Quality Choice of Experience Goods[*†]

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Abstract

This paper proposes a model of oligopolistic competition where several firms sell differentiated experience goods. Firms invest in quality and consumers observe their idiosyncratic valuations for products with noise. Both equilibrium price and quality rise with more precise information. Quality improves because with more precise signals consumers put larger weight on them when estimating their valuation, which encourages investment in quality. Price goes up because with better information firms are perceived to be more differentiated. Total welfare always goes up with the information precision, but consumer surplus and profits may got up or down. Prices and qualities also go up in the degree of product differentiation. Quality increases because the more differentiated the products, the more consumers trust their signals when assessing quality, which gives producers stronger incentive to improve quality. I show that variety and quality are inversely related, so firm entry may decrease consumer welfare by reducing average quality in the market. Other comparative statics results are explored.

1 Introduction

As originally pointed out by Nelson (1970), in many instances a consumer does not know how well different products on offer fit her needs, or how high the quality of each product is. Nevertheless, she has to make a decision on which product to buy and at what price. A large literature (to be discussed later) has taken up Nelson's notion of experience goods and studied its implications for pricing, quality choice, variety etc. To simplify analysis, many authors have assumed that consumers have no information before purchase, and find out their valuation for an experience good only after continuous use. In reality, even for experience goods, consumers have access to a wealth of pre-purchase information from

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the Internet and from other sources. They often read product reviews written by professional reviewers and ordinary consumers, watch video demonstrations, etc. Of course, a consumer's uncertainty about a product's utility cannot be fully eliminated through such information, but the availability and precision of this information is likely to have important effects. How does the Internet, with all of its constantly improving pre-purchase information, affect quality and availability of experience goods? Is price competition relaxed if consumers know more about available products? The quality of which products is more affected by the Internet - is it highly differentiated products like smartphones or rather standardized products like toasters?

I address these questions with a very tractable model of quality choice of experience goods, which is based on Perloff and Salop (1985). Imagine several firms that produce goods which are differentiated only along some experience dimension, e.g. ease of use, durability, safety etc. Consumers value each product differently, with their valuations drawn independently for each product. Since differentiation is in the experience dimension of the product, consumers do not know their valuations prior to purchase. Instead, they receive noisy but unbiased signals of their valuation for each product, and shop based on this information and observed prices.[1] One can think of a consumer who reads reviews on the internet, visits shops, consults friends, and forms imprecise opinion about her personal match with each product along the experience dimension.

Given these preferences and the information structure, I introduce the notion of quality improvement as a costly activity that uniformly increases the valuations of all the consumers for the product. That is, a firm can increase the matches of all consumers with its product along the experience dimension by spending more on R&D or components. In this formulation all consumers agree on the quality ranking of a single product, but may disagree in their comparisons of two different products. For example, a smartphone producer will be able to make its phone easier to use for all consumers if it spends more on R&D, but for some of these consumers another phone, with its unique approach to user interface, will still be easier to use.

Consumers do not observe firms' quality decisions and choose one of the products based solely on charged prices, received signals and firms' conjectured quality choices. A consumer can predict her average valuation in equilibrium, which is determined by firm's quality choice, but only her signal can inform about her idiosyncratic deviation from this average. Signals are also noisy, so they may indicate a different match from the true one.[2] Therefore, a rational consumer uses both firm's conjectured quality choice and her own pre-purchase signal when assessing her valuation for the product. In this model, when a firm increases quality it improves the average signal about its product in the market, which increases demand. However, part of this increase is ignored by consumers who attribute it to the observation noise. Due to this, quality is always lower than under full information, but product heterogeneity and pre-purchase information ensure that quality is never zero, even though the model lacks any dynamic incentives for quality improvement.

[1] I assume, implicitly, that prices are easier to discover than the experience attribute.

[2] For example, a photo camera may feel more comfortable in brief use in a shop than during continuous use later on.

The model leads to several conclusions. First, it links the precision of information in the market to equilibrium quality and markup. Unsurprisingly, quality increases in precision, but so does markup. The latter is not due to higher quality, since quality is symmetric in equilibrium and does not affect the markup. Rather, as in Meurer and Stahl (1994), more precise information increases perceived differentiation amongst firms and leads to higher prices.[3] Quality increases because, when endowed with more precise signals, consumers trust them more, which increases the responsiveness of firm's demand to its actual, rather than conjectured, investment in quality.

Neither firms nor consumers are unambiguously better off with more precise information, even though total welfare always increases. Consumers' gains from better *ex post* matches with products and higher quality may be more than offset by higher prices. Specifically, for an intermediate level of product differentiation, consumers prefer to be completely uninformed to being fully informed. For firms, the higher equilibrium price may not be enough to compensate for higher (and wasteful) investments in quality. Therefore, abstracting from unmodeled price search aspect, the Internet may have increased prices more than it has facilitated improvement of quality in the marketplace.

Not only does more precise information lead to higher prices, but it may also lead to narrower choice of goods. Higher information precision leads to firm exit when, initially, the market has many firms, higher information precision increases quality more than prices, which leads to lower profits and thus exit.

Consumer/product heterogeneity has a positive effect on both equilibrium price and quality. The effect on prices is in line with the literature, starting from Perloff and Salop (1985).[4] Namely, more heterogeneous products allow firms to charge higher prices. Even though in my model consumers observe their valuations with noise, an increase in the underlying heterogeneity still increases the monopoly power of each firm and leads to higher prices.

