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A Note on the Costs of Quality in Vertically Differentiated Duopoly

by

Peter Michaelis and Thomas Ziesemer*

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The literature on quality choice in vertically differentiated duopoly regularly assumes that either fixed costs or variable unit costs depend on quality. We analyze a generalized model where both types of costs are quality-dependent. Our findings are partially in contrast to the results obtained in the literature so far. In particular, the profit of the low-quality firm increases if variable unit costs increase for any level of quality. Hence, the low-quality firm has an incentive to engage in lobbying for governmental regulations that lead to rising variable costs of quality.

Keywords: duopoly, vertical differentiation, product quality, fixed costs, variable costs

JEL classification code: D21, D43, L13

1 Introduction

Models on quality choice in vertically differentiated duopoly regularly assume that production causes either only quality-dependent fixed costs or only quality-dependent variable costs per unit of output as analyzed in the seminal contribution of Motta (1993).[1] The only exception from these two canonical cases seems to be Brécard (2010), who adds constant unit costs $v > 0$ to Motta's (1993) model variant with quality-dependent fixed costs and price competition. Already this minor modification has far-reaching effects on the results of the model. In particular, the impact on the low quality firm and on the degree of product differentiation caused by an increase in v

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[1] The modelling of quality costs traces back to Mussa and Rosen (1978) who analyzed this issue for a monopoly that supplies a quality-differentiated spectrum of goods of the same generic type.

depends on the initial magnitude of unit costs: For a low (high) initial magnitude, an increase in ν increases (decreases) the low quality and decreases (increases) product differentiation.

Brécard (2010) findings suggest that the results of such models are highly sensitive to the assumptions on costs. To the best of our knowledge, the joint-impact caused when fixed as well as variable unit costs depend on quality has not been analyzed so far. This is a remarkable gap in the literature since in practice, it is often expected that both types of costs are increasing in quality. For example, supplying an automobile of higher quality might require not only higher efforts in research and development (leading to higher fixed costs), but also the use of more skilled workers and more expensive materials or components (leading to higher variable unit costs).

With this short note, we try to fill this gap in the literature by carrying forward the analysis of Motta (1993) and Brécard (2010). In section 2, we present an extended version of the model that accounts for both quality-dependent fixed costs as well as quality-dependent variable unit costs. In section 3, we characterize the equilibrium by the corresponding first order conditions. In section 4, we present a wide range of simulation results and compare them to those obtained in the literature so far. Section 5 provides a short welfare analysis, and in section 6, we summarize our key findings and highlight their economic implications.

2 *The Model*

Except to assume that variable unit costs also depend on quality, our model is completely identical to Brécard (2010). There are two firms $i = H, L$ each offering at price p_i a single variant of a product differentiated by quality $q_i \geq 0$. Without loss of generality, we assume $q_H > q_L$, i.e., firm H is the high- and firm L is the low-quality producer. Both firms share the same technology where variable unit costs, $c_v(q_i)$, are independent of quantity but increasing in quality. Additionally, the firms face quality-dependent fixed costs $c_f(q_i)$. To ensure comparability with Motta (1993) and Brécard (2010), we assume standard quadratic cost functions as usual in most models on quality choice in differentiated duopoly: $c_v(q_i) = (\nu/2)q_i^2$ with $\nu > 0$ and $c_f(q_i) = (f/2)q_i^2$ with $f > 0$. The firms compete in two stages: In the first stage, they simultaneously choose qualities q_i, and in the second stage they simultaneously choose prices p_i.

The demand side consists of a continuum of consumers, differing in their marginal willingness-to-pay for quality. The latter is described by the parameter θ uniformly distributed over $\theta \in [\underline{\theta}, \overline{\theta}]$ with a unit density function: $\underline{\theta} \geq 0$ and $\overline{\theta} - \underline{\theta} = 1$. Consumers buy exactly one unit of the product or none. The consumer surplus from buying variant i is $\theta q_i - p_i$; consumers that refrain from buying at all enjoy zero consumer surplus. $\widetilde{\theta} := p_L/q_L$ identifies the consumer who is indifferent between variant L at price p_L or buying nothing at all; $\widehat{\theta} := (p_H - p_L)/(q_H - q_L)$ identifies the consumer who is indifferent between buying variant L at price p_L or variant H at price p_H. Under the standard-assumption of an uncovered market (i.e., $\underline{\theta} < \widetilde{\theta}$) the demand for the

low-quality product is $d_L = (\hat{\theta} - \tilde{\theta})/\bar{\theta}$, and the demand for the high-quality product is $d_H = (\bar{\theta} - \hat{\theta})/\bar{\theta}$.

