ANNALS OF ECONOMICS AND FINANCE **20-2**, 541–563 (2019)

Pricing Policies in a Market With Asymmetric Information and Non-Bayesian Firms

Miguel Ángel Ropero*

This paper explores price-setting in a two-period duopoly model where only one firm, which is non-Bayesian, is uncertain about some market conditions. In this context, the informed firm must choose whether to maximize its profits in the first period or to choose a suboptimal price in period 1 to fool its rival in the second period. Under certain conditions, we obtain that the optimal prices set by the informed and the uninformed firms will increase with demand uncertainty. Additionally, we analyse the conditions under which the optimal prices are greater in this duopoly context than in a monopoly.

Key Words: Asymmetric information; Degree of substitutability between products; Demand uncertainty; Non-Bayesian firm; Nash Equilibrium.
JEL Classification Numbers: D43, D83, L13.

1. INTRODUCTION

In contrast to the predictions of most models in industrial organization, previous empirical literature has shown that prices increase with the entry of a new competitor in many different markets. For example, Pawels and Srinivasan (2004) found that incumbent firms increased their prices after the entry of a new competitor offering a substitute in the markets of breakfast cereals, toothbrushes, paper towels and soap. Similarly, Pazgal, Soberman and Thomadsen (2016) provided a real example in an online entertainment and gaming site in which an incumbent increased its price

* Department of Applied Economics, University of Malaga, El Ejido 6, 29071 Malaga, Spain. E-mail: maropero@uma.es. I am very grateful to Miguel Ángel Meléndez for his helpful advice. I have also benefited from discussions with Gerad Llobet at CEMFI. Furthermore, I wish to thank Masaki Aoyagi, Ulrich Doraszelski, Benjamin Hermalin, Ronald Peters and Sven Rady for their useful suggestions. I am also grateful for comments from participants at the annual meeting of the Association of Southern European Economic Theorists, at the annual meeting of the Spanish Economic Association in 2012 and at the seminar of the Department of Theoretical Economics of the University of Malaga in 2014. Of course, all errors and omissions are mine.

1529-7373/2019

when a new competitor offering a similar product entered the market. They also observed that daily rental rates for cars at some airports increased by 7% when a new rental company entered the market. Finally, Ward et al. (2002), Yamawaki (2002), Simon (2005), Goolsbee and Syverson (2008) and McCann and Vroom (2010) showed that the entry of a new firm led to price increases in the pharmaceutical, consumer packaged goods, luxury car, magazine, airline and hotel industries.

Though there is a number of models trying to shed light on the causes of those increases in prices as a result of the entry of new competitors in the market, all of them assume that the new entrant has the same information on the market conditions as the incumbent (See for example, Hauser and Shugan (1983) and Chen and Riordan (2008)). Since this assumption is not plausible in some real markets, in this paper, we will analyse a duopoly model in which one firm has more information than its rival and we will obtain the conditions under which the price set by the incumbent is greater in a duopoly market than in a monopoly.

Other assumptions considered in game theory models of firms' price decisions in oligopoly markets are also implausible in some contexts. For instance, two common assumptions are that firms update their beliefs using Bayes' rule and possess full information on the market conditions. However, these assumptions are not usually fulfilled in many competitive situations. In relation to the first assumption, Bayes' rule contains no prescription on how the agent should react to information to which she assigned probability zero because Bayes' rule is not defined in that case. Additionally, even in the cases in which Bayes' rule does apply, it might not provide an accurate description of behaviour. For example, Camerer and Loewenstein (2004) showed that decision makers tend to systematically deviate from its prescriptions. Furthermore, decision makers could have non-Bayesian reactions to unexpected news when beliefs are subjective, i.e., when there is no objectively known distribution of the outcomes and agents need to form their own subjective belief. Given this limitation of Bayes' rule, Ortoleva (2012) characterizes axiomatically an alternative updating rule. In particular, he assumes that uninformed players usually form a subjective belief about the state of the world. When these uninformed players receive new information, if the prior used by them assigned a small probability to the realized event, they might ask themselves if they were using the wrong prior to begin with. In this case, they could decide to change their priors instead of simply updating it. Similarly, Chaiken (1987) consider that when people are required to make a decision, they use a criterion and the confidence that the implications of this criterion are valid. If their confidence is above a minimum threshold, they base their decisions on this criterion without further consideration[1]. For these reasons, in our model we assume that there are some uninformed players who will never change their priors regardless of the new information they will receive.

Regarding the full information assumption, researchers in the competitive strategy area has extensively analysed the effect of demand uncertainty on pricing policies in oligopolistic markets (e.g., Klemperer and Meyer, 1986; Eden, 1990; 2009; Lucas and Woodford, 1993; Reisinger and Ressner, 2009). When these papers consider demand uncertainty, they mean that firms cannot observe some parameters of the market demand curve, such as its intercept with the vertical axis, its slope, etc., and that they have to decide subject to this lack of information. However, all these papers assume that all firms have the same information on the unknown parameter, whereas we assume that some firms have more information than others.

There are two branches of theoretical literature specifically related with the model presented here. The first one analyses what economists call signal jamming. For example, Riordan (1985) proposed a two-period model in which two firms offer homogeneous products and compete à la Cournot. In this case, what firms cannot observe is the position of the demand curve. The timing of the information in this game is as follows: In the first period, both firms choose their quantities without observing the position of the demand curve, but in the second period, they can observe the market price before setting their quantities. From this market price, each firm will update its information on the unknown parameter of the demand curve. Under these assumptions, the optimum quantities chosen in period 1 are greater than in a static Cournot model because each firm will increase its quantity in order to decrease the market price in the first period, making its rival think that the position of the demand curve is lower than it really is. Likewise, Mirman, Samuelson and Urbano (1993) developed a model with a similar framework to Riordan's in which firms offer heterogeneous products.

In a similar vein, Bernhardt and Taub (2015) analyse a duopoly buffeted by demand and cost shocks in which firms learn about shocks from common observation, private information and noisy price signals. Once again, firms internalize how outputs affect a rival's signal and hence, output. These authors distinguish how the nature of information, which can be public or private, and what firms learn about affect equilibrium outcomes. They obtained that firms weigh private information about private values by more than common values and then, prices contain more information about private value shocks than about common value shocks.

[1]Wyer and Albarracín (2014) analyze beliefs formation in a more complete way from a psychological point of view.

In these models of signal jamming, each firm tries to update its information on the unknown parameter of the demand curve by observing the market price or prices in the previous periods. Thus, each firm will want to manipulate their decisions in order to affect its rival's updating process.

The second branch of literature which is more related with the model presented here studies firms' ability to learn about the unknown parameter of the demand curve through experimentation. For example, Harrington (1992, 1995) and Aghion, Espinosa and Jullien (1993) analysed a duopoly in which both firms offer differentiated products and compete à la Bertrand in two periods. Here, the parameter that firms cannot observe is the degree of substitutability between products. In the first period, each firm has to choose its price, given the prior distribution of the unknown parameter, but in the second period, each firm can observe its own quantity sold and the prices set in period 1. Once again, using this information, each firm will update its knowledge of the degree of product differentiation.

