Confidence, optimism and quality in a Bertrand duopoly

Lucie Bottega [*], Dorothée Brécard[†], Philippe Delacote [‡§¶]

Abstract

Our paper assesses how firms communication strategy may influence and may be influenced by the consumers' beliefs about the quality of the consumed goods. We consider two kinds of communication tools: information dissemination (the true quality of the good is communicated) and advertising (the firm announces a quality above the true good quality). We give the conditions under which the communication strategies and quality are substitutes.

Keywords: consumption, Bertrand duopoly, information, adverstising.

JEL classification:

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[†]Université de Toulon, LEAD

[‡]Corresponding author: philippe.delacote@inra.fr

[§]Laboratory of Forest Economics, INRA, AgroParisTechF-54000 Nancy, France

[¶]Climate Economics Chair, Paris, France

1 Introduction

In many cases consumers when making their purchase decision have an imperfect knowledge of products true quality. This is the case when goods are characterized by experience or credence attributes. Whereas the quality of experience goods can be discovered after use or consumption, credence goods quality cannot. Examples of credence characteristics are organic food, fair trade, special health benefits, animal welfare benefits, local products (farmers markets) and country of origin.

To solve the informational problems surrounding credence goods, producers can disclose information to consumers. In this context, firms? communication strategy is of crucial importance. The aim of this paper is to study firms? choice in terms of quality and information disclosure when consumers have imperfect knowledge of product quality and firms can influence consumers? beliefs. Like investing in quality, investing in information disclosure to consumers is costly. A natural question then arises : should a firm invest to increase product quality or to increase consumers' perception of product quality? Another question of interest is to look at the substituability or complementarity of instruments used to disclosed information and the nature of the conveyed information.

We consider a Bertrand duopoly with two firms producing a low and a high quality variant. The originality of the paper lies on beliefs modeling. Whereas the literature usually uses a Bayesian approach to model uncertainty towards product quality (Mason [2009,2011], Strausz [2010]), we rather base our analysis on the concept of neo-additive capacities developed by Ellsberg [1961] that model optimistic and pessimistic attitudes towards uncertainty based on experimental studies. In our model, following Eichberger et al. [2007] beliefs formation depends on two connected components: confidence and optimism. *Confidence* reflects the fact that consumers form their beliefs weighting between the true good quality, and an interval of the best and worst possible quality. *Optimism* reflects the fact that consumers form their beliefs weighting between the best possible quality anthe worst possible quality. Firms can strategically influence consumers? belief towards good quality by using two instruments influencing optimism and confidence: advertising or information dissemation. *Advertising* can be an informative or a persuasive instrument. We follow the second strand of the literature where advertising is persuasive in the sense that it makes consumers more optimistic towards firms' product quality. While firms use advertising to increase consumer's perception of the good quality by increasing her degree of optimism, dissemination aims at making the consumers' beliefs more accurate, providing information about the good real quality. Formally,

information dissemination thus decreases the distance between the consumers' belief and the good real quality, by increasing the degree of confidence. Examples of such an instrument are labeling schemes supported by public or private agencies (e.g. the forest stewardship Council (FSC), The European Organic label).

First, we show that when consumers tend to over-estimate the quality of the product, firms only use adversiting whereas when consumers under-estimate the goods quality they prefer to combine advertisement and information dissemination.

Second, we assess the nature of the interaction between information dissemination and advertising. We show that the price discrepancy between the two communication tools plays a key role. For extreme values of the price ratio, informing and adverstising tend to be substitutes while while for intermediate value of the price ratio, they tend to be complement.

Third, we also assess the nature of the interactions between the quality of the good and informing and advertising, respectively. Adversiting tends to be a substitute to the goods quality, except when the price of ratio is very favourable to advertising. When it comes to informing, the reverse is true: information dissemination and quality are complement, unless when the price ratio is very detrimental to informing.

The rest of the paper is organized as follows : In section 2, we introduce the model. In section 3 we look at the high quality firm's choice in terms of information dissemination, advertising and quality. Section 4 concludes.