3 Equilibrium

To calculate the subgame perfect equilibrium, we solve the model by backward induction. In the second stage, the firms take the qualities as fixed and maximize profits $\pi_i = d_i(p_i - (v/2)q_i^2) - (f/2)q_i^2$ with respect to the prices p_i. From the first-order conditions $\partial\pi_i/\partial p_i = 0$ we obtain the reaction functions

$$p_L(p_H) = \frac{q_L(2p_H + vq_Hq_L)}{4q_H},\quad p_H(p_L) = \frac{2p_L + vq_H^2 + 2\bar{\theta}(q_H - q_L)}{4}$$

which can be solved for the equilibrium prices:[2]

$$(1)\qquad p_L^* = \frac{q_L[2\bar{\theta}(q_H - q_L) + vq_H(q_H + 2q_L)]}{2(4q_H - q_L)},\quad p_H^* = \frac{q_H[4\bar{\theta}(q_H - q_L) + v(2q_H^2 + q_L^2)]}{2(4q_H - q_L)}.$$

Due to the convexity of $c_v(q_i)$, for given qualities $q_H > q_L$, a rise in v causes the variable unit costs of firm H to increase more than those of L (i.e., $\partial p_H^*/\partial v > \partial p_L^*/\partial v$). This competitive advantage enables firm L to respond to an increasing v with a less severe price increase than firm H, such that p_H^*/p_L^* increases for given qualities. In contrast, in the model of Brécard (2010), the increase in variable unit costs caused by a rising v is the same for both firms. These different cost effects are the main driver for the deviations between our results and those of Brécard (2010).

Inserting p_L^* and p_H^* into $\tilde{\theta}$ and $\hat{\theta}$, as calculated in section 2, yields the indifferent consumers' positions solely in terms of qualities. From this, we obtain the corresponding demands as a function of q_L and q_H:

$$(2)\qquad d_L^* = \frac{q_H[2\bar{\theta} + v(q_H - q_L)]}{2\bar{\theta}(4q_H - q_L)},\quad d_H^* = \frac{q_H[4\bar{\theta} - v(2q_H + q_L)]}{2\bar{\theta}(4q_H - q_L)}.$$

In Brécard (2010), the demand enjoyed by both firms is decreasing when v rises for given qualities. In our model, an increase in v also leads to a decrease in *total* demand, but at the same time, the demand enjoyed by firm L increases as indicated by (2). Consequently, the change in relative prices noted above leads to a shift in demand in favor of firm L.

An uncovered market (i.e., $d_L^* + d_H^* < 1$) requires $v > v^{min}$ with

$$v^{min} := \frac{2\bar{\theta}(q_L - q_H)}{q_H(q_H + 2q_L)}.$$

[2] Due to $\partial^2\pi_L/\partial p_L^2 = -2q_H/[\bar{\theta}q_L(q_H - q_L)] < 0$ and $\partial^2\pi_H/\partial p_H^2 = -2/[\bar{\theta}(q_H - q_L)] < 0$ the second-order conditions are satisfied for any $q_H > q_L$. All calculations in our paper are done with *Mathematica 11.3*.

Due to $\nu^{min} < 0$ for $q_H > q_L$, this condition is always satisfied. Moreover, a duopoly equilibrium with both firms active in the market (which is the one of interest in this paper) requires $d_H^* > 0$ implying $\nu < \nu^{max}$ with $\nu^{max} := 4\bar{\theta}/(2q_H + q_L)$. Otherwise, firm H, which is affected more by an increase in ν, will drop out of the market and firm L will become a monopolist. In contrast to this, in the model of Brécard (2010), firm L is the first to drop out of the market if ν becomes too large. The economic reason for this difference is that Brécard's firms cannot influence the variable unit costs, whereas in our model, firm L is always able to reduce variable unit costs (and thus the accompanying price) by reducing quality without completely losing demand.

