Vertical product differentiation in the lab: Impact of consumers' preferences

Adriana Alventosa[a,*], Joana Pinho[b], Sílvia Ferreira Jorge[c], Margarida Catalão-Lopes[d]

[a] *ERI-CES, Universidad de Valencia, Spain*
[b] *Católica Porto Business School and CEGE, Universidade Católica Portuguesa, Portugal*
[c] *GOVCOPP, DEGEIT, Universidade de Aveiro, Portugal*
[d] *CEG-IST, Instituto Superior Técnico, Universidade de Lisboa, Portugal*

Abstract

We revisit a quality-then-pricing duopoly game, theoretically and experimentally exploring how heterogeneity in consumers' preferences affects firms' decisions and profits. We find that firms differentiate less their products in the lab than the theoretical model predicts, especially when the heterogeneity in consumers' preferences is high. When the heterogeneity in consumers' preferences is small, the firm producing the low-quality good profits more than the rival in the lab, which contradicts the theoretical predictions.

Keywords: Vertical product differentiation; Consumers' preferences; Experimental economics.

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*Corresponding author.** Adriana.Alventosa@uv.es. Av.de los Naranjos s/n, 46022, Valencia, Spain.

1. Introduction

Consumers' preferences differ across countries and have changed over time (PricewaterhouseCoopers, 2021). As pointed out by the theoretical literature, consumers' preferences are key determinants in firms' decisions, namely regarding qualities, prices, or market coverage (Gabszewicz and Thisse, 1979; Wauthy, 1996; Pires *et al.* 2022). Nevertheless, the experimental literature has shown that agents do not always behave according to theoretical predictions. We aim to gather these two branches of the literature by testing a quality-then-price model in the lab and studying how heterogeneity in consumers' preferences affects firms' decisions.

We consider a model of vertical product differentiation (VPD) with a finite number of heterogeneous consumers differing in the way they value quality. Each consumer decides whether to buy or not and, if buying, from which firm to buy. Firms play a two-stage game: first, they simultaneously and independently choose qualities; then, they simultaneously and independently set prices.

We present our theoretical predictions and then take the model to the lab, considering two treatments differing in the consumers' preferences heterogeneity (CHP) level. We found that, regardless of the CPH, firms choose qualities and prices significantly different from the theoretical predictions. Firms differentiated their products less than predicted by the model, with the deviation being higher for high CPH. Finally, while the theoretical model predicts a high-quality advantage when CPH is low and a low-quality advantage when CPH is high, only the former occurred in the lab.

Experimental literature on product differentiation is scarce and has been mostly focused on horizontal differentiation. The first topics to be experimentally studied in VPD concern information asymmetries and the relationship between the degree of product differentiation and price competition (Holt and Sherman, 1990; Lynch *et al.*, 1984; Mangani, 2002). However, most of this literature considered *either* quality *or* price decision – not both. To the best of our knowledge, the first experimental contribution where (sequential) quality decisions are followed by (simultaneous) price decisions is Amaldoss and Shin (2011), who explored the effect of the size of low-end markets. The closest contribution to ours is Alventosa *et al.* (2022), assuming simultaneous moves in both stages of the game. The objective of the two works, however, is completely different: Alventosa *et al.* (2022) assess how different production cost structures affect the equilibrium – a supply-side approach –

while we study how differences in CPH affect firms' decisions – a demand-side approach. As Alventosa *et al.* (2022), we obtain a divergence between theoretical predictions and experimental results, namely that there is less (vertical) differentiation in the lab than theoretically predicted.

2. Model

Consider a duopoly market: firm $i \in \{1, 2\}$ sells a good of quality k_i and charges price p_i. W.l.o.g., assume that $k_2 \geq k_1$. There are 10 heterogeneous consumers differing in how they value the good's quality. If buying firm i's good, consumer $j \in \mathcal{J} = \{1, ..., 10\}$ gets utility:[1]

$$U_j^i = \theta_j k_i - p_i,$$

where $\theta_j > 0$ captures the quality valuation of consumer j (independent of the firm's identity). A consumer indexed with a higher j values quality more. Each consumer buys, at most, one unit of the good if his/her utility is positive. A consumer buys from the firm that gives him/her the highest utility.[2]

