Vertical product differentiation under demand uncertainty

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1. Introduction

The literature on vertical product differentiation often assumes that firms fully know the consumers’ tastes (willingness to pay) for product quality. However, in reality it is too difficult for firms to find out the exact willingness to pay on the part of consumers, even though firms might be able to obtain an estimated distribution of their willingness to pay through market surveys. Accordingly, firms normally face uncertain demand while deciding their product quality.1

In this paper, I examine a quality-then-price game in a fully covered market where firms are uncertain about consumer tastes regarding quality. The equilibrium is characterized under the fixed costs and variable costs of quality improvement, respectively. It is shown that the uncertainty is a differentiation force, and the quality differentiation increases more under variable costs than under fixed costs. In addition, an increase in uncertainty leads to higher profits and higher social welfare regardless of whether under fixed or variable costs. This result contrasts with the lower welfare in the Hotelling model with uncertainty. Finally, an analysis of the case of partial market coverage with uncertainty completes this paper.

2. Literature review

The literature on vertical product differentiation often assumes that firms fully know the consumers’ tastes (willingness to pay) for product quality. However, in reality it is too difficult for firms to find out the exact willingness to pay on the part of consumers, even though firms might be able to obtain an estimated distribution of their willingness to pay through market surveys. Accordingly, firms normally face uncertain demand while deciding their product quality.1

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3. Conclusion

This study aims to draw a comparison with Meagher and Zauner (2004) and to explain the different effects of the demand uncertainty in a fully covered horizontal and vertical model.3 Accordingly, the major analysis focuses on the case of full market coverage where all consumers are served, as in Champsaun and Rocket (1989, 1990) and Crampes and Hollander (1995), among others. This analysis is applied to the market for necessaries like gas stoves, where consumers are close to being fully served. By contrast, Section 5 briefly examines the case of partial market coverage to explain how the uncertainty may act differently in an uncovered market for products like diamonds or musical instruments.

Different assumptions about the nature of costs have been made in the literature on vertical product differentiation. Some of them, like Shaked and Sutton (1983) and Tseng et al. (2010), assume that the quality improvement is associated with the fixed costs while others, such as Mussa and Rosen (1978) and Lambertini and Orsini (2000, 2001),
specify that the quality improvement is associated with the variable costs. Moreover, the linear and quadratic forms of costs are often assumed in the literature.

In this paper, I first characterize the equilibrium of a quality-then-price game under uncertainty for both quadratic fixed and variable costs in a fully covered market. The results show that the quality differentiation increases with the demand uncertainty, and it increases more under variable costs than under fixed costs. Moreover, the uncertainty leads to higher profits and welfare regardless of whether under fixed or variable costs. However, it has different effects on the quality, price and consumer surplus of the low-quality product in these two cases. In addition, it is covered case, the qualities of the two products (the high- and low-quality ones) both increase in an uncovered market due to the competition from an outside good with zero quality and price. In addition, it is found that the uncertainty has no effect on the equilibrium when there is a linear rather than a quadratic form of costs.

The rest of this paper is organized as follows. Section 2 outlines the framework of our model. Section 3 characterizes the subgame perfect Nash equilibrium (SPNE) under uncertainty for the fixed cost of quality improvement. Section 4 characterizes the SPNE under uncertainty for the variable costs of quality improvement, and draws a comparison with Meagher and Zauner (2004) to explain how the demand uncertainty acts differently in fully covered horizontal and vertical models. Section 5 provides an examination to discuss the case of partial market coverage with uncertainty. Section 6 concludes.

3. Fixed costs of quality improvement

In this section, I first assume that the cost of quality improvement falls upon the fixed costs, and specify a quadratic form, \(c q^2\), for tractability as in Tseng et al. (2010), among others. Moreover, each firm chooses its quality of product from a wide interval \(q \in [\bar{q}, \bar{q}]\) where \(\bar{q}\) and \(\bar{q}\) denote the lower and upper bounds of the quality levels, respectively.\(^5\) Thus, I may write down the profits of firms \(H\) and \(L\) as follows:

\[
\pi_H = p_H (\theta + 1 - \theta) - c q_H^2
\]

\[
\pi_L = p_L (\theta - \theta) - c q_L^2
\]

Using backward induction, I first solve the prices in the second stage:

\[
p_H = \frac{1}{3} (q_H - q_L)(2 + \theta)
\]

\[
p_L = \frac{1}{3} (q_H - q_L)(1 - \theta)
\]

Accordingly, the marginal consumer is

\[
\theta = \frac{1}{2} [1 + 2 \theta]
\]

Substituting Eqs. (3), (4) and (5) into Eqs. (1) and (2), I obtain

\[
\pi_H = \frac{1}{3} (q_H - q_L)(2 + \theta)^2 - c q_H^2
\]

\[
\pi_L = \frac{1}{3} (q_H - q_L)(\theta - 1)^2 - c q_L^2
\]

At the quality stage, the two firms make their decisions under the demand uncertainty. The expected profits of firms \(H\) and \(L\) are, respectively,

\[
E \pi_H = \int_0^1 \int_0^1 \left( \frac{1}{3} (q_H - q_L)(2 + \theta)^2 - c q_H^2 \right) f(\theta) d\theta
\]

\[
= \frac{1}{3} (q_H - q_L) \left( 4 + 4 \mu + \mu^2 + \sigma^2 \right) - c q_H^2
\]

\[
E \pi_L = \int_0^1 \int_0^1 \left( \frac{1}{3} (q_H - q_L)(\theta - 1)^2 - c q_L^2 \right) f(\theta) d\theta
\]

\[
= \frac{1}{3} (q_H - q_L) \left( 1 - 2 \mu + \mu^2 + \sigma^2 \right) - c q_L^2
\]

Then, each firm chooses a quality to maximize its expected profit. By solving the first-order conditions, I establish the equilibrium below:

**Proposition 1.** The equilibrium qualities of firms \(H\) and \(L\) are, respectively,\(^6\)

\[
(q_H^*, q_L^*) = \left( \frac{\sigma^2 + (2 + \mu)^2}{18 \alpha}, \frac{2}{q} \right)
\]

Accordingly, the expected prices are

\[
(E p_H, E p_L) = \left( \frac{(2 + \mu) \sigma^2 + (2 + \mu)^2 - 18 q \alpha}{54 \alpha}, \frac{(1 - \mu) \sigma^2 + (2 + \mu)^2 - 18 q \alpha}{54 \alpha} \right)
\]

\(^5\) Note that the quality interval \([\bar{q}, \bar{q}]\) is assumed to be wide enough to let us focus on the interior solution of firms’ quality choices whenever there is one.

\(^6\) The second-order conditions are satisfied.
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