1.1 Consumers

We consider a continuum of consumers indexed by θ. Parameter θ represents consumers? taste for quality and is uniformly distributed over [0, 1]. Consumers have imperfect knowledge (or trust) of the good quality. Two kinds of goods coexist on the market: a high-quality good and a low-quality good. The high-quality good is of quality $q_h = q$. Conversely, the low-quality good is of quality $q_l = q_{min}$, which is considered as the lowest possible quality that may be offered (e.g: by law). To simplify the analysis, we consider that: $q \in [0, 1]$, $q_{min} = 0$, and $q_{max} = 1$. Consumers decide to buy one unit or zero of the good, which can be either a low or a high-quality good. A consumer j has the following expected indirect utility function:

$$v_j(p_i, q_i, \theta_j) = m - p_i + \theta_j E(q_i) \ for \ i = h, l \tag{1}$$

p_i represents the market price for the good of quality q_i. m denotes the consumers reservation price for a low quality good. We consider that the market is fully covered, implying that the indirect

utility function needs to be positive: $p_l \leq m$. Consumers have ambiguous beliefs about quality q_i in the sense that they cannot assign a probability distribution to quality. As in Chateauneuf, Eichberger, Grant (2007), beliefs are characterized, not by a probability distribution, but by a neo-additive capacity, defined in the following way:

$$\begin{aligned} E(q_h) &= (1-\delta)q + \delta\alpha q_{max} + \delta(1-\alpha)q_{min} = (1-\delta)q + \delta\alpha \\ E(q_l) &= q_{min} = 0 \end{aligned} \tag{2}$$

with $(1-\delta)$ the degree of confidence, such that $\delta \in [0,1]$, and α the degree of optimism of the consumer, such that $\alpha \in [0,1]$. According to Eichberger et al. (2008), such an assumption means that individuals lack confidence in their belief. They are at the same time optimistic, by over-weighting the best quality q_{max}, with a weight $\delta\alpha$, and pessimistic by over-weighting the worst quality q_{min}, with a weight $(1-\delta)\alpha$. In other words, the degree of optimism characterizes consumer responses to ambiguity, measured by the degree of ambiguity δ. Note that if $\delta = 0$, the consumer has perfect information on the true quality of the good. For the sake of clarity, denote Δ the expected high quality, defined by $\Delta \equiv (1-\delta)q + \delta\alpha$.

The indifferent consumer between the high and the low quality is defined by:

$$\widetilde{\theta} = \frac{p_h - p_l}{\Delta} \tag{3}$$

Thus high- and low-quality demands are respectively:

$$\begin{cases} D_h = 1 - \widetilde{\theta} = \frac{p_l - p_h + \Delta}{\Delta} \\ D_l = \widetilde{\theta} = \frac{p_h - p_l}{\Delta} \end{cases} \tag{4}$$

1.2 Symmetric Bertrand duopoly

Assuming a symmetric Bertrand duopoly, the two Nash equilibria are $[i,j] = [h,l]$, i.e the equilibrium is necessarily made of asymmetric strategies (for otherwise (symmetric strategies), profit are zero for both firms).

Both firms maximize:

$$\max_{p_i} \pi_i(p_i) = (p_i - cq_i^2)D_i \ for \ i = h,l \tag{5}$$

with cq_i^2, the unit cost of providing quality q_i.

The first-order conditions give the equilibrium prices:

$$\begin{aligned} p_h &= \frac{2}{3}(\Delta + cq^2) \\ p_l &= \frac{1}{3}(\Delta + cq^2) \end{aligned} \tag{6}$$

High- and low-quality demands are respectively[1]:

$$\begin{aligned} D_h &= \frac{2\Delta - cq^2}{3\Delta} \\ D_l &= \frac{\Delta + cq^2}{3\Delta} \end{aligned} \tag{7}$$

Profit are:

$$\begin{aligned} \pi_h &= \frac{(2\Delta - cq^2)^2}{9\Delta} \\ \pi_l &= \frac{(2\Delta + cq^2)^2}{9\Delta} \end{aligned} \tag{8}$$

Note that the Nash equilibrium implies that only one firm produce the high-quality good. The firms being symmetric, it does not matter which one chooses to produces the high quality.

2 Quality choice, information dissemination and advertising

In this section, we consider the choice by the high-quality firm of the actual quality of the produced good. Moreover, we assume that consumers' belief may be influenced.

2.1 How can consumers beliefs be influenced?

Firms can resort to two strategies to influence consumers' beliefs: disseminating true information on the good quality (d) and advertising (a).