The main innovation of these models is that firms can choose whether or not to learn the unknown parameter by setting the level of price dispersion in the first period. For instance, Aghion, Espinosa and Jullien (1993) assume that the degree of substitutability between products can take only two values. In this case, if price dispersion between firms is high enough, each firm will learn whether the degree of substitutability between products is low or high by observing its own volume of sales, given the prices set in the first period. However, if price dispersion is low enough, each firm will not be able to learn the degree of product differentiation by observing the demand quantity it achieved in the first period. Keller and Rady (2003) developed a similar model in which firms compete over infinite periods. In all these studies, firms' actions provide not only current rewards, but also information about the underlying state of demand. Thus, each firm will choose its action depending on the value of that information. In other words, there is a conflict between short-term and long-term incentives and the equilibrium behaviour must solve this conflict of incentives.

In all the papers described above, all the firms have the same information on the demand conditions, but in some markets, some firms have informational advantages because they have more experience in the market or lower information costs than others. This type of advantages could significantly affect not only the better informed firms, but also the worse informed firms' behaviour.

In this paper, we consider a model where two firms offer differentiated products and set their prices simultaneously in two periods. One of the competitors is aware of the market demand conditions, whereas the other one cannot observe the intercept of the demand curve and the degree of substitutability between products. In addition to this, we assume that the uninformed firm considers a particular distribution function of the unknown parameters, but it never updates this distribution irrespective of the new information it receives. Using the model developed by Ortoleva (2012), we would say that the uninformed firm considers a unique prior distribution function of the unknown parameters, and it will only use the new information to update their knowledge of the state of the world when according to its priors, the probability of the new information obtained is lower than a certain threshold. However, in our model, the threshold is so low that the uninformed firm will never update its knowledge of the unknown market conditions and will continue relying on its priors. Moreover, each firm can only observe its own quantity sold and the prices set in the first period before choosing its price in period 2, but they cannot observe their rival's quantity sold[2].

The contribution of our model to previous theoretical literature is threefold. First, we introduce asymmetric information in this duopoly game where one firm knows all the demand parameters, but the other cannot observe two of those parameters. As a result of this informational advantage, the best informed firm will set its price in the first period to influence its rival's decisions in the next period. This potential effect has interesting implications for pricing policies. Hence, this paper could explain the strategies of firms in certain real markets where some firms have more information than others.

Second, unlike previous models about learning by experimentation, in our model the uninformed firm will not be able to learn the unknown parameters because we assume that the uninformed firm is non-Bayesian.

Finally, this paper adds different arguments to the price-increasing competition models. For instance, Hauser and Shugan (1983) and Chen and Riordan (2008) developed models of product differentiation in which the market moves from monopoly to duopoly and the entry of a new competitor may lead to an increase in the incumbent's price under certain conditions. However, they assume that both firms have the same information on the market conditions. When a new firm enters a market, it is unlikely that the entrant has the same information on consumers than the incumbent. In our model, we relax this strong assumption and find that the best informed firm sets a higher price in a duopoly market than under monopoly if the demand uncertainty faced by the uninformed firm is higher than a certain threshold.

This paper is organized as follows. The next section describes the model, whereas the third determines the optimum prices set in the second period, which allows us to derive some economic predictions. Section 4 deduces the optimal prices set in the first period and illustrates the main implica-

[2]Firms' inability to observe their rivals' demand quantity realized in the prior periods is usual in some industries. For example, Kalnins (2006) described hotel difficulties obtaining information on their rivals' occupancy rates in the USA.

tions of the model. Section 5 determines the conditions under which the effect of competition on prices is positive or negative, and finally, section 6 summarizes the main conclusions. The Appendix includes the proofs of each Proposition obtained.

2. THE MODEL

Market structure. Consider a duopoly lasting two periods. There are 2 risk-neutral firms in this market: firms i and u. Each firm has a constant unit cost of production equal to zero. The outputs of firms i and u at date t are denoted by q_t^i, q_t^u. Each firm simultaneously and independently chooses its price in each period. So p_t^i, p_t^u denote the prices of firms i and u at date t. Moreover, each firm sells a differentiated product. Over relevant ranges of output, the following system of linear inverse demand curves is assumed:

$$p_t^i = a - \frac{\beta}{\theta} q_t^i - \frac{\gamma}{\theta} q_t^u \tag{1}$$

$$p_t^u = a - \frac{\beta}{\theta} q_t^u - \frac{\gamma}{\theta} q_t^i \tag{2}$$

Where $t = 1, 2$; a, β, γ, θ are the demand parameters, which are greater than zero, and $\beta > \gamma$, because if $\beta = \gamma$, both products will be perfect substitutes[3]. In fact, we assume that the difference between β and γ is sufficiently high so that firm i finds it too costly to drive its competitor out of the market. As a higher value for θ is associated with a higher cross-price elasticity in this specification, the substitutability of firms' products is increasing in θ.

The values of a and θ are drawn from the twice differentiable distribution functions $F(a)$ and $G(\theta)$, with associated density functions, $f(a)$ and $g(\theta)$, where $a \in [\underline{a}, \overline{a}]$, $\theta \in [0, \overline{\theta}]$, $\overline{a} > \underline{a} \geq 0$ and $\overline{\theta} > 0$. The values of these parameters do not change over time. As usual, to avoid unnecessary complications, it is a requirement the support of θ is sufficiently small, such that no equilibria emerge in which a firm sells a negative quantity. It is assumed that,

$$E(a) = a^* \tag{3}$$

$$E(\theta) = 1 \tag{4}$$

Where $E(\cdot)$ denotes the expectations about the demand parameters. Moreover, the random variables, a and θ, are statistically independent and the

[3]The system of linear demand curves specified is the same as that considered by Klemperer and Meyer (1986) and Reisinger and Ressner (2009).

probability distribution function of θ is symmetric around 1, which is the average of θ. All this information about the distributions of a and θ is common knowledge. We assume that Nature chooses the values of a and θ in period 0. After that, the timing of the information is as follows.

Firms' information in period 1. Before choosing prices in the first period, it is assumed that firm i (the informed one) can observe all the demand parameters, including the realizations of a and θ, but firm u cannot observe those realizations.

Firms' information in period 2. Before choosing its price in period 2, each firm observes both prices chosen in period 1 and its own quantity sold in that period. In a standard model with Bayesian firms, the informed firm's optimal price set in period 1 may depend on a and θ. Thus, a Bayesian uninformed firm would use this information and its quantity sold to deduce the true value of the unknown parameters before choosing its price in period 2. However, in this model the uninformed firm is non-Bayesian, and for this reason, it does not use its information on the price set by its rival to infer the values of a and θ. It is as if the manager of the uninformed firm is so stubborn, that he never admits that he is wrong even though the new information received runs counter to what he believed at the beginning of the game. Thus, our uninformed firm will choose its price in period 2 without taking into account the price chosen by its rival.