Equilibrium quality increases in product heterogeneity for two reasons. First, the price increases, which increases marginal revenue from higher quality. But there is also another underlying cause. Higher consumer/product heterogeneity also means that consumers are less capable of predicting their match with a product entirely from the firm's quality choice, because their own valuation is more likely to be different from the average. This encourages consumers to put larger weight on their signals, which in turn gives firms an incentive to increase quality. In other words, whenever product valuation is highly idiosyncratic (the product is a true experience good) consumers rely more heavily on their own impression of the product, and less on what they think a firm's effort might have been.[5] But a firm that invests more resources in improving quality gets higher demand, because most consumers experience better first impressions in shops, receive more positive information from friends, read better reviews and hence buy the product more often.

[3] Similarly, in Anderson and Renault (2000) prices may go up with the proportion of fully informed consumers.

[4] Anderson and Renault (1999) show similar relationship in a sequential search model originally due to Wolinsky (1986).

[5] Consumers are risk-neutral in my model, so higher uncertainty only works through the information channel.

When the number of firms is considered exogenous, there is an unexpected relationship between variety and quality - provided that improving quality requires fixed outlays (e.g. R&D), quality is inversely related to the number of firms.[6] Therefore, a broader product choice comes at the expense of quality. The reverse is true for the inherit heterogeneity of those choices - the more heterogeneous products are, the higher is quality in equilibrium. So policy makers have to balance the benefits from more choice, average quality and inherent differentiation of those choices.

Related literature

Theoretical literature on quality of experience goods can be divided into two categories. Most authors deal with quality choice in a dynamic setting. There is also a small literature on quality choice in static models. Next I relate my work to these two strands of literature.

In a dynamic context, quality is provided either because of the reputational motives or because consumers repurchase the good. When a good is repurchased consumers learn its quality after the first purchase and penalize producers who do not invest in high quality by not repurchasing the good. This mechanism may sustain quality investment if initially purchases are less important compared to repurchases. For example, Riordan (1986) studies entry in a differentiated market where quality is unobserved in the first period, but is known thereafter. The longer the repeat purchase period, the higher the quality, which also increases in the number of firms. Judd and Riordan (1994) study a situation where a monopolist augments quality of an experience good temporarily in the first period to persuade consumers that their match with the product is high so that they repurchase the good in the second period when quality is back to the old low level. Liebeskind and Rumelt (1989) also study a dynamic model with repeat purchases. As in my model, in their model consumers do not observe firm's investment in quality and may experience different realizations of quality. Unlike my model, quality investment can be sustained only if consumers repurchase the good.

All the above models are appropriate for a variety of products and services, however, these models are not always suitable for consumer durable goods, chiefly because life-cycles of consumer durables are so short that the next purchase almost never involves the same product as the previous one.

Since for many product categories repurchases are not common, and most of the literature has maintained that consumers have no pre-purchase information about experience goods, the focus has been on reputation as the means of sustaining high quality. This literature, among others, includes Shapiro (1982)) Shapiro (1983), Cabral (2000), and, more recently, Dana and Fong (2011). While this the literature studies how the information about old products allows firms to credibly invest in quality of new products, my model shows that pre-purchase information about a new product can induce quality investment without reputational concerns. My model is an alternative explanation of the high quality provision for experience goods which are purchased only once by consumers.

[6] In line with this result, Hotz and Xiao (2011) report that the imposition of regulations which aim to increase quality of childcare reduces the number of child care establishments.

It is hard to disentangle the two mechanisms empirically. Improved pre-purchase information increases quality through the mechanism described here, but through more precise information about past qualities, improved pre-purchase information can also increase the value of maintaining reputation for high quality.

My model is not the first one that analyzes the role of pre-purchase information in a one-shot game. Wolinsky (1983) studies quality choice in a sequential search environment. The main contribution of Wolinsky (1983) is to show that with pre-purchase information firms may choose high quality in a static model. Wolinsky does not link the precision of information to the quality levels, because in the equilibria of his model quality is fully revealed by prices. Moreover, in Wolinsky (1983) products of the same quality are homogeneous, hence his model does not link quality with product heterogeneity. Belleflamme and Peitz (2009) study investment in quality when quality is unobserved but investment is. They show that a firm may have incentive to over-invest in quality. This is the case due to adverse selection and efficiency, two effects that are not present in my model. Bar-Isaac et al. (2010) studies quality provision for an inspection good. In this model, a monopolist chooses how costly it is for consumers to find out their valuation for the product, and also how much to invest in ensuring that the valuation is high. The firm may make inspections easy in order to commit to the high quality. The main difference compared to my model is that I study differentiated experience goods under competition and with exogenous information, while Bar-Isaac et al. (2010) focuses on a monopolist selling inspection goods with endogenous information.[7]

My model also relates to the literature on pricing of experience goods. The information structure in my model is close to Caminal and Vives (1996, 1999), who study how information about quality dissipates in the market, and how firms can manipulate this information. In Caminal and Vives (1996) consumers learn quality from past market shares, whereas in Caminal and Vives (1999), as in my model, consumers value goods differently and receive noisy signals about their valuations. Caminal and Vives, however, study dynamic pricing with fixed quality. Anderson and de Palma (2001) also study pricing when products have different exogenously given qualities. The focus in Anderson and de Palma (2001) is on pricing when qualities are asymmetric, while in my model, in equilibrium qualities are symmetric and only incentives to improve quality matter. Anderson and Renault (2009) studies incentives to disclose horizontal information in a static model. It is shown that better information may lead to deterioration of consumer surplus due to higher prices. I show a similar result, however, in Anderson and Renault (2009) information is endogenously provided by firms, while my result holds for an exogenous improvement of information precision. Another crucial distinction is that in my model quality improvement is in the experience dimension of the products, whereas in Anderson and Renault (2009) qualities are known and only horizontal match information is manipulated by firms.