In the next step, the reduced profit functions that we need for the quality game in the first stage are calculated as $\pi_i = d_i^* \cdot [p_i^* - (\nu/2)q_i^2] - (f/2)q_i^2$. Inserting d_i^* and p_i^* according to (1) and (2) and rearranging terms yields:

$$\pi_L = \frac{q_H q_L (q_H - q_L)\left[2\bar{\theta} + \nu(q_H - q_L)\right]^2}{4\bar{\theta}(4q_H - q_L)^2} - \frac{f}{2}q_L^2,$$

$$\pi_H = \frac{q_H^2 (q_H - q_L)\left[4\bar{\theta} - \nu(2q_H + q_L)\right]^2}{4\bar{\theta}(4q_H - q_L)^2} - \frac{f}{2}q_H^2.$$

In the first stage of the game, the firms maximize profits with respect to quality q_i. From $\partial\pi_i/\partial q_i = 0$ we obtain the firms' first order conditions $\sigma_i - f q_i = 0$ with:

$$\sigma_L := \frac{q_H\left[\nu(q_H - q_L) + 2\bar{\theta}\right]\left[\nu(q_H - q_L)(4q_H^2 - 15q_H q_L + 2q_L^2) + 2q_H(4q_H - 7q_L)\bar{\theta}\right]}{4\bar{\theta}(4q_H - q_L)^3},$$

$$\sigma_H := \frac{q_H\left[\nu(2q_H + q_L) - 4\bar{\theta}\right]\left[24\nu q_H^3 + 2q_L^2(\nu q_L - 4\bar{\theta}) - 2q_H^2(11\nu q_L + 8\bar{\theta}) + q_L q_H(5\nu q_L + 12\bar{\theta})\right]}{4\theta(4q_H - q_L)^3}.$$

For the special case $f = 0$ and $\nu > 0$ our model reduces to the model version of Motta (1993) where production causes only quality-dependent unit costs and the first order conditions above can be solved for Motta's equilibrium qualities $q_L^* = 0.39872\bar{\theta}/\nu$ and $q_H^* = 0.81952\bar{\theta}/\nu$.[3] In Motta's model, an increase in the cost parameter ν leads to a decrease in qualities q_i^*, prices p_i^* and profits π_i^*, whereas demands d_i^* and the degree of product differentiation q_H^*/q_L^* remain constant.

However, when both types of quality-dependent costs exist (i.e., $f > 0$ and $\nu > 0$), it is no longer possible to express the equilibrium qualities analytically.[4] Moreover, the condition that the cost parameter ν in the model of Brécard (2010) must satisfy for a duopoly to exist, $\nu < \bar{\theta}q_L/2$, depends only on q_L, while the analogous condition in our model requires $\nu < 4\bar{\theta}/(2q_H + q_L)$ and thus depends on both q_L and q_H. Therefore, the

[3] In fact, Motta (1993, p.124) presents only the solution for $\bar{\theta} = 5$ and $\nu = 1$, but by running Mathematica with different values of $\bar{\theta}$ and ν, it can easily be checked that the above generalization holds.

[4] This is a well-known general problem in models of duopolistic product differentiation that involve quality-dependent variable costs (e.g., Lambertini and Tampieri, 2012, pp.191).

ex-post substitution procedure developed by Brécard (2010) to derive some general properties of the equilibrium cannot be applied to our model and we must rely on the results of numerical evaluations as presented in the next section.

4 Numerical Evaluations

To ensure comparability with the simulations of Brécard (2010), we provisionally assume $f = \bar{\theta} = 1$ (the effects of varying f or $\bar{\theta}$ will be discussed later). Since the main interest of our analysis is the impact caused by adding quality-dependent variable unit costs to a model that already accounts for quality-dependent fixed costs, we have to combine our assumption on f with a suitable range for the cost parameter v. In this context, it should be remembered that $(v/2)q_i^2$ indicates the variable costs *per unit of output*, while $(f/2)q_i^2$ represents *total* fixed costs. Since it seems plausible to suppose that for any level of quality the former will not exceed the latter, we mainly concentrate on $v \leq f$, but we will also take a quick look at the results for the less plausible case $v > f$.[5]

Figure 1 shows the results of our calculations, with the left-hand scales referring to firm L and the right-hand scales referring to firm H.[6] The condition $v^{min} < v < v^{max}$ is satisfied for any $v \in [0, 1]$ such that both firms enjoy positive demands $d_i^* > 0$ and the market is uncovered (i.e., $d_L^* + d_H^* < 1$).[7] As indicated by Graph 1a, both qualities are strictly decreasing in v. This behavior contradicts Brécard (2010) where q_L^* increases for low values of v. The economic explanation is straightforward, since in our model the firms can compensate for an increase in v by lowering qualities.