Under these assumptions, the only extra information considered by firm u in period 2 is its own quantity sold in period 1. Using equations (1) and (2), we obtain,

$$q_t^i = \frac{a\theta}{(\beta+\gamma)} - \frac{\beta\theta}{(\beta^2-\gamma^2)}p_t^i + \frac{\gamma\theta}{(\beta^2-\gamma^2)}p_t^u \tag{5}$$

$$q_t^u = \frac{a\theta}{(\beta+\gamma)} - \frac{\beta\theta}{(\beta^2-\gamma^2)}p_t^u + \frac{\gamma\theta}{(\beta^2-\gamma^2)}p_t^i \tag{6}$$

At the end of period 1, firm u only takes into account the realization of its own demand quantity and its own price. From these market data, firm u infers the relationship between a and θ. In particular, when $t = 1$, we can rearrange equation (6) to obtain[4],

$$a = \frac{(\beta+\gamma)}{\theta}q_1^u + \frac{\beta}{(\beta-\gamma)}p_1^u - \frac{\gamma}{(\beta-\gamma)}p_1^i \tag{7}$$

Equation (7) shows that there will be a particular relationship between a and θ for each value of q_1^u, p_1^u and p_1^i.

[4]If firms use its quantity sold in previous years to predict its level of demand in the current year, which is measured by a, equation (7) properly describes the relationship between a and θ. For example, Weatherford and Kimes (2003) showed that this is usually the forecasting method used in the hotel industry.

Equilibrium: Definition and interpretation. In our analysis, we obtain the optimal prices set by each firm in each period under the assumptions of the model. On the one hand, a strategy for firm i involves the specification of a price in period 1, p_1^i, and a function determining the period-2 price from its rival's realized quantity in period 1 and both prices set in that period, $p_2^i = \psi_2^i(p_1^i, p_1^u, q_1^u)$. Firm i's price in period 2 depends on both prices set in period 1 because they affect its rival's quantity sold and firm u will use its quantity sold in period 1 to infer the relationship between a and θ. Thus, firm i takes into account its rival's deduction when it chooses its price in period 2. On the other hand, a strategy for firm u is the specification of a price in period 1, p_1^u, and a function determining the period-2 price from firm u's informational set in period 1, $p_2^u = \psi_2^u(p_1^i, p_1^u, q_1^u)$.

Then, $[p_1^{i*}, \psi_2^{i*}(p_1^i, p_1^u, q_1^u)]$ is an equilibrium strategy for firm i if and only if it solves

$$\max_{p_1^i, \psi_2^i(p_1^i, p_1^u, q_1^u)} \pi^i = p_1^i q_1^i + \delta \psi_2^i(p_1^i, p_1^u, q_1^u) q_2^i$$

where δ is the discount factor, which is common for both firms. Similarly, $[p_1^{u*}, \psi_2^{u*}(p_1^i, p_1^u, q_1^u)]$ is an equilibrium strategy for firm u if and only if it solves

$$\max_{p_1^u, \psi_2^u(p_1^i, p_1^u, q_1^u)} E(\pi^u) = E\{p_1^u q_1^u + \delta[\psi_2^u(p_1^i, p_1^u, q_1^u) q_2^u]\}$$

The expectation operator in the definition of equilibrium, $E[\cdot]$, is defined with respect to the distribution functions over (a, θ). At period 2, each firm chooses a price that maximizes expected period-2 profits, conditional on its observation of the uninformed firm's quantity sold and the prices chosen in period 1. At period 1, each competitor chooses a price that maximizes expected discounted profits, given its period-2 decision rule. This behaviour defines an equilibrium strategy.

3. OPTIMAL PRICES SET IN THE SECOND PERIOD

The first step of the analysis is to characterize the second-period decision problem of each firm. In particular, firm i maximizes its profits in the second period,

$$\max_{p_2^i} \pi_2^i = p_2^i q_2^i \tag{8}$$

However, as firm u does not know the demand conditions, it expects that firm i is facing the following problem:

$$\max_{p_2^i} E(\pi_2^i) = E(p_2^i q_2^i) \tag{9}$$

Finally, firm u maximizes its expected profits in the second period,

$$\max_{p_2^u} E(\pi_2^u) = E(p_2^u q_2^u) \tag{10}$$

We assume that the demand equations (1) and (2) are fulfilled. Solving problems (8), (9) and (10), we can obtain both firms' optimal prices in period 2. The following Proposition shows firm i's ability to fool its rival in the second period.

Proposition 1. *Firm i can affect its rival's optimal price in period 2 by changing its price in the first period provided that the degree of substitutability between products is different from that expected by firm u.*

In other words, let p_2^{u*} be the optimal price in the second period for firm u. Then,

$$\frac{\partial p_2^{u*}}{\partial p_1^i} \gtreqless 0 \text{ if and only if } \theta \gtreqless 1 \tag{11}$$

The solution of the maximization problems (8)-(10) and the demonstration of this Proposition are included in the Appendix, but its intuition is very simple. If firm i set a higher price in the first period when the degree of substitutability between products is higher than the expectation of its rival, the demand quantity of firm u realized in the first period would be greater than it expected. Hence, firm u would believe that the demand intercept is higher than expected in the first period and it would set a higher price in period 2. The opposite would occur if firm i set a lower price when θ is higher than 1. Likewise, if firm i set a lower price in the first period when the degree of substitutability between products is lower than its rival's expectation, the demand quantity of firm u realized in period 1 would be greater than it expected and once again, the uninformed firm would believe that the demand intercept is greater than expected. As a result, firm u would increase its price in the second period. The opposite would occur if firm i set a higher price in period 1 when θ is lower than 1. In a nutshell, firm i would want to deceive its rival in period 2 by increasing its price in period 1 when θ is greater than 1 and by decreasing its price when θ is lower than 1. By doing so, firm i will face a less competitive rival in the second period.

Now, we can analyse the informed firm's incentive to fool its rival by changing its price in period 1 in order to obtain more profits in the second period. This incentive can be measured by the discounted increase in firm i's profits in period 2 due to the rise in the price of the uninformed firm induced by the change in the price set by firm i in the first period, that is, $\delta \left| \frac{\partial \pi_2^{i*}}{\partial p_2^u} \cdot \frac{\partial p_2^{u*}}{\partial p_1^i} \right|$,[5] where π_2^{i*} is the profit obtained by firm i in the second period when both firms choose their equilibrium prices.

Using (5) for $t = 2$ and (A.10) (see the Appendix), we obtain this incentive for each optimal price set by firm i in the second period, that is,

$$\delta \left| \frac{\partial \pi_2^{i*}}{\partial p_2^u} \cdot \frac{\partial p_2^{u*}}{\partial p_1^i} \right| = \delta p_2^{i*} \frac{\gamma^2 |\theta^2 - \theta|}{(\beta^2 - \gamma^2)(2\beta - \gamma)} \tag{12}$$

The relationship between this incentive and θ is represented in Figure 1 for arbitrary values of the remaining demand parameters, and it is a concave function with respect to θ when θ is lower than 1 and a convex function when θ is greater than 1.