The objective of firm $i \in \{1, 2\}$ is to maximize profit:

$$\pi_i = p_i q_i - 0.5 k_i^2 q_i, \tag{1}$$

where q_i is the number of consumers served, and $0.5k_i^2 q_i$ is the total cost of producing q_i units of quality k_i. Firms play a two-stage game: first, they simultaneously and independently choose qualities; second, they observe the rival's quality and simultaneously and independently choose prices. Firms choose a quality from $\mathcal{K} = \{9, 11, 13, 15, ..., 25\}$, and a price from

[1] We consider a discrete version of Wauthy (1996) and Pires *et al.* (2022). A continuous specification is not common in the experimental literature, as it is technically demanding. However, discretization makes pure strategy equilibria less likely to exist. Recent contributions rely on the discretization of continuous games to identify mixed equilibria (e.g., Aragones and Palfrey, 2002; Hummel, 2010; and Xefteris *et al.* 2023). Mixed strategies may broaden the zone of equilibrium predictions and explain differences between theoretical and empirically observed strategies. We thank an anonymous referee for making this point, but leave this analysis to future research.

[2] A consumer indifferent between buying a good or none buys it with 50% probability.

$\mathcal{P} = \{45, 90, 135, ..., 405\}$.[3] If firms choose the same quality, the products are homogeneous and they get zero profits (Bertrand paradox).

We consider two different distributions of consumers' preferences:

- Low heterogeneity (LH): $\theta_j = 10 + 0.5(j - 1)$
- High heterogeneity (HH): $\theta_j = 10 + 2(j - 1)$

for $j \in \{1, ..., 10\}$. The lowest consumer valuation is the same ($\theta_1 = 10$) in both scenarios. However, the average and the total consumers' valuation are higher in the HH scenario (i.e., CPH is higher in the HH scenario).

Proposition 1. *Regardless of the consumers' preferences heterogeneity, there is a pure-strategies subgame perfect Nash equilibrium that prescribes both firms being active in the market.*[4]

- *In the* LH *scenario:*

k_1^{LH}	k_2^{LH}	p_1^{LH}	p_2^{LH}	π_1^{LH}	π_2^{LH}
11	15	90	135	88.5	157.5

- *In the* HH *scenario:*

k_1^{HH}	k_2^{HH}	p_1^{HH}	p_2^{HH}	π_1^{HH}	π_2^{HH}
15	25	180	405	337.5	277.5

Firms choose lower qualities, charge lower prices, and make lower profits when CPH is low. Also, in LL, the high-quality firm is the one profiting the most ($\pi_2^{LH} > \pi_1^{LH}$), while the reverse holds in HH ($\pi_2^{HH} < \pi_1^{HH}$). Regardless of CPH, firms choose different qualities in equilibrium. However, when CPH is high, one firm chooses the highest possible quality level, while the other firm chooses an intermediate quality level. When CPH is low, offering the highest possible quality no longer occurs in equilibrium, and the difference in qualities is lower.

[3] As Holt and Sherman (1990), Lynch *et al.* (1984), Luini and Mangani (2000), we discretized firms' choice sets.

[4] There is a (symmetric) equilibrium where the roles of firms 1 and 2 are exchanged.

3. Experiment

The experiment was implemented at the XLAB from the Lisbon School of Economics and Management (ISEG) between July and September 2022. We considered two treatments only differing in consumers' heterogeneity: the "low heterogeneity" (LH) treatment, with $\theta_i \in \{10, 14.5\}$; and the "high heterogeneity" (HH) treatment, with $\theta_i \in \{10, 28\}$. A total of 104 subjects participated in the two treatments (52 in each).

Subjects played the game formerly described for 5 (unpaid) trial rounds and 15 experimental rounds. All subjects were given the role of sellers (consumers were virtual). In each round, markets of two sellers were randomly formed in the room. First, the two sellers in a market simultaneously decided qualities, from $\mathcal{K} = \{9, 11, 13, ..., 25\}$. Then, both sellers observed the quality decisions, and simultaneously decided prices, from $\mathcal{P} = \{45, 90, 135, ..., 405\}$. Given the qualities and prices, the 10 (virtual) consumers were automatically allocated to the firm providing them the highest utility.