Finally, my results are also related to the literature on demand rotations (Johnson and Myatt (2006), Bar-Isaac et al. (2011b)). In this literature firms set the degree of product heterogeneity, and thus rotate their demand. My model is complementary in that I take

[7]See also Bar-Isaac et al. (2011a) for a related quality choice model where the good has two attributes, but costs of finding out a match along each attribute are separate.

product heterogeneity as given, and study the choice of quality. I find that the two factors that contribute to demand rotation, information precision and consumer heterogeneity, have qualitatively similar effects on equilibrium quality.

2 The model

2.1 Assumptions

There are n firms that each design and sell one differentiated product. There is a continuum of consumers of mass one who have to buy one unit of the product. The utility consumer l derives from product i is:

$$u_{li} = v_{li} - p_i$$

where p_i is the price charged by firm i, and v_{li} is drawn from a normal distribution with mean q_i and standard deviation σ_v.[8] It is useful to define $\eta_{li} = v_{li} - q_i$, a random variable that has mean zero and standard deviation σ_v. It can be interpreted as consumer l's idiosyncratic deviation from the population average. I assume that these deviations are independent across consumers and firms.

The parameter σ_v controls two important aspects of the model. First, it measures how differentiated products sold by different firms are. Second, it measures how predictable v_{li} is for consumer l when she knows (or correctly anticipates in equilibrium) q_i.[9]

Consumer l does not directly observe q_i, which is chosen by firm i (to be discussed later), or v_{li}. Instead, before purchase, for every product i she receives private signal s_{li}, where $s_{li} = v_{li} + \epsilon_{li}$. The observation noises ϵ_{li} are independent of all the previous variables and across consumers, and normally distributed with zero mean and standard deviation σ_s.

The signal structure above is deliberate. I am implicitly assuming that the information consumer l possesses about her valuation for product i reflects not the intended average quality, q_i (which is unknown to l), or l's deviation from this average, η_{li}, but rather l's personal valuation v_{li}. I do not allow a consumer to distinguish a producer's quality choice q_i and her own random deviation from the average. So, if a consumer receives positive information about a product she is not capable of telling whether this is due to higher quality or a higher realization of her personal match with the product along the experience attribute.[10]

[8]The normal distribution is particularly convenient because of its additive property. The assumption of normality is common in the literature. For example, Judd and Riordan (1994) and Caminal and Vives (1999) assume normality in related models. Johnson and Myatt (2006) use an example with a normal distribution in their work on demand rotations. Tunca (2008) uses normally distributed demand intercepts to study the efficiency of markets with information imprecision.

[9]The second effect can be separated with a specification $u_{li} = v_{li} + \nu_l - p_i$ where ν_l is the same for all the firms. Such modification clearly isolates the predictability of equilibrium quality effect, but does not alter the analysis. In any case, I discuss both channels through which σ_v has an effect on equilibrium price and quality throughout the paper.

[10]As will become clear later, a signal that only reflects q_i will have no effect on equilibrium, whereas a signal that only reflects η_i can only directly affect prices, but is not of any additional value in my model. Hence, I concentrate on the structure described above which gives many insights into quality investment

There are several natural justifications for this assumption. Imagine a consumer who knows that a reviewer from *Consumer Reports* gave a high rating to a product's usability. This high rating may be due to the high quality of the product or due to a good match between the reviewer and the product, but the consumer does not know which. She does know, however, that her preference on usability is correlated with the reviewer's, hence the rating provides an estimate of the consumer's total valuation but not of its parts.[11] Or imagine the consumer herself examining the product in a store. If she likes some experience dimension of the product, she cannot know whether this is because she just happens to match the product well or producer put a lot of effort into improving this dimension of quality for all consumers. Imagine holding a camera in your hand which feels comfortable to hold. Is the camera lousily designed but happens to fit your hands better than others', or is it well designed but is an average fit for you?

Firm i can set the average valuation of its product, q_i, and higher average valuation is costly. I refer to this variable as quality of product i because all consumers agree that product i is better, the higher is q_i. The cost of producing x_i units of the product of quality q_i is given by a twice continuously differentiable cost function $C(q_i, x_i)$. I assume that $C(\cdot)$ is linear in x_i, and $C_q > 0$ and $C_{qq} > 0$ for all $x_i > 0$. The last assumption is crucial and states that for any positive quantity level increasing quality is increasingly costly. This is both plausible in reality and necessary for the profit function to be well-behaved.

Even though I derive the equilibrium conditions using the more general formulation above, I illustrate my results with the following linear in quantity and quadratic in quality function:

$$C(q_i, x_i) = \tfrac{1}{2}(f + c \cdot x_i)q_i^2 = \underbrace{\frac{f q_i^2}{2}}_{\text{fixed cost}} + \underbrace{\frac{c\ q_i^2}{2}}_{\text{marginal cost}} \cdot x_i \tag{1}$$

where $f, c \geq 0$, and at least one is positive. This function reflects two different types of costs associated with increasing quality. First, there is a fixed (relative to quantity produced) component captured by f. For example, by investing more in software a firm can improve its product, which increases only the fixed cost, but does not change the marginal cost. Second, quality improvement may require better materials or components, which has no effect on fixed costs but increases the marginal cost. This feature is captured by the coefficient c. A combination of the two cases is also possible, where using a better component increases marginal cost, but at the same time requires R&D effort which also increases fixed costs.[12] In this cost function, the marginal cost of zero quality is normalized to zero without loss of generality.

