Learning through Experimentation in an Oligopoly Market with Asymmetric Information

Abstract

Unlike previous literature, in which firms compete in the market with the same information, this article analyses a two-period duopoly game in which only one firm is completely informed about the market conditions, whereas the other firm is unaware of one parameter of the demand curve. In this setting, we describe how the informed firm uses its price set in period 1 in order to reveal or to hide its private information and how the uninformed firm uses its own price in period 1 in order to learn the market conditions when they are not revealed by its rival. Specifically, we obtained the conditions under which the informed firm sets a higher price than its short-run optimum in the first period to hide its private information in certain cases and to reveal that information in others. Likewise, this paper describes the conditions under which the uninformed firm sets a lower price than its short-run optimum in period 1 in order to learn the unknown parameter. We found that the informed firm´s cost of revealing its private information to its rival is lower than the uninformed firm´s cost of learning the market conditions.

Keywords: learning through experimentation, pooling equilibrium, separating equilibrium, signalling game, undefeated equilibrium.

JEL Classification: D43, D82, L13.

I. INTRODUCTION

a) Motivation

The level of competition in a market depends on the degree of product differentiation, which is determined by consumers´ perceptions. For example, when consumers perceive the products on sale as perfect substitutes, firms´ prices tend to be as close as possible to the marginal cost. On the contrary, when products are perceived by consumers as highly differentiated, firms may set their prices above the marginal cost and make greater profits. Nowadays, consumers´ perceptions are highly influenced by influencers, social networks and other technological stimuli, which makes difficult to estimate the cross-price elasticity of demand. In spite of those difficulties, some firms have more information than others. For example, Davis (2007) showed that Tesco has a technological advantage in the ability to analyse customer data for targeted offers and for this reason, this company ends up with more data on joint customers compared to the rival.

This article analyses a two-period Hotelling´s duopoly model in which each firm is located at one extreme point of a unit-length line representing a street and both sell the same product. Consumers are distributed uniformly along that line and incur a transportation cost when buying the product from one of those firms. If the prices set by both firms are identical, a consumer will be more interested in buying the product from the closest firm when the transportation cost is positive, and both products will be perfect substitutes when the transportation cost is zero. For this reason, the transportation cost will be a measure of product differentiation in this model.

Assuming that each consumer buys only one unit of the product, there will always be a consumer located at a particular point of the unit-length line who will be indifferent as to whether to buy the product from one firm or from its rival, given the prices set by each.

Then, those consumers located on the left of that indifferent consumer will buy the product from the firm located at left extreme point of the street, whereas those located on the right will buy the product from the other. In this way, we obtain each firm´s demand, but that demand will be subject to a random variation or *shock* in each period, which cannot be observed by firms. In this context, both firms will compete for customers by simultaneously setting their prices in each period.

Previous literature usually assumes that either both firms know the transportation cost or none of the firms knows that parameter. However, in this paper we will introduce asymmetric information. In particular, we will assume that only one firm knows the transportation cost. In period 1, each firm sets its price, given its own information. In the second period, firms observe the prices set in the previous period and their own quantity sold before choosing their prices.

In our model, the uninformed firm will use the price set by its rival in period 1 to infer the unknown parameter in period 2. For this reason, the informed firm will have to decide whether to set its short-run optimum price in period 1, revealing its private information, or to set a suboptimal price, hiding its information from its rival. Setting suboptimal prices in the short-run in order to hide private information is usually called *signal jamming*. Our results suggest that the informed firm will hide its private information from its rival in period 1 when it is sufficiently patient. Specifically, when the discount factor (δ in our model) is sufficiently high, the informed firm´s additional discounted profit in period 2 will be greater than the cost of signal jamming in period 1. However, when the prior probability of a low transportation cost (ϕ in our model) is sufficiently high, we will show that the uninformed firm will be too competitive in period 1. As a result, the informed firm´s cost of setting a high price in period 1 in order to hide its private information will be too high and consequently, signal jamming will never be profitable irrespective of the discount factor.