4. Results

In the lab, subjects did not choose the quality levels predicted by the theoretical model (Proposition 1). In Table 1, we present the results of quality choices. All differences with respect to the theoretical predictions and between treatments are statistically significant when applying a Wilcoxon Rank Signed test (WRS, hereinafter) with continuity correction (p-value $< 1.895 \times 10^{-8}$ in all cases).

Table 1: Quality choices

Treatment	Average observed quality	Theoretical prediction	Difference
LH	$\overline{k_1^{LH}} = 13.0718$	$k_1^{LH} = 11$	$2.0718 > 0$
	$\overline{k_2^{LH}} = 15.6051$	$k_2^{LH} = 15$	$0.6051 > 0$
HH	$\overline{k_1^{HH}} = 16.4359$	$k_1^{HH} = 15$	$1.4359 > 0$
	$\overline{k_2^{HH}} = 20.0513$	$k_2^{HH} = 25$	$-4.9487 < 0$
HH-LH	$\overline{k^{HH}} - \overline{k^{LH}} = 3.9051$	$k^{HH} - k^{LH} = 7$	$-3.0940 < 0$

Result 1. *Average market qualities are higher when CPH is high.*

In LH the average product differentiation, $\overline{k_2^{LH}} - \overline{k_1^{LH}} = 2.533$, was significantly below the theoretical prediction, $k_2^{LH} - k_1^{LH} = 4$. This also happened in HH, where $\overline{k_2^{HH}} - \overline{k_1^{HH}} = 3.615$ is significantly below $k_2^{HH} - k_1^{HH} = 10$ (WRS test, p-value $< 2.2 \times 10^{-16}$ for both comparisons).

Result 2. *Product differentiation is lower than the theoretical prediction and this deviation is higher when CPH is high (Figure 1). Firms differentiate their products more when CPH is high.*

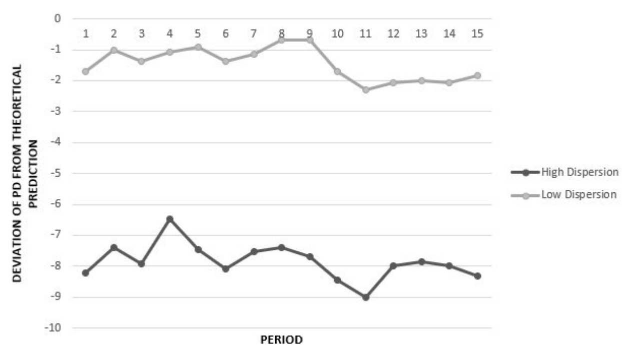

Figure 1: Evolution of deviation of product differentiation from the theoretical prediction

Although the theoretical model predicts that firms never choose the same quality level (to avoid fierce price competition), we observed a significant proportion of markets in the lab where subjects chose the same quality. In LH, 26.67% of the markets the products were homogeneous, mostly for qualities between 11 and 17 (mode at 13). In HH, subjects offered homogeneous products in 19.74% of the markets, mostly for qualities between 15 and 23 (mode at 17).

As subjects did not choose the equilibrium qualities in the first-stage in the lab, the prices in Proposition 1 could not be the equilibrium prices of the second-stage. Solving the second-stage for LH with $k_1 = \overline{k_1^{LH}}$ and $k_2 = \overline{k_2^{LH}}$,[5] we obtain the same (second-stage) equilibrium prices: $p_1^{LH} = 90$ and $p_2^{LH} = 135$. The same occurs only partially in HH: for qualities $k_1 = \overline{k_1^{HH}}$ and $k_2 = \overline{k_2^{HH}}$, the (second-stage) equilibrium price of the low-quality firm

[5]Further details on the computation of these prices can be provided upon request.

is the same as in Proposition 1, $p_1^{HH} = 180$, but the price of the high-quality firm is lower: $\hat{p}_2^{HH} = 225 < 405 = p_2^{HH}$.

In Table 2, we present the results of price choices. All differences with respect to the theoretical predictions are significant (WRS test, p-value $<$ 0.01 in all cases).