Timing of the model is simple. All the firms simultaneously choose their prices and qualities. After this, consumers observe prices and receive private signals about their match with each firm and make a one-time purchase. I look for a symmetric pure strategy

and pricing.

[11] Caminal and Vives (1999) makes a similar argument.

[12] Note that this functional form does not allow a firm to choose whether to improve quality in fixed cost intensive or marginal cost intensive way, depending on the quantity x it plans to produce. Such flexibility would make the model less tractable.

Perfect Bayesian Equilibrium (PBE).

2.2 Equilibrium

I solve the model by first deriving consumers' optimal behavior, and then given this, solving firms' optimization problem.

Consumers

Since all consumers make decisions in the same way, from now on, I suppress subscript l and discuss a representative consumer. In order to choose the best offer in the market a consumer needs to estimate her vector of valuations $\mathbf{v} = (v_1, v_2, ..., v_n)$ using the vector of signals $\mathbf{s} = (s_1, s_2, ...s_n)$ and the vector of prices $\mathbf{p} = (p_1, p_2, ..., p_n)$, and choose the firm with the highest value of $E(v_i|\mathbf{s}, \mathbf{p}) - p_i$.

Assume that a consumer observes signal s_i and believes that firm i chose $\hat{q}_i$. Using the fact that all variables in the model are normally distributed, the posterior distribution of v_i will be normal with the mean equal to

$$E(v_i|s_i, \hat{q}_i) = \frac{\sigma_v^2}{\sigma_v^2 + \sigma_s^2} s_i + \frac{\sigma_s^2}{\sigma_v^2 + \sigma_s^2} \hat{q}_i \equiv \omega s_i + (1 - \omega)\hat{q}_i. \tag{2}$$

Whenever $\sigma_v^2 = \sigma_s^2 = 0$, consumer should use $\omega = 1$ because her signal equals v_i.

The expression in (2) can be understood as $\hat{q}_i$ and s_i both being used as two independent observation on v_i and weighted by their variances. Parameter ω will play a crucial role in later analysis as it measures how much consumers react to their signals. It is increasing in σ_v and decreasing in σ_s. The former because larger dispersion of valuations increases the weight consumers put on their signal, the latter because more noise in the signal decreases the weight consumers put on their signals.

PBE (or any other widely used solution method) places only one requirement on $E(\mathbf{v}|\mathbf{s}, \mathbf{p})$, namely that upon observing the equilibrium price vector $\mathbf{p}^*$ (all equilibrium variables are marked by asterisks) the consumer's belief $\hat{\mathbf{q}}$ is equal to the equilibrium quality vector $\mathbf{q}^*$, and this belief is used along with $\mathbf{s}$ to derive the correct posterior distribution of $\mathbf{v}$. Note that consumers, in principle, are allowed to condition $\hat{\mathbf{q}}$ on $\mathbf{p}$ and $\mathbf{s}$ out of equilibrium.[13] Due to the arbitrariness of out-of-equilibrium beliefs there are many equilibria.[14] Through $\hat{q}_i(\mathbf{p}, \mathbf{s})$ consumers' beliefs affect the profit maximizing price firm i charges, which in turn affects the choice of q_i. To simplify the analysis I make the following assumption

Assumption 1. *Consumers hold fixed belief* $\hat{\mathbf{q}}$ *which is independent of* $\mathbf{p}$ *and* $\mathbf{s}$.

I analyze my model where $\hat{q}_i$ is a function of p_i in Section 2.4.

[13] This seemingly apparent possibility is often overlooked in the literature. For more details see Section 2.4.

[14] Concepts like the intuitive criterion have no bite on such beliefs because firms have no private information apart from their own choice of q_i. In my model firms have no types, thus refinements that constrain which types can be believed to have made a particular out-of-equilibrium move have no relevance in this context.

Firms

Now I turn to the firm's optimization problem. Let q^* and p^* be the symmetric equilibrium quality and price chosen by all firms but i. Since I assume that beliefs do not change with i's deviation, and they have to be correct in equilibrium, $\hat{q}_i = q^*$ for any p_i.

Then consumer buys good i only if

$$\omega s_i + (1-\omega)q^* - p_i > \omega s_j + (1-\omega)q^* - p^*$$

holds for all $j \neq i$.[15] Using $s_i = q_i + \eta_i + \epsilon_i$ and $s_j = q^* + \eta_j + \epsilon_j$ and dividing both sides by $\omega\lambda$ (where $\lambda = \sqrt{\sigma_v^2 + \sigma_s^2}$) the previous inequality becomes:

$$\frac{\epsilon_i + \eta_i}{\lambda} > \frac{\epsilon_j + \eta_j}{\lambda} + \frac{\omega(q^* - q_i) + p_i - p^*}{\omega\lambda}.$$

First terms on both sides of the inequality are independently distributed standard normal variables. Let $G(x)$ and $g(x)$ denote the cumulative distribution function and probability density function of a standard normal variable, respectively. Then the demand for firm i can be written as

$$D_i(p_i, q_i) = \int_{-\infty}^{+\infty} \left[G\left(x - \frac{\omega(q^* - q_i) + p_i - p^*}{\omega\lambda} \right) \right]^{n-1} g(x)\ dx. \tag{3}$$

Given the above, expected profit of firm i is

$$\pi_i(p_i, q_i) = p_i D_i(p_i, q_i) - C(q_i, D_i(p_i, q_i)). \tag{4}$$

Assuming that the profit function is well-behaved, the unique symmetric equilibrium is defined by the following first order conditions:

$$p^* - C_x(q^*, 1/n) = \frac{\omega\lambda}{\gamma(n)} \tag{5}$$

$$C_q(q^*, 1/n) = \frac{\omega}{n}, \tag{6}$$

where $\gamma(n) = n(n-1)\int_{-\infty}^{+\infty} g(x)^2 G(x)^{n-2}\ dx$. To derive the above equations I have used the fact that in a symmetric equilibrium all firms receive an equal share of the market, so $x^* = 1/n$.