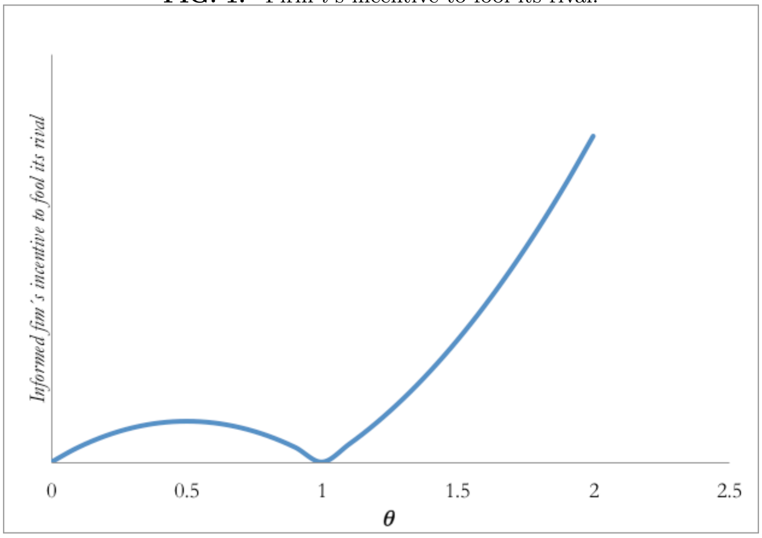
When $0 < \theta < 1$, firm i wants to decrease its price in period 1 to face a less competitive rival in period 2 as Proposition 1 shows. When θ increases in this region, there are two opposite effects of a decrease in firm i's price in period 1. First, the fall in the price set by the informed firm in period 1 will decrease the uninformed firm's sales closer to its own expectation as θ increases in this region because θ will be closer to 1, which is firm u's expectation. Then, firm u will have a lower incentive to increase its price in the second period. Second, the higher the degree of substitutability between products, the greater the increase in firm i's quantity sold in the second period caused by a less competitive rival in that period. As we can observe in Figure 1, when $0 < \theta < 0.5$, the second effect prevails over the first, but the opposite occurs when $0.5 < \theta < 1$, that is, when the degree of substitutability between products is so close to firm u's expectation that firm i can hardly fool its rival.

When $\theta > 1$, firm i wants to increase its price in period 1 to fool its rival in period 2. In this region, we also find two effects as θ goes up. First, when firm i increases its price in period 1, the difference between firm u's quantity sold in this period and its expectation will increase with θ. Therefore, firm u's deception will increase with θ in this region and then, the effect of an increase in the price set by firm i in period 1 on the price set by firm u in period 2 will also increase with θ. Second, the increase in firm i's quantity sold caused by the rise in firm u's price in period 2 will increase with the degree of substitutability between products. Now, both effects are mutually reinforcing and for this reason, Figure 1 shows that firm i's incentive to fool its rival grows at an increasing rate as θ rises in this region.

---

[5]From Proposition 1, firm i wants to increase its price when θ is greater than 1, whereas it wants to decrease its price when θ is lower than 1 to face a less competitive rival in period 2. As I am measuring firm i's profits from these changes in its price, I use the absolute value.

FIG. 1. Firm i's incentive to fool its rival.



Firm i must take into account that the uninformed firm's choice in the first period will affect its own demand quantity, which will be used to estimate the relationship between a and θ. Thus, firm u will deceive itself in period 1 to a certain extent and consequently, it will change its price in period 2. As a result, firm i must anticipate its rival's inference and adjust its price in period 2 when firm u's price changes in period 1, as Proposition 2 shows.

PROPOSITION 2. *Changes in firm u's price in period 1 will affect firm i's optimal price in the second period provided that the degree of substitutability between products is different from that expected by firm u.*

In other words, let p_2^{i*} be the equilibrium price in the second period for firm i. Then,

$$\frac{\partial p_2^{i*}}{\partial p_1^u} \gtreqless 0 \text{ if and only if } \theta \lesseqgtr 1 \tag{13}$$

The demonstration of this Proposition is also in the Appendix, but its intuition is similar to the previous one. In particular, if firm u set a higher price in the first period when θ is greater than 1, its demand quantity achieved in period 1 would be lower than it expected. Then, firm u would infer that the demand intercept is lower than it thought and it would set a lower price in period 2. Firm i would anticipate its rival's behavior and would set a lower price in the second period. The opposite would occur if θ were lower than 1.

4. OPTIMAL PRICES SET IN THE FIRST PERIOD

The following step is to analyse the decisions of firms in the first period, given the decision rules in the second period. The problem of firm i in the first period will be:

$$\max_{p_1^i} \pi^i = p_1^i q_1^i + \delta \pi_2^{i*} \tag{14}$$

The first-order condition for this problem will be:

$$\frac{\partial \pi^i}{\partial p_1^i} = q_1^{i*} + p_1^{i*} \frac{\partial q_1^i}{\partial p_1^i} + \delta \frac{\partial \pi_2^{i*}}{\partial p_1^i} = 0 \tag{15}$$

Where q_1^{i*} is the demand quantity for firm i in period 1 when both firms choose the equilibrium prices. We apply the envelope theorem, that is, $\frac{\partial \pi_2^{i*}}{\partial p_1^i} = p_2^{i*} \frac{\partial q_2^{i*}}{\partial p_1^i}$, where q_2^{i*} is the demand quantity for firm i in period 2 when both firms choose the equilibrium prices.

However, firm u expects that firm i faces the following maximization problem:

$$\max_{p_1^i} E(\pi^i) = E(p_1^i q_1^i) + \delta E(\pi_2^{i*}) \tag{16}$$

Then, the expected first-order condition of firm i will be:

$$\frac{\partial E(\pi^i)}{\partial p_1^i} = E\left[q_1^{i*} + p_1^{i*} \frac{\partial q_1^i}{\partial p_1^i} + \delta \frac{\partial \pi_2^{i*}}{\partial p_1^i}\right] = 0 \tag{17}$$

Once again, a similar version of the envelope theorem can be applied, that is, $E\left(\frac{\partial \pi_2^{i*}}{\partial p_1^i}\right) = E\left(p_2^{i*} \frac{\partial q_2^{i*}}{\partial p_1^i}\right)$.

Finally, the problem of the risk-neutral firm u in period 1 will be:

$$\max_{p_1^u} E(\pi^u) = E(p_1^u q_1^u) + \delta E(\pi_2^{u*}) \tag{18}$$

Where π_2^{u*} is the profit obtained by firm u in the second period when both firms choose their equilibrium prices. Now, the expected first-order condition of firm u will be:

$$\frac{\partial E(\pi^u)}{\partial p_1^u} = E\left[q_1^{u*} + p_1^{u*} \frac{\partial q_1^u}{\partial p_1^u} + \delta \frac{\partial \pi_2^{u*}}{\partial p_1^u}\right] = 0 \tag{19}$$

Where q_1^{u*} is the demand quantity for firm u in period 1 when both firms choose their optimal prices.

Now, we can analyse the effect of demand uncertainty on firms' behaviour in our model. In particular, the following Proposition explains the informed firm's reaction to an increase in the demand uncertainty we are considering here.