Moreover, an increase in v leads to a continuous decrease in product differentiation q_H^*/q_L^* since q_H^* decreases faster than q_L^*.[8] The economic reason, as already mentioned above, is that because of the convexity of $c_v(q_i)$, the variable unit costs of firm H are more affected by an increase in v than those of firm L. Hence, there are two opposite effects on the prices as shown in Graph 1b: The direct effect of higher costs, which are only partially offset by the reduction in qualities, tends to increase prices. The indirect effect of a lower product differentiation tightens competition and tends to depress prices (see also Shaked and Sutton, 1982). Concerning firm H, the indirect effect always dominates so that p_H^* is continuously decreasing. With respect to firm L we find that the direct effect dominates and p_L^* increases until v reaches the threshold

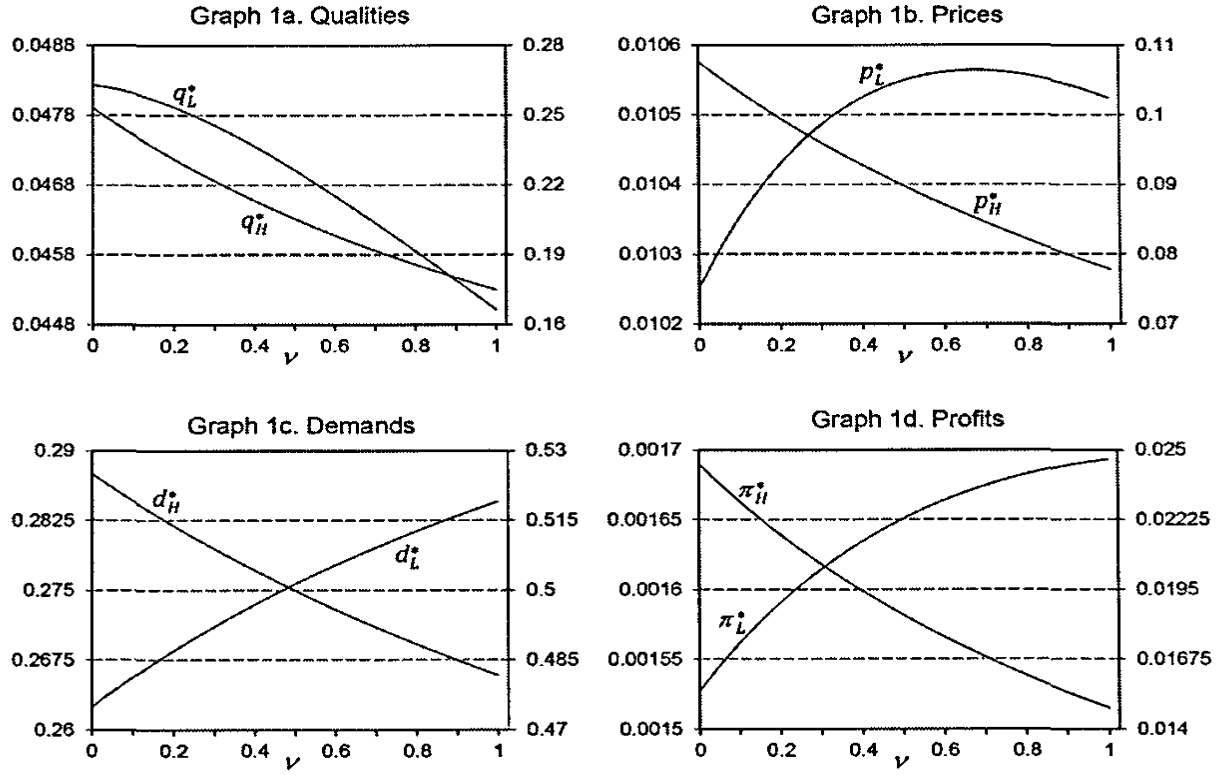
[5] For example, considering an automobile manufacturer, the case $v > f$ would imply that for any given quality, the total fixed costs that must be spent on automobile production are less than the variable costs of producing one single automobile.

[6] See Table A1 (Appendix) for the numerical results underlying Figure 1 and a calculation of the second-order conditions. The proof that leapfrogging can be ruled out proceeds analogously to Motta (1993).

[7] In equilibrium, the lower bound v^{min} is a strictly *decreasing* function of v with $v^{min} = -4.62892$ for $v = 0$ and the upper bound v^{max} is a strictly *increasing* function of v with $v^{max} = 7.20903$.

[8] In particular, we obtain $q_H^*/q_L^* = 5.25123$ for $v = 0$ and $q_H^*/q_L^* = 3.88491$ for $v = 1$ (see Table A1 Appendix).