Since equilibrium qualities are symmetric and consumers *have* to buy one of the goods, the equilibrium markup (left-hand side of Eq. (5)) does not depend on q^*. This means that the markup is fully determined by the heterogeneity of valuations consumers attach to different firms. Unsurprisingly, then, the expression for p^* closely resembles equation (15) from Perloff and Salop (1985). Because in my model consumer does not observe v_i directly, to pick the best product she uses the estimates $E(v_i|s_i, q^*)$ which are linear combinations of s_i and q^* (Eq. (2)). These linear combinations are normally distributed with a standard deviation equal to $\omega\lambda$. So in my model the perceived degree of product

[15] Strict inequality is used because the probability of equality is zero due to the normal distributions.

differentiation is measured by $\omega\lambda$ and not σ_v. Taking this into account, Eq. (5) is precisely the same as the pricing equation in Perloff and Salop (1985). Interestingly, even though noise is added to v_i, consumers take it into account and firm's demand is more elastic with noise than it would be without it. This follows from $\omega\lambda < \sigma_v$, so, for a given quality level, prices are always lower in the model with observation noise.

The expression for equilibrium quality in (6) is quite intuitive. A unit increase of quality increases the estimated valuation for the product by ω units, which directly follows from Eq. (2). Hence, a simultaneous price increase of ω units would leave firm's demand unchanged at $\frac{1}{n}$. It follows that the marginal benefit from one additional unit of quality is $\frac{\omega}{n}$, which in equilibrium has to be equal to its marginal cost, which is given by C_q.

For the cost function from Eq. (1), the equilibrium quality is given by the following simple expression:

$$q^* = \frac{\omega}{c + nf} \ . \tag{7}$$

The equilibrium price, then, is

$$p^* = \frac{\omega^2 c}{2(c + nf)^2} + \frac{\omega\lambda}{\gamma(n)} \tag{8}$$

where the first term is the marginal cost of production. Equilibrium profit is given by:

$$\pi^* = \frac{\omega\lambda}{n\gamma(n)} - \frac{\omega^2 f}{2(c + nf)^2}. \tag{9}$$

Second order conditions for the case when $n = 2$ are given in the Appendix. For $n > 2$, these conditions are considerably more involved. Numerical simulations suggest that for relevant parameters the profit function in (4) is well-behaved and reaches its maximum at $\{p^*, q^*\}$.

For firms to participate in the market, their profits have to be non-negative. This is always true for $f = 0$ or f sufficiently high. Clearly, when there are fixed costs of providing quality, profit may be negative, thus if f is intermediate, to discourage investment in quality, c should be sufficiently high.

2.3 Comparative statics

My model has rich comparative statics. In this section, I look at how the observation precision, the degree of product differentiation, and the number of firms affects equilibrium quality and price. Most of the results that follow are derived for the quadratic cost function, but qualitatively hold for the more general cost formulation.

Product differentiation

The equilibrium price generally increases in the degree of product differentiation in Perloff-Salop type models. In my model, what matters is perceived product differentiation (taking into account the information noise), but it too goes up with the true degree of product differentiation.

Proposition 1. *Equilibrium price p^* and quality q^* are both increasing in the degree of product differentiation σ_v.*

Proof. Follows immediately from (5) and (6) and convexity of costs with respect to q. □

The positive relationship between the degree of product differentiation and equilibrium quality is new to the literature. The quality increases with σ_v whenever $\sigma_s > 0$. The reason is the following. When σ_v goes up, consumer puts more weight on her signal, because now i's conjectured quality choice is less informative about v_i. Since s_i is the only channel through which actual q_i, and not $\hat{q}_i$, affects i's demand, firm i gets a stronger incentive to invest in quality.

One may wonder if the positive relationship between q^* and σ_v is due to the increase in the equilibrium price that also results from higher σ_v. To see that the quality increase is not solely due to higher prices, note that for $\sigma_s = 0$, equilibrium quality is independent of σ_v, even though the equilibrium price still increase with it. It is therefore not only higher prices, but also the information channel described above which leads to higher quality with higher σ_v.

Another interesting aspect of my model is that for $\sigma_v = 0$ and $\sigma_s > 0$ quality is always zero, regardless of how small the observation noise is. This has two underlying reasons that could be separated in a more general model. First, when products are homogeneous, prices go down to zero, so firms have no incentive to provide quality. But even if prices were positive, quality would still be zero. This is because when $\sigma_v = 0$, consumer discards her signal (see Eq. (2)) when estimating v_i, and completely relies on her equilibrium conjecture. Since a firm's deviation to lower quality cannot be detected, no firm would choose $q_i > 0$. This feature of my model is related to the literature on observability and commitment initiated by Bagwell (1995), who shows that a slightest noise in observation makes commitment impossible.[16]

Observation noise

It has been shown in Meurer and Stahl (1994) and Anderson and Renault (2009) that prices of differentiated products go down to marginal cost when consumers do not have the necessary information about product characteristics. I show a continuous version of this result by allowing the information to vary from being completely precise to completely uninformative, and a new result on qualities. Importantly, my focus is on the exogenous shift in the information precision (the Internet), whereas the literature (including the above) has focused on endogenous information provision.

