen in the current model if the monopolist has a fuller set of options: disclose both attributes, disclose quality, disclose location, and disclose neither attribute?

First realize that whenever two firms of the same location both choose to reveal only the location, the higher quality firm would want to deviate to reveal also its quality. Therefore at most one firm chooses to reveal any given location. For consumers, seeing only the location

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21. See Branco, Sun and Villas-Boas (2010) for a discussion on this last question.

revealed is equivalent to seeing both quality and location. Therefore, the monopolist essentially has only three options in equilibrium.

The most profitable equilibrium is likely to have the following property. There exists a quality threshold. Firms with quality higher than the threshold reveal both quality and location if located close to 0.5, and reveal only quality otherwise. As quality increases, the set of central firms that choose to reveal both quality and location becomes smaller. Firms with quality lower than the threshold reveal both quality and location if located close to 0.5, and reveal neither attribute otherwise. As all firms revealing neither attribute must be earning the same profit, the boundary of the set of such firms is an iso-profit curve. Overall, giving the monopolist an additional option of revealing only one of the two attributes indeed changes his equilibrium behavior in a nontrivial way. A comparison between this richer game and the games analyzed in previous sections might be interesting. Interested readers can refer to Sun (2010) for a discussion on how firms may use different formats to display consumer ratings, in order to achieve the goal of maximizing profits through showing only partial information in the presence of multiple product attributes.

APPENDIX

Proof of Proposition 1. For each possible (v, l), the monopolist chooses a price to maximize his profit. Firm (v, l) has the same equilibrium strategies as firm $(v, 1 - l)$, for any possible location l. Hence I examine only firms with $l \in [0, \frac{1}{2}]$. When a firm charges price p and is located at $l \in [0, \frac{1}{2}]$, its profit is

$$\pi^c(p; v, l) = p \cdot D^c(p; v, l) = \begin{cases} p, & \text{if } 0 \leq p < v - (1 - l) \\ p(l + v - p), & \text{if } v - (1 - l) \leq p < v - l \\ 2(v - p)p, & \text{if } v - l \leq p < v \\ 0, & \text{if } p > v \end{cases}$$

There are four possible cases depending on the relationship between v and l.

- If $0 \leq v \leq 2l$, profit is maximized at $p = \frac{v}{2}$, corresponding demand is v, and maximum profit is $\frac{v^2}{2}$.
- If $2l < v \leq 3l$, profit is maximized at $p = v - l$, corresponding demand is $2l$, and maximum profit is $2l(v - l)$.
- If $3l < v \leq 2 - l$, profit is maximized at $p = \frac{v+l}{2}$, corresponding demand is $\frac{v+l}{2}$, and maximal profit is $\frac{(v+l)^2}{4}$.

- If $v > 2 - l$, profit is maximized at $p = v + l - 1$, corresponding demand is 1, and maximum profit is $v + l - 1$. □

Proof of Proposition 2. Assume the following off-equilibrium-path belief: consumers would assume that a firm is located as far from 0.5 as possible if it deviates to nondisclosure. Under this belief, all firms are better off sticking to the equilibrium path and earning their complete-information profit. □

Proof of Lemma 1. If Lemma 1 is false, there must exist two distinct locations $l_A, l_B \in [0, 1]$ such that in a partially revealing equilibrium (F1) the monopolist chooses nondisclosure at l_A and l_B, and (F2) he earns a strictly higher profit at l_A than at l_B. Given (F1), if the monopolist charges the same equilibrium price at l_A and l_B, he obtains the same equilibrium demand at l_A and l_B by equations (1) and (2). Therefore, he makes the same equilibrium profit at l_A and l_B, which contradicts (F2). Hence, the monopolist charges different equilibrium prices at l_A and l_B.