Figure 1
Effects of an Increase in ν – Simulation Results for $f = \overline{\theta} = 1$



Left-hand scales refer to firm *L*, right-hand scales refer to firm *H*.

$\tilde{\nu} = 0.67517$. These price effects contradict the results of Brécard (2010), where a rise in ν always leads to an increase in both prices.

Next, Graph 1c shows the impact of a rising ν on the demand enjoyed by the firms. In line with the model of Brécard (2010), where both demands are decreasing, firm H's demand also decreases because the price reduction is not sufficient to compensate for the decline in quality. Concerning firm L, however, we obtain that a rise in ν leads to an increase in demand. As we have checked, this effect even persists for $\nu > f$. Hence, due to its competitive advantage, firm L can charge a higher price for a lower quality while attracting a higher demand. On balance, firm L can pull over more consumers from firm H than it loses to the "no buy"-fraction. Moreover, together with the declining demand of firm H, we arrive at a slight decrease in market coverage of about 2.14 percentage points.[9]

Finally, Graph 1d shows the total effect on the firms' profits. As was to be expected, we observe a decline in profit for firm H. However, in contrast to Brécard (2010), an increase in ν leads to an increasing profit of firm L. This somewhat surprising effect persists even when ν exceeds the threshold $\tilde{\nu} = 0.67517$ at which the price for the low-quality product begins to decline again. Naturally, the profit of L cannot continue to grow indefinitely as ν rises. According to our simulations, π_L^* begins

[9] As indicated in Table A1 (Appendix), we obtain $d_L^* + d_H^* = 0.78749$ at the lower end $\nu = 0$ and $d_L^* + d_H^* = 0.76619$ at the upper end $\nu = 1$.

to decrease continuously if ν becomes too large and exceeds $\bar{\nu} = 1.28043$. This threshold, however, lies beyond the plausible range $\nu \in [0, 1]$.

With respect to the other variables shown in Figure 1, no additional effects emerge when values beyond $\nu = 1$ are considered: Both qualities and prices as well as the demand and the profit enjoyed by firm H are continuously decreasing, whereas the demand enjoyed by firm L is continuously increasing.

So far, compared to Brécard (2010), the result that the profit of firm L increases when ν increases seems to be explained by the convexity of $c_v(q_i)$, which leads to a corresponding competitive advantage of the low-quality producer. However, in the Motta-version of our model with $f = 0$, the profit of firm L is *decreasing* as ν increases, even though variable unit costs are convex in quality.[10] Accordingly, the convexity of $c_v(q_i)$ alone is not sufficient to generate a competitive advantage strong enough to explain the above result. A sufficiently strong competitive advantage obviously only arises if there are both variable unit costs and fixed costs that are convex in quality, so that their effects reinforce each other.

Of course, one might ask how the results in Figure 1 depend on our specific assumptions on f and $\bar{\theta}$. For analyzing the more general case, we express the relation between ν and f as $\nu = \alpha \cdot f$ with $\alpha > 0$. By running our model with numerous different magnitudes of f and $\bar{\theta}$, we found that the equilibrium qualities can be rewritten as $q_i^*(\alpha, f, \bar{\theta}) = \left(\bar{\theta}/f\right) \cdot \tilde{q}_i^*(\alpha)$, where $\tilde{q}_i^*(\alpha)$ indicates the qualities for $f = \bar{\theta} = 1$ as shown in Graph 1a. Consequently, varying f or $\bar{\theta}$ only moves the qualities shown in Graph 1a up or down in parallel, but the general shape of the curves remains unchanged. This effect carries over to the other variables of our model. In particular, the firms' profits in equilibrium can be rewritten as $\pi_i^*(\alpha, f, \bar{\theta}) = \left(\bar{\theta}^2/f\right) \cdot \tilde{\pi}_i^*(\alpha)$ where $\tilde{\pi}_i^*(\alpha)$ are the profits for $f = \bar{\theta} = 1$ as shown in Graph 1d.[11] Hence, a higher willingness to pay for quality (i.e., an increase in $\bar{\theta}$) leads to higher profits in equilibrium. Moreover, since $\pi_i^*(\alpha, f, \bar{\theta})$ is only a monotonous transformation of $\tilde{\pi}_i^*(\alpha)$, we obtain $\bar{\nu} = 1.28043 \cdot f$ for the threshold beyond which the profit of firm L begins to decline again. As an example, Figure 2 shows the impact of an increase in ν on firm L's profit for $\bar{\theta} = 1$ and different magnitudes of f, with the dashed parts of the lines indicating the less plausible range $\nu > f$.