Proposition 2. *Equilibrium price p^* and quality q^* are both decreasing in the noisiness of the signal σ_s.*

Proof. Follows immediately from (5) and (6) and convexity of costs with respect to q. □

[16] Zero quality result is suggested in footnote 3 in Maggi (1999) who resolves the commitment problem by introducing private information.

For the price, the reason lies in how the effective product differentiation depends on σ_s.[17] Even though the actual product differentiation in the market depends on σ_v and does not change with σ_s, when consumers are unaware of their true valuation for an experience good, they rely on a signal to evaluate it. The effective differentiation, then, is measured by $\omega\lambda$, the dispersion of the random variable ωs_i, which is decreasing in σ_s. When $\sigma_s = \infty$, consumers cannot distinguish the goods at all (even though they know that *ex post* one of the goods is a better match), and firms end up engaging in Bertrand competition.

The relationship between q^* and σ_s is also intuitive. The better a consumer can observe her valuation, the larger the weight she puts on s_i. As with an increase in σ_v, with higher ω firms have stronger incentive to invest in quality. Of course, in my symmetric model all this investment is wasted from a firm's perspective, but the incentive to increase quality above that of competitors' still depends on ω, which in turn is decreasing in σ_s.

Are consumers better off with more precise information? It turns out that depending on the parameters consumers may be worse or better off. Information precision affects consumers in three largely independent ways. First, as discussed above, prices go up with more information. Second, equilibrium quality goes up, which increases their utility. Finally, with more precise information consumers are better allocated between firms which also increases utility. Whether the first effect dominates over the other two depends on parameters.

For illustration let us consider the case when $n = 2$, $c = 0$, and $f = 1$, and compare the expected utility when $\sigma_s = 0$ to when $\sigma_s = \infty$.[18]

It is easy to show that for $\sigma_v \in (\pi - \sqrt{\pi^2 - \sqrt{\pi}}, \pi + \sqrt{\pi^2 - \sqrt{\pi}})$ the expected utility with perfect information is lower than with no information.[19] This is because with full information quality is constant regardless of σ_v at 1. With very low σ_v, prices are close to zero with or without information, so full information is preferred by consumers due to higher quality. When σ_v is very high, the improvement from near-perfect allocation of consumers to products far outweighs higher prices so full information is preferred. For intermediate σ_v price increase from full information dominates both the quality increase and better allocation of consumers and, as a result, consumers are worse off.

The relationship between the equilibrium profit y^* and σ_s is also ambiguous. On the one hand, more observational noise means lower prices. But on the other hand, higher noise also results in lower quality, which is wasteful for firms. Since p^* is a fixed markup over the marginal cost, only the fixed cost portion matters for this trade-off. Even for the cost function given in (1) it can be shown that equilibrium profits can go up or down depending on parameters. Namely, if σ_s is sufficiently large equilibrium profit decreases in σ_s, but for small σ_s and relatively large σ_v the opposite is true.

Even though consumers and firms may be better or worse off, the relationship between information precision and total welfare is unambiguous.

[17] In a related model, Anderson and Renault (2000) show that prices may go up with the proportion on fully informed consumers in the market.

[18] I take the two extremes of the information precision because for intermediate σ_s the expected match of a consumer with firms is hard to compute.

[19] Here π stands for the ratio of circle's circumference to its diameter, and not profits.

Proposition 3. *Consumers and firms may be better or worse off with noisier information, but total welfare always goes down with more noise.*

Proof. See Appendix. □

Recall that prices are irrelevant for welfare because of the perfectly inelastic demand, so they can be discarded from welfare analysis. Therefore, what matters is only the level of investment in quality, and the efficiency of consumer allocation to firms. With less information equilibrium quality falls, while socially optimal quality is provided by the market when $\omega = 1$ (full information). Therefore, more information noise leads to inferior quality choices. At the same time, with less information consumers tend to be misallocated more (receive a wrong signal), which again decreases welfare. These two effects work in the same direction and guarantee that an increase in σ_s leads to lower total welfare.

Number of firms

In this section I take n as exogenous and look at its impact on other equilibrium variables. In the next section I will treat n as endogenous. In my model, variety can be captured by two coefficients - the degree of product differentiation σ_v and the number of firms n. Since σ_v describes preferences (firms have no control over it in my model), n can be taken as the sole measure of product variety that changes with market conditions.

Proposition 4. *Equilibrium quality and variety are inversely related whenever $f > 0$.*[20]

Proof. Follows directly from Eq. (6). □

Since quality expenses are purely wasteful from the perspective of firms, if $f > 0$ with more firms and a smaller market share, each firm has a declining incentive to invest in quality. This means that consumers can either get more variety or higher quality, but not both.

It is easy to verify numerically that $\gamma(n)$ is increasing in n, hence p^* decreases with the number of firms. So n has three distinct effects on consumers - equilibrium price goes down with the number of firms, expected match increases with more firms, and equilibrium quality (weakly) goes down with more firms. If $f = 0$, the latter is not true and consumers are unambiguously better off with more firms. If, however, $f > 0$, the last effect may dominate and result in deterioration of consumer welfare.

Total welfare clearly increases with n whenever $f = 0$, but may go down otherwise. To see this note that for $f = 0$ equilibrium quality is independent of n and there are no fixed costs of maintaining more firms. With more firms better matches are generated on average, so total welfare has to go up. However, when $f > 0$, n may be too large due to the fixed costs, so welfare may be decreasing in n.

[20] For a more general cost function, the condition is $C_q(q, 0) > 0$ for any $q > 0$.