First, true information about the good quality may be disseminated. Information dissemination aims at making the consumers' beliefs more accurate, providing information about the good's real quality. d is the amount spent in dissemination, at a per-unit cost p_d. Formally, information dissemination thus decreases the distance between the consumers' belief Δ and the good real quality q, by increasing the degree of confidence $(1-\delta)$. This can be expressed as follows: $\delta(d)$, with $\delta_d < 0$, $\delta_{dd} > 0$.

Second, advertising aims at increasing consumer's perception of the good quality Δ, by increasing her degree of optimism $\alpha(a)$, with $\alpha_a > 0$, $\alpha_{aa} < 0$. a is the amount spent in advertising, at a per-unit cost p_a.

The expected quality can be rewritten as a function of the real high quality, q, spending in information dissemination, d, and spending in advertising, a: $\Delta(q, d, a) = (1 - \delta(d))q + \delta(d)\alpha(a)$. Note that an increase in information dissemination, by enhancing confidence, undermines the role

[1]To involve positive high-quality demand, the perceived quality has to be high enough with regard to the unit production cost $2\Delta > cq^2$

of advertising, because it reduces the weight of the degree of optimism in quality expectation, whereas the reverse is not true. More precisely, q, d and a affect $\Delta(q,d,a)$ as follows:

- $\Delta_q = (1-\delta(d)) > 0$;
- $\Delta_d = \delta_d(\alpha(a)-q) > 0, \forall q > \alpha(a)$;
- $\Delta_a = \delta(d)\alpha_a > 0$;
- $\Delta_{qq} = 0$;
- $\Delta_{dd} = \delta_{dd}(\alpha(a)-q) < 0, \forall q > \alpha(a)$;
- $\Delta_{aa} = \delta(d)\alpha_{aa} < 0$;
- $\Delta_{qa} = 0$;
- $\Delta_{qd} = -\delta_d > 0$;
- $\Delta_{da} = \delta_d\alpha_a < 0$.

Thus, expected quality is increasing in the true quality and the level of advertising. In contrast, information dissemination increases expected quality only when the true quality is larger than the degree of optimism ($q > \alpha(a)$), that is when consumers underestimate the high quality ($\Delta < q$).

We now turn to the communication stage and investigate information and advertising strategies.

2.2 Information dissemination and advertising by the high-quality firm

2.2.1 Demand for information dissemination and advertising

The high-quality firm maximizes its profit, with respect to the amount spent in information dissemination (d) and advertising (a), considering quality $q = \overline{q}$ as given:

$$\max_{d,a} \pi_h(\overline{q},d,a) = \frac{(2\Delta(\overline{q},d,a) - c\overline{q}^2)^2}{9\Delta(\overline{q},d,a)} - p_d d - p_a a \tag{9}$$

First-order conditions give the inverse demand function of information dissemination d^* and advertising a^* by the high-quality firm[2]:

$$\begin{aligned} p_d &= \frac{(4\Delta(\overline{q},d^*,a^*)^2 - c^2\overline{q}^4)}{9\Delta(\overline{q},d^*,a^*)^2}\Delta_d \\ p_a &= \frac{(4\Delta(\overline{q},d^*,a^*)^2 - c^2\overline{q}^4)}{9\Delta(\overline{q},d^*,a^*)^2}\Delta_a \end{aligned} \tag{10}$$

[2]Second-order conditions are given in appendix A.

Note that the level of information dissemination d^* is positive only when quality is underestimated by the consumer ($\Delta(\overline{q}, a^*, d^*) < \overline{q}$) otherwise the profit would be decreasing in d, meaning that no dissemination would be implemented. In contrast, the level of advertising a^* is always positive. Bringing together the conditions for informing and for duopoly existence, Figure 1 shows three configurations for market structure and information disclosure according to production cost and quality perception:

- In Region I, consumers over-estimate quality q and both firms produce ($2\Delta > cq^2$). The high-quality firm delivers no information to consumers because information disclosure would be counter-productive ($\Delta_d < 0$). In other words, there is information overload.
- In region II, consumers under-estimate the high quality and both firms produce ($2\Delta < cq^2$). The high-quality firm has an interest in delivering information and in advertising its product in order to maximize its profit, in accordance with FOC (10).
- In Region III, only the low-quality firm is viable because the production cost of the high-quality firm is too high with regard to the perceived quality of the product ($2\Delta < cq^2$) and, thereby, with regard to consumers' willingness-to-pay the high-quality product.