Our findings are summarized in the following proposition. Additionally, Table 1 provides a synoptical comparison of our results with those of Brécard (2010), where the different models are characterized by the respective profit functions.

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[10] The same holds for the second Motta-version of our model with $\nu = 0$ when the parameter f is increasing.

[11] Similarly, we obtain $p_i^*(\alpha, f, \bar{\theta}) = (\overline{\theta^2}/f) \cdot \tilde{p}_i^*(\alpha)$ with $\tilde{p}_i^*(\alpha)$ indicating the prices for $f = \bar{\theta} = 1$ shown in Graph 1b. The threshold beyond which $\tilde{p}_i^*$ begins to decrease again is $\tilde{\nu} = 0.67517 \cdot f$. The demands as shown in Graph 1c remain unchanged when f or $\bar{\theta}$ is varied.

Figure 2
Effects of an Increase in v on Firm L's Profit for $\bar{\theta} = 1$ and Different Magnitudes of f

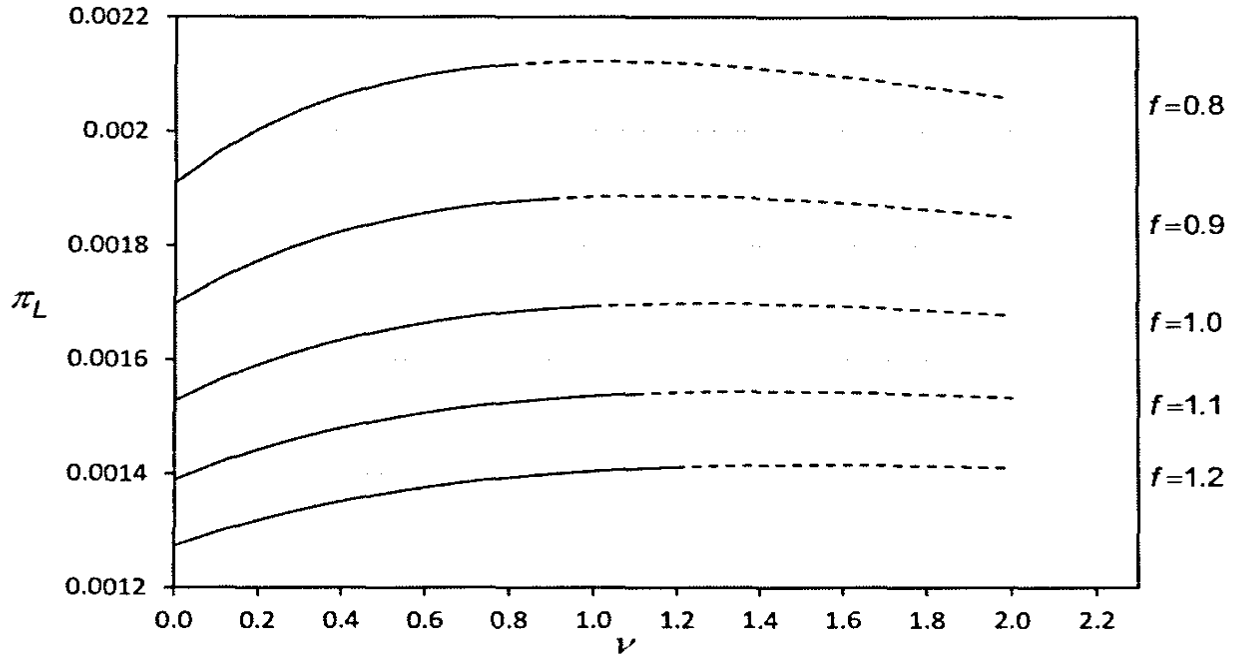


Table 1
Effects of an Increase in v: Comparison of Our Results with Those of Brécard (2010)

	Brécard (2010) $\pi_i = d_i(p_i - v) - f/2q_i^2$	Our approach $\pi_i = d_i(p_i - v/2q_i^2) - f/2q_i^2$
Quality firm L	increasing for low v decreasing for high v	decreasing
Quality firm H	decreasing	decreasing
Product differentiation	decreasing for low v increasing for high v	decreasing
Price firm L	increasing	increasing for low v decreasing for high v
Price firm H	increasing	decreasing
Demand firm L	decreasing	increasing
Demand firm H	decreasing	decreasing
Market coverage	decreasing	decreasing
Profit firm L	decreasing	increasing for low v decreasing for high v
Profit firm H	decreasing	decreasing