PROPOSITION 3. *The higher the demand uncertainty faced by firm u, the greater the optimal price set by firm i in period 1, except for intermediate values of θ.*

In other words, $\frac{\partial p_1^{i*}}{\partial \sigma_\theta^2}$ depends on θ in the following manner:

$$\frac{\partial p_1^{i*}}{\partial \sigma_\theta^2} > 0 \ \text{ if } \ 0 < \theta < 1 + \frac{2(2\beta - \gamma)}{\gamma\sqrt{\delta}} \tag{20}$$

$$\frac{\partial p_1^{i*}}{\partial \sigma_\theta^2} < 0 \ \text{ if } \ 1 + \frac{2(2\beta - \gamma)}{\gamma\sqrt{\delta}} < \theta < 1 + \frac{\beta(2\beta - \gamma)\sqrt{8}}{\gamma^2\sqrt{\delta}} \tag{21}$$

$$\frac{\partial p_1^{i*}}{\partial \sigma_\theta^2} > 0 \ \text{ if } \ \theta > 1 + \frac{\beta(2\beta - \gamma)\sqrt{8}}{\gamma^2\sqrt{\delta}} \tag{22}$$

$$\frac{\partial p_1^{i*}}{\partial \sigma_\theta^2} = 0 \ \text{ if } \ \theta = 1 + \frac{2(2\beta - \gamma)}{\gamma\sqrt{\delta}} \text{ or } \theta = 1 + \frac{\beta(2\beta - \gamma)\sqrt{8}}{\gamma^2\sqrt{\delta}} \tag{23}$$

The proof of this Proposition is included in the Appendix. To understand it, we need to turn back to firm i's incentive to mislead its rival (Proposition 1). In particular, an increase in demand uncertainty faced by the uninformed firm will affect this incentive in two ways. First, the greater the demand uncertainty, the greater firm i's capacity to fool its rival (uncertainty effect). Secondly, as the relationship between a and θ is decreasingly convex with respect to θ (see equation (7)), a mean-preserving spread of θ will increase firm u's expectation about the demand intercept in the second period due to Jensen's inequality, that is, firm u will deceive itself to a certain extent. Thus, it will be less necessary for firm i to mislead its rival when demand uncertainty increases due to this second effect (self-deception effect).

We can distinguish several regions. When $\theta < 1$, the region in which the informed firm wants to decrease its price in period 1 to face a less competitive rival in period 2, the self-deception effect is greater than the uncertainty effect because the demand intercept expected by firm u will increase more for low values of θ, given the high convexity of the relationship between a and θ in this region. Thus, the rise in firm u's uncertainty will bring down firm i's incentive to mislead its rival by decreasing its price in the first period, and for this reason, firm i's optimal price increases with demand uncertainty as shown by (20). Due to continuity, this also occurs for some values of θ greater than 1. When $\theta > 1$, a region in which the informed firm wants to increase its price in period 1 to face a less competitive rival in period 2, the convexity of the relationship between a and θ is so high for low values of θ that the self-deception effect will dominate the uncertainty one. Hence, an increase in demand uncertainty will bring down firm i's incentive to deceive its rival by raising its price in period 1 and then, firm i's optimal price will decrease with demand uncertainty when θ is sufficiently low as shown by (21). However, the uncertainty effect will dominate the self-deception one for sufficiently high values of θ because the convexity of the relationship between a and θ shown by equation (7) is lower and lower. In this case, a rise in the variability of θ will increase firm i's incentive to raise its price in period 1 in order to mislead its rival in period 2, as shown by (22).

Now, the following Proposition shows the effect of uncertainty on the uninformed firm's behaviour.

PROPOSITION 4. *The higher the demand uncertainty faced by the uninformed firm, the greater its optimal price in period 1, that is,*

$$\frac{\partial p_1^{u*}}{\partial \sigma_\theta^2} > 0 \quad \forall\ \theta \tag{24}$$

The Appendix includes the proof of this Proposition. Once again, we have to focus our attention on firm i's incentive to mislead its rival to understand this Proposition. As Figure 1 shows, firm i's incentive to reduce its price is concave with respect to θ when it is lower than 1, whereas firm i's incentive to increase its price is convex when θ is greater than 1. It means that a reduction in θ below its expectation would increase firm i's incentive to deceive its rival by decreasing its price in period 1, but to a lesser extent than a rise in θ above its expectation of the same magnitude would increase firm i's incentive to deceive firm u by increasing its price. Thus, a mean-preserving spread of θ will provide firm i with incentives, on average, to inflate its price and then, firm u will expect to face a less competitive rival. For this reason, the uninformed firm's optimal price increases with demand uncertainty.

5. THE EFFECT OF COMPETITION ON PRICES

Finally, it is interesting to compare the price set by the informed firm in period 1 to the price set by this firm in a monopoly market. This comparison can be helpful to understand the consequences of a new entrant under certain circumstances. For example, when a new firm enters the market, the incumbent usually has better information about consumers because it has more experience in the market. We can then obtain some useful predictions about prices under these conditions, comparing the price set by an informed monopolist to the price set by the informed firm in this model.

PROPOSITION 5. *When the realized demand parameters are sufficiently close to their expectations, the optimal price set by the informed firm in period 1 in this duopoly context is higher than the optimal price set by this firm in a monopoly market provided that the demand uncertainty faced by the uninformed firm is sufficiently enough.*

In other words, within certain intervals of both unknown parameters around their averages, $a \in (a^* - \lambda, a^* + \lambda), \theta \in (1 - \omega, 1 + \omega)$, where λ and ω are sufficiently low real numbers, there exists a threshold, $\overline{\sigma_\theta^2}$, for σ_θ^2, such that $p_1^{i*} \gtreqless p_1^{iM}$ when $\sigma_\theta^2 \gtreqless \overline{\sigma_\theta^2}$

Where p_1^{iM} is the optimal price set by an informed monopolist in the first period under the demand conditions given by (1) and (2). If we denote the total market demand in each period as q_t, we can prove that $p_1^{iM} = \frac{a}{2}$ by substituting p_t for p_t^i and p_t^u and q_t for $q_t^i + q_t^u$ when $t = 1$ in the linear demand curves (1) and (2). It is easy to see that p_1^{iM} is greater than p_1^{i*} when $a = a^*$, $\theta = 1$ and $\sigma_\theta^2 = 0$. Since p_1^{i*} is a continuous function with respect to a and θ around the averages of both unknown parameters, p_1^{iM} does not depend on σ_θ^2 and $\frac{\partial p_1^{i*}}{\partial \sigma_\theta^2} > 0$ when θ is around its average as Proposition 3 shows, then, the demonstration of Proposition 5 is straightforward. In other words, as usual, our informed firm would set a lower price in this duopoly context than in a monopoly market if there were no uncertainty about demand. However, as Proposition 3 shows, firm i would increase its price in period 1 when demand uncertainty increases in order to fool its rival in the next period. Thus, if the demand uncertainty is sufficiently enough, the price set by firm i will become greater than the monopoly price when θ is close to 1.

To end this Section, the following Proposition shows the same comparison for firm u, but this result is more general because it does not depend on θ.