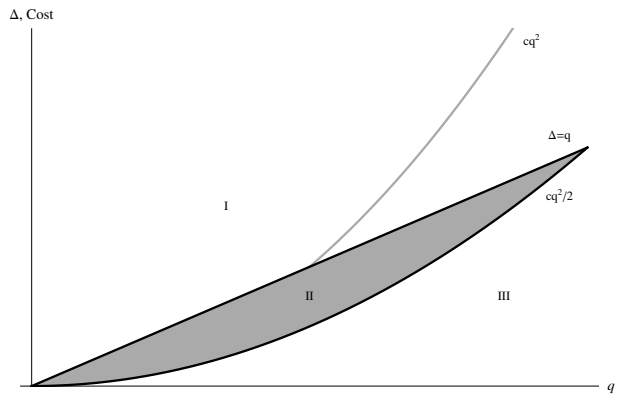

Figure 1: Market structure and expected quality

Result 1: *In markets where consumers are optimistic enough upon the good's quality ($\alpha(a^*) > \overline{q}$), the firm only invests in advertising. In contrast, the firm invests both in advertising and information dissemination when consumers under-estimate the true quality of the goods.*

Result 1 states that when consumers over-estimates the quality ($\Delta > q$), information disclosure would be counter-productive ($\Delta_d < 0$), revealing that the true quality is actually lower than the

expected quality. This can be interpreted as an 'information overload' situation. In this case, the only remaining communication tool is advertising, which further improves consumer optimism regarding the high-quality. Conversely, information disclosure is efficient when consumers have a poor image of the high-quality product.

For the remaining of the paper, we restrict to the most interesting case where the firms both invest in advertising and information dissemination. Thus we assume that consumers are pessimistic about the high quality: $\alpha(a) < \overline{q}$.

2.2.2 Degree of substitution of information and advertising

When consumers under-estimate the high quality ($\Delta(\overline{q}, a^*, d^*) < \overline{q}$), then the marginal rate of technical substitution between advertising and information dissemination is given by:

$$MRTS_{da} = \frac{p_d}{p_a} = \frac{\Delta_d}{\Delta_a} \tag{11}$$

This condition can be rewritten:

$$f(\overline{q}, d^*, a^*) = \Delta_d p_a - \Delta_a p_d = 0 \tag{12}$$

Using the implicit function theorem, we have[3]:

$$\frac{\partial d^*}{\partial a^*} = -\frac{f_a}{f_d} = -\frac{\Delta_{da} p_a - \Delta_{aa} p_d}{\Delta_{dd} p_a - \Delta_{da} p_d} \tag{13}$$

Advertising and information are thus substitute if $\frac{\partial d}{\partial a} < 0$, that is if:

$$\begin{cases} \frac{p_d}{p_a} > \frac{\Delta_{da}}{\Delta_{aa}} \\ \frac{p_d}{p_a} > \frac{\Delta_{dd}}{\Delta_{da}} \end{cases} \quad or \quad \begin{cases} \frac{p_d}{p_a} < \frac{\Delta_{da}}{\Delta_{aa}} \\ \frac{p_d}{p_a} < \frac{\Delta_{dd}}{\Delta_{da}} \end{cases} \tag{14}$$

and complement otherwise.

Figure 2 depicts changes in thresholds $\frac{\Delta_{dd}}{\Delta_{da}}$ and $\frac{\Delta_{da}}{\Delta_{aa}}$ according to variations in a, for given d and q.[4] It exhibits 4 areas: In Regions I and IV, because the relative price is lower or higher than both thresholds, information dissemination and advertising are substitutables; In Regions II and III, because the relative price is between the two thresholds, information dissemination and advertising are complementary. Such results are synthesized in Result 2 below.

Result 2: *Information dissemination and advertising tend to be substitutes when the price discrepancy is large enough. They tend to be complement when the relative price is intermediate.*

[3] See Appendix A for further details.