Entry

Here I assume that entry is free, except for the fixed costs of producing non-zero quality i.e. any firm can enter the market for free with a product with $q_i = 0$. Since prices are a fixed markup over marginal cost, we have to require that $f > 0$, or otherwise, for any finite n, profits are never equal to zero. Zero profit condition can be obtained from (8). After some rearrangement we get:

$$\frac{2\lambda}{\omega} = \frac{fn^*\gamma(n^*)}{(c+n^*f)^2}. \tag{10}$$

where n^* denotes the equilibrium number of firms.[21]

The right-hand side of the last equality is increasing in n^* for relatively small f, and decreasing otherwise. The left-hand side is increasing in σ_s, but is non-monotone in σ_v - it is decreasing for $\sigma_v < \sqrt{2}\,\sigma_s$ and increasing for $\sigma_v > \sqrt{2}\,\sigma_s$.

Proposition 5. *For sufficiently small f the equilibrium number of firms n^* increases in the variance of the signal.*

Proof. See Appendix. □

So more precise information about products leads to less firms in the market. However, for this to be true, as a consequence of small f, the initial number of firm in the market has to be relatively large.

Zero profit condition can also be rewritten as:

$$\sqrt{\frac{2\,\omega\lambda}{fn^*\gamma(n^*)}} = q^*. \tag{11}$$

Using the last expression and Proposition 5 we can see that, for relatively small f, equilibrium quality is increasing in the precision of information, so Proposition 2 holds even if the number of firms is endogenous.[22] However, for larger f the reverse may be true.

As in Proposition 1, for relatively low σ_v and f, equilibrium quality is also increasing in σ_v even with free entry, but for large σ_v the opposite may be true.

Costs of quality

Recent developments in information technologies have lead to cheaper software development, hardware design and manufacturing. How does this decline in costs of providing quality, as measured by c and f, affect consumers and firms?

Equilibrium quality is always inversely related to c and f, and so is consumer surplus and total welfare. However, if $nf > c$, equilibrium profit increases in f. The reason for this lies in the wastefulness of higher quality for firms. On the one hand, a higher f makes

[21] For simplicity, I treat n as a continuous variable.

[22] This follows from the fact that $\gamma(n)n$ is increasing and $\omega\lambda$ is decreasing in σ_s, hence equilibrium quality is decreasing in σ_s.

providing quality more costly, which for a given quality level decreases profits. But on the other hand, higher f also decreases equilibrium quality which may offset higher cost of quality. When f is small quality is high so increasing f leads to lower profit. As f grows quality steadily shrinks so after a certain level quality falls faster than by how much the cost of providing it increases, hence profit increases in f. Profit is always increasing in c whenever $f > 0$, and is independent of c otherwise. This is because price is a fixed markup over marginal cost, but higher c leads to lover quality, which allows firms to save on fixed costs, if they exist.

2.4 Equilibrium multiplicity

Until now, I have assumed that consumers' conjectures on quality were unaffected by price deviations. This section illustrates that both equilibrium quality and price will change if this assumption is relaxed. To simplify analysis I will make a reasonable assumption that consumer belief $\hat{q}_i$ may only depend on p_i out of equilibrium. Using the same method as before, demand for firm i is

$$D_i(p_i, q_i) = \int_{-\infty}^{+\infty} \left[G\left(x - \frac{q^* - \omega q_i - (1-\omega)\hat{q}(p_i) + p_i - p^*}{\omega\lambda} \right) \right]^{n-1} g(x)\, dx. \tag{12}$$

It is clear that, because $\hat{q}(p_i)$ is arbitrary out of equilibrium, any price p^* can be supported in equilibrium provided that profits at this price are non-negative. To see this note that consumer demand depends on $\hat{q}(p_i)$, which is arbitrary, so by altering out of equilibrium beliefs consumers can lead firms to charge a continuum of prices. This does not mean that q^* is also arbitrary. To the contrary, for a specific symmetric equilibrium price p^*, equilibrium quality is still given by the first order condition

$$C_q(q^*, 1/n) = \frac{\gamma(n)}{n\lambda}(p^* - C_x(q^*, 1/n)).$$

For the cost function I have used before, this condition simplifies to

$$q^* = \frac{\sqrt{2c\gamma(n)^2 p^* + (c+nf)^2\lambda^2} - (c+nf)\lambda}{\gamma(n)c}. \tag{13}$$

So even though the price is indeterminate, equilibrium quality is fully determined by the price.

Finally, for equilibrium to exist, profits have to be non-negative. Using the previous expression for q^*, the non-negativity of profits implies that $p^* \leq \frac{2(c+nf)^3\lambda^2}{n^2 f^2 \gamma(n)^2}$.

Proposition 6. *Any price $p^* \in \left[0, \frac{2(c+nf)^3\lambda^2}{n^2 f^2\gamma(n)^2}\right]$ can be sustained in equilibrium by some symmetric beliefs $\hat{q}(p)$ provided that equilibrium quality q^* solves (13).*

Proof. The statement about quality follows from the first order condition, so if all firms charge p^*, then all of them will set quality equal to q^*. For p^* to be a profit maximizing price assume that $\hat{q}(p) = q^*$ for $p = p^*$ and $\hat{q}(p) = 0$ for all $p \neq p^*$. Then all firms will choose to charge p^* and profits will be non-negative, hence p^*, q^* and $\hat{q}(p)$ constitute an equilibrium. □

Which out of equilibrium beliefs $\hat{q}(p)$ are more natural is an open question in the literature. I have studied passive beliefs where $\hat{q}(p) = \hat{q}$. Not only has this been the norm in the literature, but Judd and Riordan (1994) and Bar-Isaac et al. (2010) have not even consider other possibilities and report equilibrium uniqueness.