If firm l_B deviates to charge firm l_A's equilibrium price, he gets firm l_A's equilibrium demand by equations (1) and (2), and hence gets firm l_A's equilibrium profit. Firm l_B can make a higher profit in the deviation, contradicting the definition of an equilibrium. □

Proof of Lemma 2. Note that $\pi^c(v, l) = \max_p \pi^c(p; v, l)$. By definition of a partially revealing equilibrium, for any nondisclosing firm (v, l),

$$\pi^c(v, 0) = \pi^c(v, 1) \leq \pi^c(v, l) < \pi^P(v).$$

I now show $\pi^P(v) \leq \pi^c(v, \frac{1}{2})$. Consider any equilibrium price p charged by some nondisclosing firm. For any given consumer $c \in [0, 1]$,

$$
\begin{aligned}
EU(c; p; v, l) &= v - p - E(|c - l| | l \in L(p)) \\
&\leq v - p - |c - E(l | l \in L(p))| \\
&= U(c; p; v, E(l | l \in L(p))),
\end{aligned}
$$

where the second line is given by Jensen's inequality. As a result,

$$
\begin{aligned}
\pi^P(v) &= p \cdot D^p(p; v, L(p)) \\
&= p \cdot m(\{c \mid EU(c; p; v, l) \geq 0\}) \\
&\leq p \cdot m(\{c \mid U(c; p; v, E(l | l \in L(p))) \geq 0\}) \\
&= p \cdot D^c(p; v, E(l | l \in L(p))) \\
&\leq \pi^c(v, E(l | l \in E(p))) \\
&\leq \pi^c \left(v, \frac{1}{2} \right).
\end{aligned}
\tag{4}
$$

□

Proof of Proposition 3. In a partially revealing equilibrium, all nondisclosing firms earn $\pi^p(v)$ by Lemma 1. Let

$$L = \{l \mid g(l) > 0 \text{ and } \pi^c(v, l) < \pi^p(v)\}.$$

By definition, $L \neq \emptyset$. Suppose $l \in L$ and $g(l') > 0$. If $|l' - \frac{1}{2}| \geq |l - \frac{1}{2}|$, then $\pi^c(v, l') \leq \pi^c(v, l) < \pi^p(v)$, and hence $l' \in L$. By Lemma 2, there exists a location $f \in (0, \frac{1}{2}]$ such that $\pi^c(v, f) = \pi^p(v)$ and $L = [0, f) \cup (1 - f, 1]$. ☐

Proof of Lemma 3. Disclosing firms make their complete-information profit in both equilibria. By Proposition 3, nondisclosing firms earn $\pi^c(v, f_A)$ in A and $\pi^c(v, f_B)$ in B. Because $0 < f_B < f_A \leq \frac{1}{2}, \pi^c(v, f_B) \leq \pi^c(v, f_A)$ by Proposition 1. ☐

Proof of Example 1. Given any quality v and disclosure threshold f, if all nondisclosing firms in $[0, f) \cup (1 - f, 1]$ charge the same price, a consumer located at $c \in [0, f] \cup [1 - f, 1]$ has an expected mismatch of $\frac{1}{2} - c + \frac{c^2}{2f}$, and all consumers located in $(f, 1 - f)$ expect the same mismatch of $\frac{1-f}{2}$. Therefore, the indifferent consumer c^* is given by $\frac{1}{2} - c^* + \frac{c^{*2}}{2f} = v - p$.

Therefore, nondisclosing firms solve

$$\max_p \ \pi^p(p; v, f) \equiv \left[1 - 2f \left(1 - \sqrt{1 - \frac{1 - 2v + 2p}{f}} \right) \right] p.$$

It is straightforward to show that the objective function is concave in p for all $p > 0$:

$$\frac{d^2\pi^p(p; v, f)}{(dp)^2} = -\frac{4}{\sqrt{1 - \frac{1 - 2v + 2p}{f}}} - \frac{2p}{f \left(1 - \frac{1 - 2v + 2p}{f} \right)^{\frac{3}{2}}} < 0.$$