[4] See Appendix B for further details

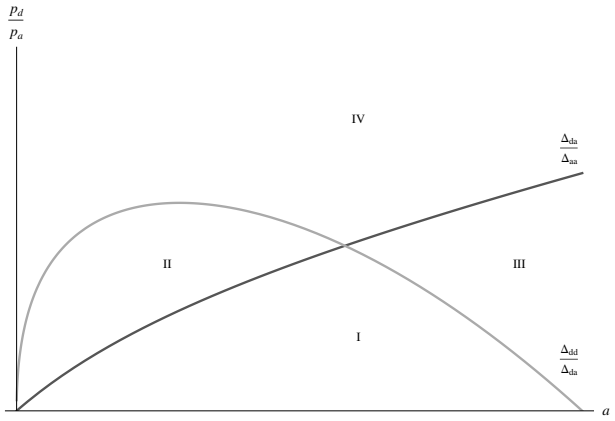

Figure 2: Substitutability and complementarity between a, d and q

Results 2 arises from the asymmetric impacts of the degrees of confidence and optimism on the expected quality and, thereby, the profit. When the firm invests more in information disclosure, this enhances consumer confidence in quality though reducing consumer sensitivity to advertising. The firm can then advertise more in order to counter the effect of information on optimism weight. In this case, advertising and information are complements. Conversely, the firm can reduce its advertising effort because of the low efficiency of such a communication way on consumers' beliefs.

2.2.3 Impact of quality on information dissemination and advertising

Levels of information and advertising are influenced by the quality choice made by the firm at the first stage of the game. Using the implicit function theorem, it is possible to see how the good's quality affects the optimal levels of information dissemination and advertising[5]:

$$\frac{\partial d^*}{\partial \overline{q}} = -\frac{f_q}{f_d} = -\frac{\Delta_{dq} p_a}{\Delta_{dd} p_a - \Delta_{da} p_d} \tag{15}$$

$$\frac{\partial a^*}{\partial \overline{q}} = -\frac{f_q}{f_a} = -\frac{\Delta_{dq} p_a}{\Delta_{da} p_a - \Delta_{aa} p_d} \tag{16}$$

Consequently, higher quality leads to greater information when relative price $\frac{p_d}{p_a}$ is in Region I or III in Figure 2, and to lower information otherwise. Higher quality entails more advertising when relative price $\frac{p_d}{p_a}$ is in Region I or II in Figure 2 and less advertising otherwise.

Result 3: *Informing tend to be complement with quality, unless the price of informing is really high compared to the price of advertising. Similarly, advertising tends to be substitutes with*

[5]Recall that $\Delta_{aq} = 0$. See Appendix A for further details.

Table 1: Substitution and complementarity between advertising, informing, and quality

$\frac{p_d}{p_a}$	I	II	III	IV
$\frac{\partial d}{\partial a}$	-	+	+	-
$\frac{\partial a}{\partial q}$	+	+	-	-
$\frac{\partial d}{\partial q}$	+	-	+	-

quality, unless the price of advertising is low enough compared to the price of informing.

Table 1 shows the direction of pairwise relations between q, d and a according to areas of relative price $\frac{p_d}{p_a}$ (as defined in Figure 2). It shows that, when the relative price of information is low (*i.e.* in Region I), the higher the quality of its product, the more the firm will promote it through information or advertising. Nevertheless, both communication modes are substitutes.[6] The firm will thus choose to promote either optimism or confidence of consumers for a given high quality. In contrast, when the relative price is high (in region IV), though both communication tools are substitutes, the firm will spend even less in advertising or in information that quality is high. For an intermediate relative price (in Regions II and III), higher quality plays in opposite direction on advertising and information, which are complementary means of communication. For a given quality, the firm has thus an interest in fostering both optimism and confidence of consumers in order to improve their perception of the high quality.

3 Conclusion

In many situations, consumers have a blurred knowledge of the true quality of the good they consumer, especially when dealing with non observable attributes. In those cases, consumers may over-estimate or under-estimate the true goods' quality. In this context, the firm producing the concerned good have to choose their communication strategy. In one word, the firm can either disseminate information on the good quality, or advertise the good quality over its true value. Our paper precisely assess how firms may communicate about the quality of the goods they sell, depending on the consumer beliefs on those qualities.

[6]These results are not contradictory since the properties of complementarity and substituability between information, advertising and quality are established all other things being equal.

First, we show that firms combine information dissemination and advertising only on markets where consumers tend to over-estimate the quality of the consumed goods. In contrast, firms combine both communication tools whenever consumers under-estimate the goods quality.