PROPOSITION. *Consider a duopoly model of quality-choice with a low-quality firm L and a high-quality firm H. Assume price competition and the existence of quality-dependent fixed costs* $c_f(q_i) = (f/2)q_i^2$ *as well as quality-dependent variable unit costs* $c_v(q_i) = (v/2)q_i^2$. *When* v *rises, both qualities, product differentiation and market coverage decrease; the same applies to the price charged by firm H, its demand, and its profit. The combination of two convex cost functions leads to a competitive advantage for firm L, which enables it to increase the price with increasing* v *despite the reduction in quality, as long as* $v < 0.67517f$ *holds. The demand faced by firm L is continuously increasing when v increases, and its profit is increasing as long as* $v < 1.28043f$ *holds.*

5 *Welfare Analysis*

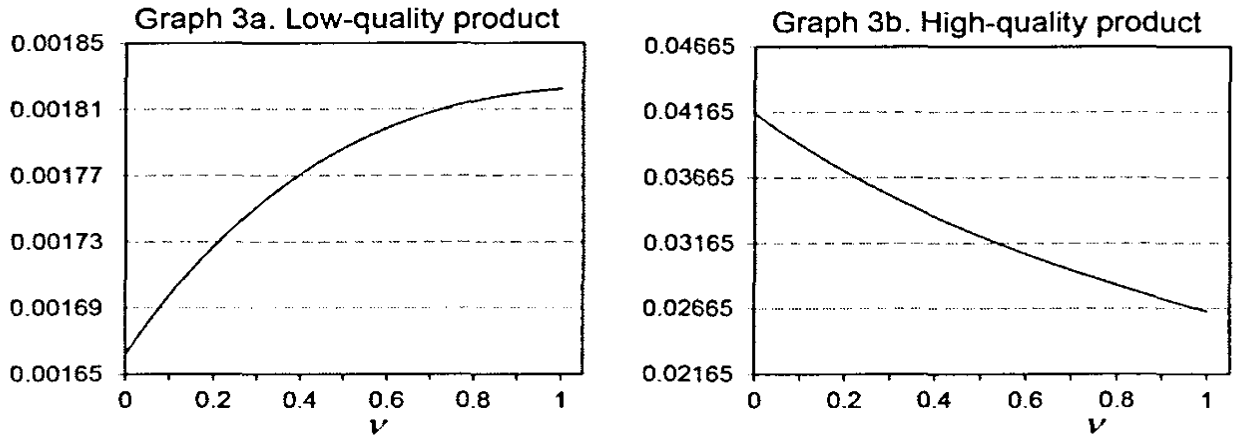
The following analysis of the welfare effects of an increasing v concentrates on the case $f = \bar{\theta} = 1$ shown in Figure 1, but due to $q_i^*(\alpha, f, \bar{\theta}) = \left(\bar{\theta}/f\right) \cdot \tilde{q}_i^*(\alpha)$ the results can be generalized. As can be seen from the figures in Table A1 (Appendix), total profits $\pi_L^* + \pi_H^*$ decrease as v rises. To calculate the effects on consumer surplus, we first denote the location of the *average* consumer buying product variant i by $\breve{\theta}_i$. Since θ is distributed uniformly over $\theta \in [0, 1]$, we obtain $\breve{\theta}_L = \left(\tilde{\theta} + \hat{\theta}\right)/2$ and $\breve{\theta}_H = \left(\hat{\theta} + 1\right)/2$. Using $\tilde{\theta} = p_L/q_L$ and $\hat{\theta} = (p_H - p_L)/(q_H - q_L)$ as well as the prices according to (1), this can be rewritten solely in terms of qualities: $\breve{\theta}_i(q_H, q_L)$. Hence, the consumer surplus enjoyed by the average consumer buying variant i is given by $\breve{u}_i(q_H, q_L) = \breve{\theta}_i(q_H, q_L)q_i - p_i(q_H, q_L)$. Finally, weighting $\breve{u}_i(q_H, q_L)$ by demands according to (2), we obtain the total consumer surplus s_i that is induced by the consumption of product variant i: $s_i(q_H, q_L) = d_i(q_H, q_L) \cdot \breve{u}_i(q_H, q_L)$. Inserting the equilibrium-qualities q_L^* and q_H^* according to Figure 1 yields the consumer surplus generated in the two market segments as shown in Figure 3.[12] Hence, when v is increasing, consumer surplus induced by the high-quality product is decreasing and consumer surplus induced by the low-quality product is increasing. The latter effect, however, is solely due to the shift in market shares. For each individual consumer, consumer surplus is decreasing since both quality-adjusted prices p_i^*/q_i^* are increasing (see Table A1). Consequently, total consumer surplus is decreasing,[13] and so does total welfare.