Moreover, at $p = v - 0.5$, $\frac{d\pi^p(p; v, f)}{dp} = 2(1 - v) > 0$, and at $p = v - \frac{1-f}{2}$, $\frac{d\pi^p(p; v, f)}{dp} < 0$. Therefore, the optimal price p^* has to be such that

$$\frac{1 - f}{2} < v - p^* < \frac{1}{2}.$$

Letting

$$\frac{d\pi^p(p; v, f)}{dp} = 1 - 2f + 2f\sqrt{1 - \frac{1 - 2v + 2p^*}{f}}$$

$$- \frac{2p}{\sqrt{1 - \frac{1 - 2v + 2p^*}{f}}} = 0, \tag{5}$$

we have

$$p^*$$

$$= \frac{-1 - 8f + 8f^2 + 24fv + \sqrt{1 - 20f + 84f^2 - 128f^3 + 64f^4 + 24fv - 96f^2v + 96f^3v}}{36f}.$$

Note that equation (5) has two real roots, and only the bigger root is positive.

Let

$$G(v, f) \equiv \pi^p(v, f) - \pi^c(v, f) \equiv \pi^p(p^*; v, f) - \pi^c(v, f). \tag{6}$$

A partially revealing equilibrium exists when $G(v, f) = 0$.

Given the explicit functional form of $G(v, f)$ in (6), I use Mathematica to plot the function over the $v - f$ plane and see if a solution to $G(v, f) = 0$ exists. An exhaustive search shows that a solution exists if and only if $v \geq 0.584$. ☐

Proof of Proposition 4. The following off-equilibrium-path belief can support any possible partially revealing equilibrium. When a firm deviates to nondisclosure and an off-equilibrium-path price, every consumer believes that he is located as far from 0.5 as possible. Under this belief, no firm benefits from charging an off-equilibrium-path price. Moreover, no firm benefits from changing its disclosure strategy.

When $1 > v > 2 - \sqrt{2}$,

$$\pi^c(v, 0) = \frac{v^2}{4} < v - \frac{1}{2} < \frac{v^2}{2} = \pi^c\left(v, \frac{1}{2}\right).$$

Therefore, there exists $f \in (0, \frac{1}{2})$ such that $v - \frac{1}{2} = \pi^c(v, f)$.

Suppose all firms located in $L = [0, f) \cup (1 - f, 1]$ charge the same price. Because $g(0) = g(1) > 0$, there exist at least two such firms. The two consumers located at 0 and 1 expect the highest mismatch, 0.5. To see this, realize two facts. First, they expect a mismatch of 0.5:

$$E(|0 - l| | l \in L) = E(|1 - l| | l \in L)) = \frac{1}{2}.$$

Second, they have the highest expected mismatch. Let $0 \leq c_1 < c_2 \leq \frac{1}{2}$,

$$E(|c_2 - l| \,|\, l \in L) - E(|c_1 - l| \,|\, l \in L)$$
$$\leq (c_2 - c_1) \cdot \Pr(l \in [0, c_2)| l \in L)$$
$$\quad - (c_2 - c_1) \cdot \Pr(l \in [c_2, f] \cup [1 - f, 1]| l \in L)$$
$$= (c_2 - c_1) \cdot (\Pr(l \in [0, c_2)| l \in L) - \Pr(l \in [c_2, f] \cup [1 - f, 1]| l \in L))$$
$$\leq 0.$$

As a result, nondisclosing firms earn $\pi^p(v) = v - \frac{1}{2}$ if they all charge $v - \frac{1}{2}$, and a partially revealing equilibrium with disclosure threshold f exists.

Now consider $v \geq 1$. The proof is the same as in that of Example 1. By Proposition 1, $\pi^c(v, \frac{1}{2}) = v - \frac{1}{2}$. If all firms except the one located at 0.5 choose nondisclosure and charge $p = v - \frac{1}{2}$, all consumers expect a mismatch of lower than 0.5 and hence purchase the product. Nondisclosing firms' profit is $v - \frac{1}{2} = \pi^c(v, \frac{1}{2})$. As the complete-information profit is strictly increasing as location approaches 0.5, there exists a partially revealing equilibrium with $f = 0.5$. □

Proof of Proposition 5. If $v \geq 1$, $f = \frac{1}{2}$ in the HPSE by Proposition 4. Consider $v < 1$. Denote the HPSE profit of nondisclosing firms by $\pi_H^p(v)$ when quality is v. By Proposition 3, $\pi_H^p(v) = \pi^c(v, f)$, where f is the disclosure threshold in the HPSE. Let $\Delta v > 0$ be an infinitesimal increase in quality and f' the disclosure threshold in the HPSE when quality is $v + \Delta v$. I show $f' \geq f$ by proving two claims.