There are at least two other natural ways to resolve this issue. First, we may impose a high level of rationality on $\hat{q}(p_i)$ and assume that consumer beliefs are such that not only for p^*, but also for all out-of-equilibrium p_i, consumer beliefs are consistent with the profit maximization. This requires to solve a first degree differential equation, and is fairly complicated. Second, one may use a forward induction type argument and reason that upon observing any p_i consumers choose $\hat{q}_i$ which maximizes firm's profit for this price. This is also hard to solve mathematically.[23] It seems intuitive that in both cases, given that equilibrium beliefs will move in the same direction as prices, the outcomes will feature higher prices and qualities compared to the equilibrium I have derived. The comparative statics exercises should remain qualitatively unchanged.

3 Conclusion

This paper develops a tractable model of quality choice of experience goods. The framework incorporates several features analyzed elsewhere in the literature. Quality is allowed to be observable before purchase with exogenously determined noise. It is shown that only when consumers face uncertainty about their valuations, do intermediate levels of observability play any role. When combined, the partial observability and the dispersion of valuations allow for higher than minimum quality. The equilibrium quality is shown to be increasing continuously in both the observability and the dispersion.

There are several interesting issues that can be studied with the model presented here. Endogenous information acquisition by consumers, particularly for multi-attribute goods with the attributes of various observability is an interesting next step. The role of advertising as an additional signaling device is also interesting. Advertising can also be considered as a costly effort that changes observability of quality. It seems intuitive that advertising effort will be inversely related to product differentiation. If true, this means that firms will spend more on informative advertising in markets where differentiation is low (PCs, televisions etc.). Formal analysis of these issues may shed some light on the relationship between quality, advertising and prices.

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Appendix

Second order conditions for profit maximization for n = 2

Here we show that for two firms and the cost function in (1) the solution given by the first order conditions (5) and (6) is indeed valid. Second order conditions for profit maximization are $y_{pp}(p^*, q^*) < 0$, $y_{qq}(p^*, q^*) < 0$ and $y_{qq}(p^*, q^*) \cdot y_{pp}(p^*, q^*) > y_{pq}(p^*, q^*)^2$. To show that all of these conditions hold, first we derive the following:

$$\begin{aligned} y_{pp}(p^*, q^*) &= -\frac{\gamma(2)}{\lambda\omega} \\ y_{qq}(p^*, q^*) &= -\left(\frac{c}{2} + f + \frac{c\gamma(2)q^*}{\lambda}\right) \\ y_{pq}(p^*, q^*) &= \frac{cq^* + \omega\gamma(2)}{2\lambda\omega}\ . \end{aligned}$$

Clearly, $y_{pp}(p^*, q^*)$ and $y_{qq}(p^*, q^*)$ are negative. The condition $y_{qq}(p^*, q^*)y_{pp}(p^*, q^*) > y_{pq}(p^*, q^*)^2$ can be rewritten as

$$\frac{\lambda}{\omega\gamma(2)} > \frac{2f^2}{(c+2f)^3} \ .$$

This inequality is implied by the non-negativity of equilibrium profits.

Comparison of consumer utility with no information and full information

Expected utility when $\sigma_s = \infty$ is

$$u_\infty = 0.$$

The last expression is derived using $p^* = q^* = 0$ and the fact that the average match between a consumer and a randomly chosen firm is zero.

For $\sigma_s = 0$ we have $p^* = 2\sqrt{\pi}\ \sigma_v$, $q^* = 1$ and expected match equal to $1 + \frac{\sigma_v^2}{\sqrt{\pi}}$, so

$$u_0 = 1 + \frac{\sigma_v^2}{\sqrt{\pi}} - 2\sqrt{\pi}\ \sigma_v = 1 + \frac{\sigma_v}{\sqrt{\pi}}(\sigma_v - 2\pi).$$

For $u_0 > u_\infty$ we need that $\sigma_v \in \left(\pi - \sqrt{\pi^2 - \sqrt{\pi}}, \pi + \sqrt{\pi^2 - \sqrt{\pi}}\right)$.

Proof of Proposition 3

The example in the main text shows that consumers can be worse or better off. The derivative of equilibrium profit with respect to σ_s has the same sign as

$$2nf\sigma_v^2\gamma(n) - (c+nf)^2(\sigma_s^2 + \sigma_v^2)^{3/2}.$$

When profits are zero, this expression is always positive. But for n large enough profits are positive and this expression is negative, hence profits can be either increasing or decreasing in σ_s.

Total welfare does not depend on prices as long as they are all equal. Socially efficient quality level is given by $q^e = \frac{1}{c+nf}$. Total welfare is increasing in quality for $q < 1$, so total welfare decreases in σ_s in terms of quality. Finally, the higher σ_s, the more frequent is the misallocation of consumers to products, which also decreases welfare, hence total welfare decreases in σ_s.[24]

Proof of Proposition 5

Take the difference between the right-hand side of (10) evaluated at $n+1$ and n. After some algebra the difference can be written as $n(c+fn)^2(\gamma(n+1) - \gamma(n)) + (c+fn)^2\gamma(n+1) - nf(2c+f+2fn)\gamma(n)$. Since $\gamma(n)$ is increasing in n, the first two terms of the last

[24] This statement is harder to show as it is necessary to calculate expected consumer surplus for a given noise level σ_s and show that it decreases in σ_s. I do not do this here, but it is fairly obvious that such is the case.

expression are always positive, so for small enough f the whole expression is also positive. Hence the right-hand side of (10) is decreasing in n for small enough f.