[12] See Table A1 (Appendix) for the numerical results underlying Figure 3.

[13] This can easily be verified by adding up both parts of consumer surplus as shown in Table A1 (Appendix).

Figure 3

Effects of an Increase in ν on the Consumer Surplus Generated by the Low-Quality and the High-Quality Product – Simulation Results for $f = \bar{\theta} = 1$



6 *Summary and Conclusions*

The literature on quality choice in vertically differentiated duopoly under price competition regularly assumes that either fixed costs or variable unit costs depend on quality (Motta, 1993). The only exception seems to be Brécard (2010), who adds constant unit costs to Motta's (1993) model variant with quality-dependent fixed costs. In continuing this work, we contributed to the literature by analyzing a more general model where both types of costs depend on quality. Our results are partially in contrast to those obtained so far in this research area. In particular, under plausible assumptions, the profit of the low-quality firm will increase if variable unit costs increase for any given level of quality.

At first glance, the latter result might seem a minor footnote in the literature, but it allows us to better understand the behavior of firms in the face of governmental regulations like, e.g., energy taxes. From the work on "raising rivals' costs" it is well-known that heterogeneity in production technology induces a preference for regulation among firms with low adjustment costs (see, e.g., Salop and Scheffman, 1983; Michaelis, 1994; Kennard, 2020). Our analysis has added a second reason for such behavior: When firms share the same technology but produce different qualities at different costs, it can be advantageous for the low-quality firm to engage in lobbying for governmental interventions that lead to an increase in the variable costs of quality. This behavior is particularly tempting when improving quality requires a higher use of energy or environmentally harmful inputs. In such cases, the low-quality firm can assert environmental protection reasons and thus hide its selfishness by greenwashing its lobbying activities. Hence, policy makers should be cautious when firms that offer low-quality product variants demand additional regulations that would increase the costs of quality.

Appendix

Table A1 shows a selection of the numerical results underlying Figures 1–3. Additionally, the second order conditions evaluated in the equilibrium are indicated as $\phi_i := \partial^2 \pi_i(q_L, q_H)/\partial q_i^2 |_{q_L = q_L^*,\ q_H = q_H^*}$. $\phi_i < 0$ as shown in the last two rows of Table A1 proofs that the second order conditions are satisfied in equilibrium.

Table A1
Numerical Results for $f = \bar{\theta} = 1$ and $\nu \in [0, 1]$

ν	0	0.2	0.4	0.6	0.8	1
q_L^*	0.04824	0.04792	0.04736	0.04665	0.04585	0.04501
q_H^*	0.25331	0.23124	0.21333	0.19842	0.18577	0.17487
q_H^*/q_L^*	5.25123	4.82574	4.50482	4.25366	4.05144	3.88491
p_L^*	0.01025	0.01043	0.01052	0.01056	0.01056	0.01052
p_H^*	0.10766	0.09955	0.09280	0.08707	0.08214	0.07784
p_L^*/q_L^*	0.21248	0.21765	0.22213	0.22637	0.23032	0.23373
p_H^*/q_H^*	0.42501	0.43051	0.43501	0.43882	0.44216	0.44513
d_L^*	0.26250	0.26849	0.27348	0.27771	0.28135	0.28454
d_H^*	0.52499	0.51386	0.50429	0.49588	0.48840	0.48165
$d_L^* + d_H^*$	0.78749	0.78235	0.77777	0.77359	0.76975	0.76619
π_L^*	0.00153	0.00159	0.00163	0.00166	0.00168	0.00169
π_H^*	0.02444	0.02167	0.01945	0.01764	0.01612	0.01484
$\pi_L^* + \pi_H^*$	0.02597	0.02326	0.02108	0.01924	0.01780	0.01653
s_L^*	0.00166	0.00173	0.00177	0.00180	0.00181	0.00182
s_H^*	0.04156	0.03714	0.03366	0.03082	0.02846	0.02645
$s_L^* + s_H^*$	0.04322	0.03887	0.03543	0.03262	0.03027	0.02827
ϕ_L	−1.34986	−1.42859	−1.50661	−1.58387	−1.66037	−1.73612
ϕ_H	−0.77828	−0.79490	−0.80851	−0.81965	−0.82871	−0.83601

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