PROPOSITION 6. *The uninformed firm sets a higher price in period 1 than in a monopoly situation if the demand uncertainty is sufficiently high.*

In other words, there exists a threshold, $\overline{\overline{\sigma_\theta^2}}$, for σ_θ^2, such that, $\forall \theta, p_1^{u*} \gtreqless p_1^{uM}$ when $\sigma_\theta^2 \gtreqless \overline{\overline{\sigma_\theta^2}}$

Where p_1^{uM} is the optimal price set by an uninformed monopolist in the first period under the demand conditions given by (1) and (2). Since $p_1^{uM} = \frac{a^*}{2}$, as usual, p_1^{uM} is greater than p_1^{u*} when $\sigma_\theta^2 = 0$. However, since $\frac{\partial p_1^{u*}}{\partial \sigma_\theta^2} > 0$ from Proposition 4, then, the demonstration of Proposition 6 is also obvious. Once again, the uninformed firm would set a lower price in this duopoly context than in a monopoly if there were no demand uncertainty. Nevertheless, as Proposition 4 shows, firm u's optimal price in period 1 increases with demand uncertainty. For this reason, if the variance of θ is sufficiently high, firm u's optimal price will become greater than the monopoly price because the latter does not depend on demand uncertainty.

6. CONCLUSIONS

Previous theoretical literature has provided some explanations for the increase in prices when a new competitor enters some particular markets. However, the assumptions used by those models are too strong in some real contexts. For example, they assume that the new competitor has the same information on the market conditions as the incumbent. Similarly, they also consider that the inexperienced new rival is a perfect Bayesian firm that is able to gather the necessary information on the market outcomes in the first period to perfectly update its knowledge of the market demand curve.

In the initial periods of competition, in which new firms are struggling to understand the environment in which they make their decisions, these assumptions may not be plausible. For this reason, this paper presents a two-stage game model where two firms offer differentiated products and one of them faces demand uncertainty, which affects both the intercept of the demand curve and the degree of product differentiation in the market. Moreover, the uninformed firm is a non-Bayesian firm, that is, it does not use the information provided by its rival's decision in the previous period to update its knowledge of the market conditions. In each period, each firm only observes its own quantity sold and both competitors set their prices simultaneously and non-cooperatively. This model might help to explain some empirical puzzles.

In particular, this model can provide a more plausible explanation for the recent price-increasing competition evidence obtained by some empirical papers. For example, Ward et al. (2002) found that the entry of new private labels raised prices of national brands in the food industry, and Thomadsen (2007) obtained that prices may be higher under duopoly competition than under monopoly in the fast-food industry. We show that even when the expectations about the demand parameters are close to their realized values, the incumbent, which is better informed on market conditions, will set a higher price with the new competitor than without it if demand uncertainty faced by the new entrant is sufficiently high.

We end by pointing out some limitations of the model. Firstly, the results of this paper may depend on the functional forms of the demand and cost curves. Similarly, the assumption of statistical independence between unknown demand parameters can be too restrictive in some contexts. Furthermore, some firms might have imperfect but better information on market conditions than others. Lastly, the demand conditions can be more instable in some markets and the results can change when firms compete in infinite periods. Although the robustness of the predictions of this model to these alternative assumptions is an open question for future research, it could help to explain pricing policies in some contexts. Specifically, the implications of the model can be fulfilled in markets where one firm has much more experience than its rivals and the latter have imperfect information about the demand conditions and do not perfectly use the Bayesian rule to update its limited knowledge.

APPENDIX A

PROOF OF PROPOSITION 1. Following the backward induction method, we begin with the analysis of the equilibrium in the second period. Starting with firm u, it chooses its price to maximize its profit in the second period,

$$\max_{p_2^u} E(\pi_2^u) = E(p_2^u q_2^u)$$

Using equation (7), $E(\theta) = 1$, and the demand equation (6) when $t = 2$, the problem of this risk-neutral firm will be:

$$\max_{p_2^u} E(\pi_2^u) = q_1^u p_2^u + \frac{\beta}{(\beta^2 - \gamma^2)} p_1^u p_2^u - \frac{\gamma}{(\beta^2 - \gamma^2)} p_1^i p_2^u - \frac{\beta}{(\beta^2 - \gamma^2)} p_2^{u2} + \frac{\gamma}{(\beta^2 - \gamma^2)} p_2^i p_2^u \tag{A.1}$$

Then, firm u's expected reaction function is

$$p_2^u = \frac{(\beta^2 - \gamma^2)}{2\beta} q_1^u + \frac{1}{2} p_1^u - \frac{\gamma}{2\beta} p_1^i + \frac{\gamma}{2\beta} p_2^i \tag{A.2}$$

However, firm u expects that firm i will face the following problem:

$$\max_{p_2^i} E(\pi_2^i) = E(p_2^i q_2^i)$$

Then, using (7), firm i's demand equation (5) when $t = 2$ and $E(\theta) = 1$, the expected problem of firm i will be

$$\max_{p_2^i} E(\pi_2^i) = q_1^u p_2^i + \frac{\beta}{(\beta^2 - \gamma^2)} p_1^u p_2^i - \frac{\gamma}{(\beta^2 - \gamma^2)} p_1^i p_2^i - \frac{\beta}{(\beta^2 - \gamma^2)} p_2^{i2} + \frac{\gamma}{(\beta^2 - \gamma^2)} p_2^u p_2^i \tag{A.3}$$

Then, the expected reaction function of firm i is

$$p_2^i = \frac{(\beta^2-\gamma^2)}{2\beta} q_1^u + \frac{1}{2} p_1^u - \frac{\gamma}{2\beta} p_1^i + \frac{\gamma}{2\beta} p_2^u \tag{A.4}$$

We can substitute p_2^i from equation (A.4) into (A.2) to obtain the optimal price set by firm u in the second period, p_2^{u*},

$$p_2^{u*} = \frac{(\beta^2-\gamma^2)}{(2\beta-\gamma)} q_1^u + \frac{\beta}{(2\beta-\gamma)} p_1^u - \frac{\gamma}{(2\beta-\gamma)} p_1^i \tag{A.5}$$

As firm i knows a and θ, it chooses its price to maximize its profit in period 2, $\max_{p_2^i} \pi_2^i = p_2^i q_2^i$

Then if we use the demand equation (5) when $t = 2$, the problem of this firm will be:

$$\max_{p_2^i} \pi_2^i = \frac{a\theta}{(\beta+\gamma)} p_2^i - \frac{\beta\theta}{(\beta^2-\gamma^2)} p_2^{i2} + \frac{\gamma\theta}{(\beta^2-\gamma^2)} p_2^u p_2^i \tag{A.6}$$

Thus, the reaction function of firm i will be:

$$p_2^i = \frac{(\beta-\gamma)a}{2\beta} + \frac{\gamma}{2\beta} p_2^u \tag{A.7}$$

If p_2^{u*} from equation (A.5) is included in (A.7), firm i's optimal price is obtained:

$$p_2^{i*} = \frac{(\beta-\gamma)a}{2\beta} + \frac{\gamma(\beta^2-\gamma^2)}{2\beta(2\beta-\gamma)} q_1^u + \frac{\gamma}{2(2\beta-\gamma)} p_1^u - \frac{\gamma^2}{2\beta(2\beta-\gamma)} p_1^i \tag{A.8}$$

As firm i knows a, θ, p_1^i and p_1^u before choosing its price in the second period, it will know q_1^u. Now, from (A.5), we can analyse the change in the uninformed firm's optimal price in the second period due to a change in the informed firm's price in the first period given the value of p_1^u:

$$\frac{\partial p_2^{u*}}{\partial p_1^i} = \frac{(\beta^2-\gamma^2)}{(2\beta-\gamma)} \frac{\partial q_1^u}{\partial p_1^i} - \frac{\gamma}{(2\beta-\gamma)} \tag{A.9}$$