CLAIM 1.

$$D^c(p^c(v, f); v, f) \leq D_H^p(p; v, L(p)),$$

where the right-hand side is the HPSE demand of any firm (v, l) that chooses nondisclosure and charges equilibrium price p.

Because

$$p \cdot D_H^p(p; v, L(p)) = p^c(v, f) \cdot D^c(p^c(v, f); v, f), \tag{7}$$

it is sufficient to show $p \leq p^c(v, f)$, where p is any equilibrium price charged by some nondisclosing firm in the HPSE.

Because $\pi_H^p(v) \leq \pi^c(v, l)$ for any $l \in [\frac{v}{2}, \frac{1}{2}]$ and a firm chooses to disclose its location when indifferent, it is impossible that $f \in (\frac{v}{2}, \frac{1}{2}]$. Consider two other cases. First, $f \in [\frac{v}{3}, \frac{v}{2}]$. Suppose a nondisclosing

firm (v, l) charges $p' > p^c(v, f) = v - f$ in the HPSE, then

$$\pi_H^p(v) = p' \cdot D_H^p(p'; v, l) \le p' \cdot D^c(p'; v, E(l \mid l \in L(p')))$$

$$= p' \cdot D^c(p'; v, \frac{1}{2}) = p' \cdot D^c(p'; v, f) < \pi^c(v, f),$$

where the first inequality is from (4), and the last equality comes from the fact that $D^c(p'; v, \frac{1}{2}) = D^c(p'; v, f) = 2(v - p')$ as in the proof of Proposition 1. The inequalities above contradict the definition of f.

Second, $f \in [0, \frac{v}{3})$. Suppose a nondisclosing firm charges price $p' > p^c(v, f)$ in the HPSE. A consumer located at c has an expected mismatch of

$$E(|c - l| | l \in L(p')) \begin{cases} \ge |c - E(l \mid l \in L(p'))| = |c - \frac{1}{2}| & \text{if } c \notin [f, 1 - f] \\[2mm] \ge \frac{1}{2} - f, \\[2mm] = \int_0^f \Pr(l \mid l \in L(p')) & \text{if } c \in [f, 1 - f] \\[2mm] (c - l + 1 - l - c) dl \ge \frac{1}{2} - f, \end{cases}$$

where the second line comes from the fact that

$$\int_0^f l \Pr(l \mid l \in L(p')) dl \le f \int_0^f \Pr(l \mid l \in L(p')) dl = \frac{1}{2} f.$$

Therefore, every consumer's expected mismatch is greater than $\frac{1}{2} - f$. As firm (v, l) charges p' in the HPSE and gets a positive demand, $v - p' \ge \frac{1}{2} - f$. Because $f < \frac{v}{3}$, $v - p^c(v, f) = \frac{1}{2}(v - f)$. Because we assumed $p' > p^c(v, f)$, $\frac{1}{2}(v - f) > \frac{1}{2} - f$. This is impossible when $v \le \frac{3}{4}$, as $\frac{1}{2}(v - f) - (\frac{1}{2} - f) \le \frac{1}{2}(v + \frac{1}{3} - 1) \le 0$. When $\frac{3}{4} < v < 1$,

$$\pi^c\left(v, \frac{v}{3}\right) \le v - \frac{1}{2} < \frac{v^2}{2} = \pi^c\left(v, \frac{1}{2}\right).$$

There exists $f' \in [\frac{v}{3}, \frac{1}{2}]$ with $v - \frac{1}{2} = \pi^c(v, f')$, which means that there is a partially revealing equilibrium with threshold f' in which all nondisclosing firms charge price $v - \frac{1}{2}$. Therefore, $f \in [0, \frac{v}{3})$ cannot be the threshold of the HPSE with $p' > p^c(v, f)$.