Table 2: Price choices

Treatment	Average observed price	Off-the equilibrium prediction	Difference
LH	$\overline{p_1^{LH}} = 104.4808$	$p_1^{LH} = 90$	$14.4808 > 0$
	$\overline{p_2^{LH}} = 143.7115$	$p_2^{LH} = 135$	$8.7115 > 0$
HH	$\overline{p_1^{HH}} = 175.5$	$p_1^{HH} = 180$	$-4.5 < 0$
	$\overline{p_2^{HH}} = 238.5$	$p_2^{HH} = 225$	$13.5 > 0$

We estimate prices as a function of qualities, using a linear Ordinary-Least-Squares estimation:

$$price_{i,t} = \beta_0 + \beta_1 quality_{i,t} + \beta_2 quality_{j,t} + \beta_3 HH, \qquad (2)$$

where $price_{i,t}$ and $quality_{i,t}$ correspond to the price and quality of firm i in period t, $quality_{j,t}$ is the quality level of firm j in period t, and HH is a dummy variable that takes 1 if the observation corresponds to HH treatment and 0 otherwise. We obtain $\hat{\beta}_0 = -128.7141$, $\hat{\beta}_1 = 17.6019$, $\hat{\beta}_2 = 0.7998$ and $\hat{\beta}_3 = 11.0426$. All these coefficients are significant at a 0.1% level. This has two relevant implications: (i) the quality of *both* goods positively affects the firm's price, but its own quality impacts more than the competitor's;[6] (ii) moving from LH to HH increases prices by more than 11 units.

Results on average profits are presented in Table 3:[7]

[6] Running one regression for LH and another one for HH, leads to analogous results: $\hat{\beta}_1^{LH} = 16.2650, \hat{\beta}_2^{LH} = 1.0756, \hat{\beta}_1^{HH} = 18.4472$ and $\hat{\beta}_2^{HH} = 0.7453$, all significant to a 1% level.

[7] Differences in profits between the two firms are all statistically significant (WRS test, p-value < 0.02), except profits of the 10 first rounds in HH (WRS test, p-value $= 0.5175$).

Table 3: Profits

Treatment	Low-quality firm	High-quality firm	Advantage
LH	71.2397	22.2372	Low
HH	123.4564	117.759	Low

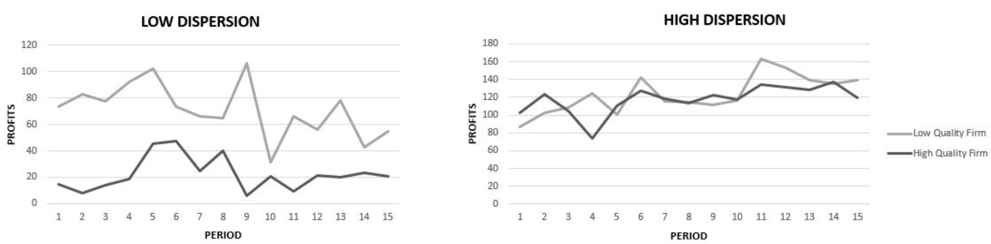

Figure 2: Evolution of average profits of low and high-quality firms

Result 3. *There is a low-quality firm advantage in profits for the two levels of CPH.*

Comparing across treatments, the average profits under HH (120.6077) were significantly higher than under LH (46.7385) – WRS test, p-value $< 2.2 \times 10^{-16}$– which corroborates the theoretical predictions.

5. Conclusions

To the best of our knowledge, this is the first experimental contribution exploring the impact of heterogeneity in consumers' preferences in a vertical product differentiation setting. The theoretical results shed light on how the equilibrium configuration and the degree of product differentiation depend on CPH. Nevertheless, our experimental results show significant departures from the theoretical predictions. In the lab, firms differentiate products less than the model predicts under both treatments, this deviation being higher when CPH is high. Results regarding who profits go in line with the theoretical prediction when CPH is high, but the advantage of the low-quality firm is small. This alignment does not occur, however, when CPH is low, because the low-quality firm also makes higher profits than the high-quality firm.

Our results corroborate previous literature showing that, in the lab, product differentiation is "softer" than the theoretical models predict.

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