Equation (6) when $t = 1$ is used to calculate $\frac{\partial q_1^u}{\partial p_1^i}$ given p_1^u and this is included in (A.9). Hence, we have the following result:

$$\frac{\partial p_2^{u*}}{\partial p_1^i} = \frac{\gamma(\theta-1)}{(2\beta-\gamma)} \tag{A.10}$$

As $\beta > \gamma$, Proposition 1 has been demonstrated. ∎

PROOF OF PROPOSITION 2. We can now calculate the reaction of the informed firm's optimal price in the second period due to a change in the uninformed firm's price in period 1 from equation (A.8), given the value of p_1^i,

$$\frac{\partial p_2^{i*}}{\partial p_1^u} = \frac{\gamma(\beta^2-\gamma^2)}{2\beta(2\beta-\gamma)}\frac{\partial q_1^u}{\partial p_1^u} + \frac{\gamma}{2(2\beta-\gamma)} \tag{A.11}$$

Using firm u's demand equation (6) when $t=1$ to obtain $\frac{\partial q_1^u}{\partial p_1^u}$ given p_1^i, we arrive at the following result.

$$\frac{\partial p_2^{i*}}{\partial p_1^u} = \frac{\gamma(1-\theta)}{2(2\beta-\gamma)} \tag{A.12}$$

As $\beta > \gamma$, Proposition 2 has been demonstrated. ▌

BAYESIAN NASH EQUILIBRIUM. Now, we obtain the optimal prices in the first period from the maximization problems of firms i and u, that is, from (14), (16) and (18). First of all, we obtain the reaction functions of both firms. Starting with the informed firm, we substitute firm i's demand equation (5) for $t=1$ into (14), use the envelope theorem, calculate $\frac{\partial p_2^{i*}}{\partial p_1^i}$ and $\frac{\partial p_2^{u*}}{\partial p_1^i}$ using equations (A.8) and (A.5), and q_1^u is substituted by the expression (6) for $t=1$. After these substitutions and some operations, the reaction function of firm i in the first period will be:

$$p_1^i = \frac{m}{n} + \frac{s}{n}p_1^u \tag{A.13}$$

Where,

$$\begin{aligned} m &= 4\beta(\beta-\gamma)(2\beta-\gamma)^2 a + \delta\gamma^2(\beta-\gamma)(2\beta-\gamma+\gamma\theta)a(\theta-1) \\ n &= 8\beta^2(2\beta-\gamma)^2 - \delta\gamma^4(\theta-1)^2 \\ s &= 4\beta\gamma(2\beta-\gamma)^2 - \delta\beta\gamma^3(\theta-1)^2 \end{aligned}$$

Now, we proceed with solving the informed firm's problem as expected by firm u. Assuming that $E(\theta)=1$, $E(a)=a^*$ and that a and θ are statistically independent, substituting firm i's demand equation (5) for $t=1$ into (16), using the envelope theorem, calculating $\frac{\partial p_2^{i*}}{\partial p_1^i}$ and $\frac{\partial p_2^{u*}}{\partial p_1^i}$ from (A.8) and (A.5), and substituting q_1^u by the expression (6) for $t=1$, the expected reaction function of firm i in the first period can be expressed as:

$$p_1^i = \frac{m'}{n'} + \frac{s'}{n'}p_1^u \tag{A.14}$$

Where,

$$\begin{aligned} m' &= 4\beta(\beta-\gamma)(2\beta-\gamma)^2 a^* + \delta\gamma^2(\beta-\gamma)(2\beta+\gamma)a^*\sigma_\theta^2 \\ n' &= 8\beta^2(2\beta-\gamma)^2 - \delta\gamma^4\sigma_\theta^2 \\ s' &= 4\beta\gamma(2\beta-\gamma)^2 - \delta\beta\gamma^3\sigma_\theta^2 \end{aligned}$$

Finally, we solve the uninformed firm's problem in period 1 given by (18). Assuming that $E(\theta)=1$, $E(a)=a^*$ and that a and θ are statistically independent, substituting firm u's demand equation (6) for $t=1$ into (18), using the envelope theorem, and calculating $\frac{\partial p_2^{i*}}{p_1^u}$ and $\frac{\partial p_2^{u*}}{\partial p_1^u}$ from (A.8) and (A.5), respectively, the expected reaction function of firm u in the first period can be expressed as:

$$p_1^u = \frac{t}{u} + \frac{v}{u}p_1^i \tag{A.15}$$

Where,

$$\begin{aligned} t &= 2(\beta-\gamma)(2\beta-\gamma)^2 a^* + 2\delta(\beta-\gamma)(2\beta^2-\gamma^2)a^*\sigma_\theta^2 \\ u &= 4\beta(2\beta-\gamma)^2 + \delta\beta(2\beta^2-\gamma^2)\sigma_\theta^2 \\ v &= 2\gamma(2\beta-\gamma)^2 + \delta\gamma(2\beta^2-\gamma^2)\sigma_\theta^2 \end{aligned}$$

As firm u expects firm i to behave as obtained in equation (A.14), this is substituted into firm u's reaction function in (A.15) and the optimal price set by this uninformed firm in the first period is the following:

$$p_1^{u*} = \frac{tn' + vm'}{un' - vs'} \tag{A.16}$$

By including this price in the reaction function of firm i from equation (A.13), the optimal price set by the informed firm in period 1 can be expressed as:

$$p_1^{i*} = \frac{m(un'-vs') + s(tn'+vm')}{n(un'-vs')} \tag{A.17}$$

PROOF OF PROPOSITION 3. First, we obtain the derivative of the optimal price set by firm i in period 1 with respect to the variance of θ from (A.17):

$$\frac{\partial p_1^{i*}}{\partial \sigma_\theta^2} = \frac{2\delta\gamma(\beta-\gamma)(2\beta-\gamma)a^* K[32\beta^2(2\beta-\gamma)^4 - 4\delta\gamma^2(2\beta-\gamma)^2(2\beta^2+\gamma^2)(\theta-1)^2 + \delta^2\gamma^6(\theta-1)^4]}{[n(un'-vs')]^2} \tag{A.18}$$

Where,

$$\begin{aligned}
K &= 8\beta K_1^3 K_2 K_3 + \delta^2\gamma^3 K_4 K_5 \sigma_\theta^4 + 8\delta\gamma^3 K_1^2 K_4 K_6 \sigma_\theta^2 \\
K_1 &= 2\beta - \gamma \\
K_2 &= 2\beta + \gamma \\
K_3 &= 24\beta^4 - 8\beta^3\gamma - 12\beta^2\gamma^2 + 8\beta\gamma^3 - \gamma^4 \\
K_4 &= 2\beta^2 - \gamma^2 \\
K_5 &= 8\beta^4 - 8\beta^2\gamma^2 + \gamma^4 \\
K_6 &= 4\beta^2 - \gamma^2
\end{aligned}$$