CLAIM 2. *Define f^* by*

$$\pi_H^p(v) + \Delta v \cdot D_H^p(p_m; v, l) = \pi^c(v + \Delta v, f^*),$$

where p_m is the highest equilibrium price charged by any nondisclosing firm in the HPSE. When quality increases to $v + \Delta v$, a symmetric partially revealing equilibrium with disclosure threshold f^* exits.

I first show that f^* is well defined:

$$
\begin{aligned}
\pi^c(v + \Delta v, f) &= \pi^c(v, f) + \Delta v \cdot D^c(p^c(v, f); v, f) \\
&\leq \pi^p_H(v) + \Delta v \cdot D^p_H(p_m; v, l) \\
&\leq (p_m + \Delta v) \cdot D^c(p_m + \Delta v; v + \Delta v, \tfrac{1}{2}) \\
&\leq \pi^c(v + \Delta v, \tfrac{1}{2}),
\end{aligned}
$$

where the second line is from Claim 1, and the third from (4). Given the set of inequalities above, f^* is well defined and $f^* \geq f$.

Let $L(p_m)$ be the set of locations of nondisclosing firms that charges p_m. Let $L^* = [f, f^*) \cup (1 - f^*, 1 - f] \cup L(p_m)$. I show that when v increases by Δv, firms in L^* and all other nondisclosing firms can increase their profit to a level higher than $\pi^c(v + \Delta v, f^*)$.

First consider firms in L^*. Realize that

$$
|c - l| + |c - (1 - l)| \leq |c - l'| + |c - (1 - l')|,
$$
$$
\forall l \in L^*, \forall l' \in L(p_m), \forall c \in [0, 1],
$$

and the inequality is strict for some c. That is, everything else equal, when we enlarge $L(p_m)$ to L^*, more consumers would buy the product. Therefore, when both quality and price increase by Δv, demand for firms in L^* would be at least $D^p_H(p_m; v, l)$ and their profit is at least $\pi^c(v + \Delta v, f^*)$. Now consider nondisclosing firms outside $L(p_m)$, their demand is higher than $D^p_H(p_m; v, l)$ to begin with, and therefore when both quality and price increase by Δv, their profit would also be at least $\pi^c(v + \Delta v, f^*)$.

Given their profit is continuous in price and it is zero when price is zero, nondisclosing firms can adjust their prices to earn exactly $\pi^c(v + \Delta v, f)$. It is possible that two or more sets of firms have to charge the same price after the adjustment. In this case, demand is the same at the adjusted price for each of these sets and would remain unchanged when we merge the sets into a new set: consumers' expected mismatch increases in $|c - 0.5|$, and the two indifferent consumers have the same expected mismatch before and after the merge.

Therefore, there exists a symmetric partially revealing equilibrium with threshold f^* when quality is $v + \Delta v$. Given the definition of a HPSE, the quality threshold in the HPSE with quality $v + \Delta v$ has to be greater than f^*, and hence greater than f. □

Proof of Example 2.   Mandating disclosure forces the monopolist into the complete-information benchmark. By Lemma 2, the monopolist's profit in a partially revealing equilibrium is higher than his complete-information profit at every location. Therefore, mandating disclosure always reduces the monopolist's profit.

Now consider expected consumer welfare. By Proposition 4, $f = \frac{1}{2}$ in the HPSE when quality $v = 1$. By Lemma 2,

$$\pi_H^p(1) = \pi^c\left(1, \frac{1}{2}\right) = \frac{1}{2}. \tag{8}$$

Price in the HPSE has to be 0.5. For any other price p',

$$D_H^p(p'; 1, a) \le D^c(p'; 1, E(l \mid l \in \{a, 1 - a\})) = D^c\left(p'; 1, \frac{1}{2}\right),$$