Second, we assess the nature of the interaction between information dissemination and advertising. We show that the price discrepancy between the two communication tools is key. When the price ratio takes extreme values, informing and advertising tend to be substitutes. In contrast, they tend to be complement when the price ration is intermediate.

Third, we also assess the nature of the interactions between the quality of the good and informing and advertising, respectively. Advertising tends to be a substitute to the goods quality, except when the price ratio is very favorable to advertising. When it comes to informing, the reverse is true: information dissemination and quality are complement, unless when the price ratio is very detrimental to informing.

Acknowledgement

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Appendix A

The second-order conditions of the optimal choice of d and a are $\pi_{aa} < 0$, $\pi_{dd} < 0$ and $\pi_{dd}\pi_{aa} - \pi_{da}^2 > 0$ with:

$$\pi_{aa} = (\frac{\Delta_{aa}}{\Delta_a} - \frac{2\Delta_a}{\Delta(q,d,a)})p_a + \frac{8\Delta_a^2}{9\Delta(q,d,a)} \quad (17)$$

$$\pi_{dd} = (\frac{\Delta_{dd}}{\Delta_d} - \frac{2\Delta_d}{\Delta(q,d,a)})p_d + \frac{8\Delta_d^2}{9\Delta(q,d,a)} \quad (18)$$

$$\pi_{da} = (\frac{\Delta_{ad}}{\Delta_d} - \frac{2\Delta_a}{\Delta(q,d,a)})p_d + \frac{8\Delta_a\Delta_d}{9\Delta(q,d,a)} \quad (19)$$

$$= (\frac{\Delta_{ad}}{\Delta_a} - \frac{2\Delta_d}{\Delta(q,d,a)})p_a + \frac{8\Delta_a\Delta_d}{9\Delta(q,d,a)} \quad (20)$$

$$(21)$$

Insofar as $\Delta_{xx} < 0$ and $\Delta_x > 0$, when $\Delta < q$, the first term of π_{xx} is always negative (for $x = a, d$), while the second term is positive. Moreover, $\Delta_{ad} < 0$, thus the first term of π_{ad} is always negative, while the second term is positive. As a consequence, second-order conditions are fulfilled for sufficiently high prices of information and advertising and/or specific form for $\Delta(q,d,a)$ such

as:

$$8\Delta_d^3 < 9(2\Delta_d^2 - \Delta\Delta_{dd})p_d \tag{22}$$

$$8\Delta_a^3 < 9(2\Delta_a^2 - \Delta\Delta_{aa})p_a \tag{23}$$

Note that if $8\Delta_a\Delta_d^2 < 9(2\Delta_a\Delta_d - \Delta\Delta_{ad})p_d \iff 8\Delta_a^2\Delta_d < 9(2\Delta_a\Delta_d - \Delta\Delta_{ad})p_a$, then $\pi_{da} < 0$.

In order to analyze impact of quality on information dissemination and advertising, we derive the following second derivative:

$$\pi_{aq} = -\frac{2c^2q^3((1-\delta(d))q + 2\alpha(a)\delta(d))\alpha_a}{9\Delta(q,d,a)^3} < 0 \tag{24}$$

$$\pi_{dq} = \frac{2c^2q^3((1-\delta(d))q + 2\alpha(a)\delta(d))(q-\alpha(a))}{9\Delta(q,d,a)^3}\delta_d - \frac{4\Delta^2 - c^2q^4}{9\Delta(q,d,a)^2}\delta_d \tag{25}$$

Appendix B

Functional forms used for the simulations are:

$$\alpha(a) = (\frac{a}{(a+1)})^x \; with \; x < 1 \tag{26}$$

$$\delta(d) = 1 - (\frac{d}{(d+1)})^y \; with \; y < 1 \tag{27}$$

The expected quality is then defined by: $\Delta(q,d,a) = (\frac{d}{(d+1)})^y q + (1-(\frac{d}{(d+1)})^y)(\frac{a}{(a+1)})^x$. Because $\Delta_{aa} < 0$, $\Delta_{dd} < 0$ and $\Delta_{da} < 0$, $\Delta(q,a,d)$ is a concave function with respect to d and a, if $\Delta_{aa}\Delta_{dd} - \Delta_{ad}^2 > 0$, that is $\frac{\Delta_{dd}}{\Delta_{da}} > \frac{\Delta_{ad}}{\Delta_{aa}}$. Otherwise, $\Delta(q,a,d)$ has an indeterminate form and $\frac{\Delta_{dd}}{\Delta_{da}} < \frac{\Delta_{ad}}{\Delta_{aa}}$.