As $\beta > \gamma > 0$, then, $K_1, K_2, K_3, K_4, K_5, K_6 > 0$ and $K > 0$. Thus, the sign of $\frac{\partial p_1^{i*}}{\partial \sigma_\theta^2}$ depends on the sign of $32\beta^2(2\beta-\gamma)^4 - 4\delta\gamma^2(2\beta-\gamma)^2(2\beta^2 + \gamma^2)(\theta-1)^2 + \delta^2\gamma^6(\theta-1)^4$. If we substitute $(\theta-1)^2$ with X and $(\theta-1)^4$ with X^2 in the last expression and solving it for zero,

$$32\beta^2(2\beta-\gamma)^4 - 4\delta\gamma^2(2\beta-\gamma)^2(2\beta^2+\gamma^2)X + \delta^2\gamma^6X^2 = 0 \tag{A.19}$$

It is clear that the feasible solutions of this equation are:

$$X_1 = \frac{8\beta^2(2\beta-\gamma)^2}{\delta\gamma^4} \tag{A.20}$$

$$X_2 = \frac{4(2\beta-\gamma)^2}{\delta\gamma^2} \tag{A.21}$$

Thus, the only positive values of θ which satisfy equation (A.19) are:

$$\theta_1 = 1 + \frac{2(2\beta-\gamma)}{\gamma\sqrt{\delta}} \tag{A.22}$$

$$\theta_2 = 1 + \frac{\beta(2\beta-\gamma)\sqrt{8}}{\gamma^2\sqrt{\delta}} \tag{A.23}$$

Thus, part (23) of Proposition 3 has been proven. It is clear that the sign on the left-hand side of (A.19) is positive when $0 < \theta < \theta_1$ or $\theta > \theta_2$ and negative when $\theta_1 < \theta < \theta_2$. Hence, Proposition 3 has been proven.

PROOF OF PROPOSITION 4. From (A.16), the effect of an increase in the variance of θ on the optimum price set by firm u in period 1 is:

$$\frac{\partial p_1^{u*}}{\partial \sigma_\theta^2} = \frac{16\delta\beta^2(\beta-\gamma)K_1^4K_2[4\beta K_1(4\beta^2+\beta\gamma-2\gamma^2)-K_5]a^*}{(un'-vs')^2} + \frac{16\delta^2\beta\gamma^3(\beta-\gamma)K_1^3K_4K_6a^*\sigma_\theta^2+2\delta^3\beta\gamma^3(\beta-\gamma)K_1K_4K_5a^*\sigma_\theta^4}{(un'-vs')^2} \tag{A.24}$$

Since $\beta > \gamma$, this derivative is positive and Proposition 4 has been proven. ▌

REFERENCES

Aghion, Philippe, María Paz Espinosa, and Bruno Jullien, 1993. Dynamic duopoly with learning through market experimentation. *Economic Theory* **3**, 517-539.

Bernhardt, Dan, and Bart Taub, 2015. Learning about common and private values in oligopoly. *RAND Journal of Economics* **46(1)**, 66-85.

Camerer, Colin F., and George Loewenstein, 2004. Behavioural economics: Past, present, future. In Advances in Behavioural Economics. Edited by Colin F. Camerer, George Loewenstein and Matthew Rabin, 3-11. Princeton, NJ: Princeton University Press.

Chaiken, Shelly, 1987. The heuristic model of persuasion. In Social Influence: The Ontario Symposium (Vol. 5, pp. 3-39). Edited by M. P. Zanna, J. M. Olson, and Z. P. Herman. Hillsdale, NJ: Lawrence Erlbaum Associates.

Chen, Yongmin, and Michael H. Riordan, 2008. Price-increasing competition. *RAND Journal of Economics* **39**, 1042-1058.

Eden, Benjamin, 1990. Marginal cost pricing when spot markets are complete. *Journal of Political Economy* **98**, 1293-1306.

Eden, Benjamin, 2009. Efficient barriers to trade: A sequential trade model with heterogeneous agents. *Journal of International Economics* **77**, 234-244.

Goldsbee, Austan, and Chad Syverson, 2008. How do incumbents respond to the threat of entry? Evidence from the major airlines. *Quarterly Journal of Economics* **123(4)**, 1611-1633.

Harrington, Joseph E., 1992. Uncertainty over product differentiation in a price-setting duopoly. *Economic Letters* **39**, 283-288.

Harrington, Joseph E., 1995. Experimentation and learning in a differentiated-products duopoly. *Journal of Economic Theory* **66**, 275-288.

Hauser, John R., and Steven M. Shugan, 1983. Defensive marketing strategies. *Marketing Science* **2(4)**, 319-360.

Kalnins, Arturs, 2006. Markets. The U.S. lodging industry. *Journal of Economic Perspectives* **20**, 203-218.

Keller, Godfrey, and Sven Rady, 2003. Price dispersion and learning in a dynamic differentiated-goods duopoly. *RAND Journal of Economics* **34**, 138-165.

Klemperer, Paul D., and Margaret A. Meyer, 1986. Price competition versus quantity competition: The role of uncertainty. *RAND Journal of Economics* **17**, 618-638.

Lucas, Robert E. Jr., and Michael Woodford, 1993. Real effects of monetary shocks in an economy with sequential purchases. NBER Working Papers 4250.

McCann, Brian T., and Govert Vroom, 2010. Pricing response to entry and agglomeration effects. *Strategic Management Journal* **31**, 284-305.

Mirman, Leonard J., Samuelson, Larry, and Amparo Urbano, 1993. Duopoly signal jamming. *Economic Theory* **3**, 129-149.

Ortoleva, Pietro, 2012. Modelling the change of paradigm: Non-Bayesian reactions to unexpected news. *American Economic Review* **102(6)**, 2410-2436.

Pawels, Koen, and Shuba Srinivasan, 2004. Who benefits from store brand entry? *Marketing Science* **23(3)**, 364-390.

Pazgal, Amit, , David Soberman,and Raphael Thomadsen, 2016. Profit increasing asymmetric entry. *International Journal of Research in Marketing* **33**, 107-122.

Reisinger, Markus, and Ludwig Ressner, 2009. The choice of prices versus quantities under uncertainty. *Journal of Economic & Management Strategy* **18**, 1155-1177.

Riordan, Michael H., 1985. Imperfect information and dynamic conjectural variations. *RAND Journal of Economics* **16**, 41-50.

Simon, Daniel, 2005. Incumbent pricing responses to entry. *Strategic Management Journal* **26**, 1229-1248.

Thomadsen, Raphael, 2007. Product positioning and competition: The role of location in the fast food industry. *Marketing Science* **26**, 792-804.

Ward, Michael B., Jay P. Shimshack, Jeffrey M. Perloff,and J. Michael Harris, 2002. Effects of the private-label invasion of food industries. *American Journal of Agricultural Economics* **84(4)**, 961-973.

Weatherford, Larry R., and Sheryl E. Kimes, 2003. A comparison of forecasting methods for hotel revenue management. *International Journal of Forecasting* **19(3)**, 401-415.

Wyer, Robert S., and Dolores Albarracín, 2014. Belief formation, organization and motivational influences. In The Handbook of Attitudes. Edited by Albarracín, D., Johnson, B.T. and Zanna, M.P. 2014. Psychology Press, New York.

Yamawaki, Hideki, 2002. Price reactions to new competition: A study of us luxury car market. 1986-1997. *International Journal of Industrial Organization* **20**, 19-39.