and

$$\pi_H^p(1) = p' \cdot D_H^p(p'; 1, a) \le p' \cdot D^c\left(p'; 1, \frac{1}{2}\right) < \pi^c\left(1, \frac{1}{2}\right) = \frac{1}{2},$$

which contradicts (8). The expected consumer surplus hence is

$$CS^p = \frac{1}{2} - \left(\frac{1}{2}a^2 + \frac{1}{2}(1 - a)^2\right).$$

Now consider consumer welfare under complete information. If $\frac{1}{3} \le a < \frac{1}{2}$, price is $1 - a$, and a consumer would buy the product if her location is in $[0, 2a]$. Consumers located in $[0, a]$ have a surplus of $1 - (1 - a) - (a - c)$, and consumers located in $(a, 2a]$ have a surplus of $1 - (1 - a) - (c - a)$. Aggregating over all consumers who purchase, the expected consumer surplus under complete information equals a^2, which is strictly smaller than CS^p. If $0 \le a < \frac{1}{3}$, complete-information price is $\frac{1+a}{2}$, and a consumer would buy the product if her location is in $[0, \frac{1+a}{2}]$. Consumers located in $[0, a]$ have a surplus of $1 - \frac{1+a}{2} - (a - c)$ and consumers located in $(a, \frac{1+a}{2}]$ have a surplus of $1 - \frac{1+a}{2} - (c - a)$. Aggregating over all consumers who purchase, the expected consumer surplus under complete information equals $\frac{(1+a)^2}{8} - a^2$, which is smaller than CS^p if $3 - 2\sqrt{2} < a < \frac{1}{3}$ and bigger than CS^p if $0 \le a \le 3 - 2\sqrt{2}$.   □

Proof of Proposition 6.   Nondisclosing firms earn the same equilibrium profit by the same reasoning of Lemma 1. For any given v, there exists a threshold $f(v) \in [0, 0.5]$ such that firm (v, l) chooses disclosure if and only if $l \in [f(v), 1 - f(v)]$, by the same reasoning in the proof of Proposition 3. The only thing left to show is that if $0 \le v_1 < v_2$, $f(v_1) \ge$

$f(v_2)$. Suppose $f(v_1) < f(v_2)$. There exists a location l such that $f(v_1) < l < f(v_2)$. Firm (v_2, l) chooses nondisclosure in equilibrium whereas firm (v_1, l) chooses disclosure, which implies $\pi^c(v_1, l) \geq \pi^c(v_2, l)$. By Proposition 1, $\pi^c(v_1, l) < \pi^c(v_2, l)$, a contradiction. $\qquad\square$

Proof of Proposition 7. In the proof of Proposition 4 we know that the two consumers at 0 and 1 expect the highest mismatch, $\frac{1}{2}$, if all nondisclosing firms charge the same price. When this price is $\underline{v} - \frac{1}{2}$, all consumers purchase the product, demand is 1 and profit is $\underline{v} - \frac{1}{2}$. When $\underline{v} > 2 - 2\sqrt{2}$, $\underline{v} - \frac{1}{2} > \frac{v^2}{4}$, and there exists a uniform-price partially revealing equilibrium in which at least the two firms $(\underline{v}, 0)$ and $(\underline{v}, 1)$ choose nondisclosure. $\qquad\square$

Proof of Example 3. If the two firms with quality v_H choose disclosure, their equilibrium profit is $\frac{1}{4}v_H^2$ if $0 \leq v_H < 2$, and $v_H - 1$ if $v_H \geq 2$. If every firm chooses nondisclosure and charges the same price, consumers expect quality to be $\frac{1}{2}(v_L + v_H)$, and their mismatch to be 0.5. When (1) $0 \leq v_H < 2$ and $\frac{1}{4}v_H^2 \leq \frac{1}{2}(v_L + v_H) - \frac{1}{2}$, or (2) $v_H \geq 2$ and $v_H - 1 \leq \frac{1}{2}(v_L + v_H) - \frac{1}{2}$, there exists a Nonrevealing Equilibrium in which every firm charges price $\frac{1}{2}(v_L + v_H) - \frac{1}{2}$. $\qquad\square$

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