Setting x and y to 1/2, Figures A1 and A2 show that the concavity condition is fulfilled when a is lower than a given threshold, denoted $\hat{a}(d,q)$, which is increasing in q (Fig.A1) and decreasing in d (Fig.A2). Furthermore, simulations show that $\hat{a}(d,q)$ is relatively insensitive to changes in d when $d > 1$ (for example, $\hat{a}(0.01, 0.4) = 0.165$, $\hat{a}(1, 0.4) = 0.096$ and $\hat{a}(10, 0.4) = 0.094$). Note that the quality undervaluation condition, $q > \alpha(a)$, imposes $a < 0.19$ when $q = 0.4$, $a < 0.56$ when $q = 0.6$ and $a < 1.78$ when $q = 0.8$. Because the relation between quality, information and advertising depends on the relative price of communication tools against thresholds $\frac{\Delta_{dd}}{\Delta_{da}}$ and $\frac{\Delta_{ad}}{\Delta_{aa}}$, Figures A1 and A2 lead to define 4 regions (depicted in Figure 2 in Section 3.2.2 for given q and d), depending on whether $\frac{p_d}{p_a}$ is lower than, between or higher than $\frac{\Delta_{dd}}{\Delta_{da}}$ and $\frac{\Delta_{ad}}{\Delta_{aa}}$.

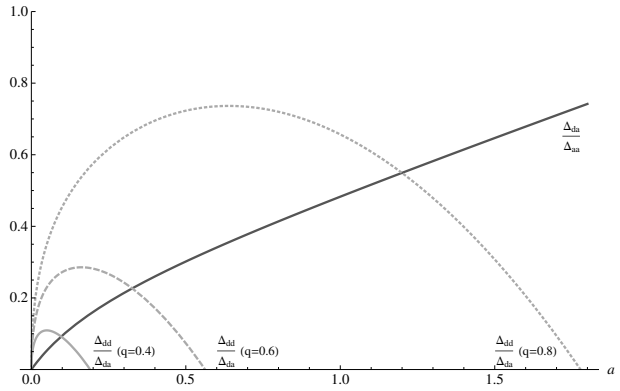

Figure 3: Figure A1. Thresholds for relative price p_d/p_a for some values of q and $d = 1$

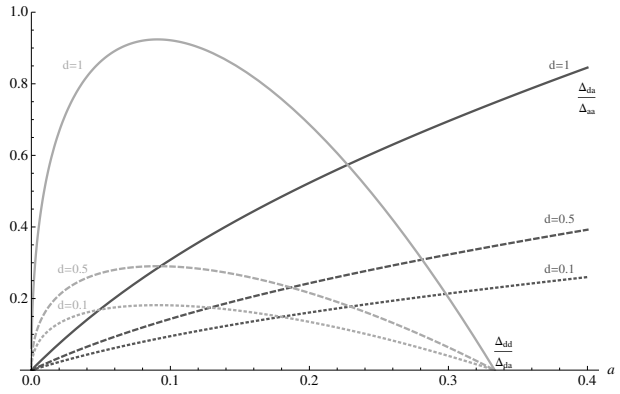

Figure 4: Figure A2. Thresholds for relative price p_d/p_a for some values of d and $q = 0.5$

Appendix C: Choice of the quality

Before choosing its communication strategy, the firm has to make the choice of its good's true quality.

$$\max_q \pi_h(q, a^*, d^*) = \frac{(2\Delta(q, d^*, a^*) - cq^2)^2}{9\Delta(q, d^*, a^*)} - p_a a^* - p_d d^* \tag{28}$$

The first-order condition implicitly give the optimal quality of the good q^*:

$$\frac{\partial \pi_h}{\partial q} = \frac{(2\Delta(q^*, d^*, a^*) - cq^2)((\Delta_q + \Delta_d d_q + \Delta_a a_q)(2\Delta(q^*, d^*, a^*) - cq^2) - 4\Delta(q^*, d^*, a^*)cq^*)}{9\Delta(q^*, d^*, a^*)^2} - p_a a_q - p_d d_q (\frac{q}{q^*}$$