The assumptions of our model will also allow us to understand how firms may set a short-run suboptimal price in period 1 so that the uninformed firm learns the true value of the transportation cost before choosing its price in period 2. Setting suboptimal prices in the short-run in order to make a firm aware of some parameter of the demand curve is usually called *learning through experimentation*. Thus, unlike previous literature, our model will study the effects of the interaction between signal jamming and learning through experimentation. According to our results, the informed and uninformed firms will produce learning in period 1 when it is sufficiently patient. Specifically, when the discount factor (δ in our model) is sufficiently high, the informed firm´s additional discounted profit in period 2 will be greater than the cost of producing learning in period 1. However, when the prior probability of a low transportation cost (ϕ in our model) is either too low or too high, the cost of learning will always be greater than the additional profit from doing so irrespective of the discount factor.

In our paper, we use two critical concepts: experimentation and learning through experimentation. We follow Datta et al. (1998), who defined experimentation as taking some action to alter the distribution of posterior beliefs. In our model, the action through which firms may alter the distribution of posterior beliefs is a short-run suboptimal price in period 1. Additionally, if setting a suboptimal price in a one-shot game in period 1 leads to a non-degenerate distribution of posterior beliefs in period 2, we will say that firms are producing learning through experimentation. In other words, if one of the firms manipulates its price in period 1 and after that manipulation, the uninformed firm believes that the transportation cost is high or low in our model, we will conclude that there is learning through experimentation.

The concept of informative experimentation we will use is similar to that firstly introduced by Blackwell (1951). According to this concept, an experiment will be more informative on a variable than another providing that the set of values that the variable can take under the first experiment includes the set of values that the variable can take under the second. In our model, when a firm sets the price that produces learning through experimentation, the quantity sold by firm 2 in period 1 can take a set of values, which includes the set of values taken by that quantity sold without the price that produces learning. However, as we assume that the random shock of the market demand curves has a uniform distribution, firms will learn either everything or nothing in our model, which is the same assumption as that introduced by Aghion *et al.* (1993).

In games with asymmetric information, a certain characteristic of one of the players is unknown to another player. As a result, two strategies will arise to solve the problems caused by asymmetric information: *signalling* and *screening*. When the informed agent makes a decision to reveal its private information to the uninformed agent, the informed player is using *signalling* to address the problem caused by asymmetric information. In models of signalling, the informed player signals its private information when each type of informed player makes a different decision. In our model, we say that there is signalling when each type of informed firm sets a different price, that is, when the price set by firm 1 in period 1 depends on the transportation cost. Nevertheless, when it is the uninformed player who designs some kind of mechanism in order to make its rival reveal his or her hidden characteristic, it is said that the uninformed player is using *screening*. In our model, not only may the informed firm signal the unknown parameter through its price set in period 1, but the uninformed firm may also set a short-run suboptimum price in period 1 in order to incentivize its rival to reveal its private information in that period. In the latter case, the price set by the uninformed firm in period 1 will be the mechanism used to make its rival reveal the true value of the unknown parameter in period 1. Although both firms set their prices simultaneously in period 1, the discount factor is common knowledge in our model. For this reason, both firms are able to anticipate whether the discount factor is sufficiently high so that their rivals find it profitable to produce learning through experimentation. As a result, if the discount factor is not sufficiently high and firm 2 sets its non-experimenting price in period 1, we will show that firm 1 will have incentives to produce learning revealing the unknown parameter. Therefore, we study a situation in which *signalling* and *screening* are possible at the same time.

The equilibrium of our model must specify the prices set by both firms in both periods. Additionally, after observing the informed firm´s price in period 1, the uninformed rival will form certain beliefs about the unknown parameter. The concept of equilibrium used will be a *sequential equilibrium*.

As this concept imposes no requirements on the beliefs outside the equilibrium path, there are multiple equilibria. Therefore, we will use the refinement defined by Mailath et al (1993) in order to select a unique equilibrium.

b) Related literature and contribution of the model

Previous theoretical research has analysed *learning through experimentation* in oligopolistic markets where all firms have the same information on the market conditions.

In particular, Aghion et al. (1993) used a two-period Hotelling´s duopoly model, in which none of the firms knows the transportation cost. These authors found that when firms are sufficiently patient (they value future profits sufficiently), the prices set by both firms in period 1 will be different in order to learn the true value of the transportation cost. Likewise, when the demand is too volatile, firms do not set different prices because that kind of experimentation is too costly.

A more flexible duopoly model, with infinite periods, was introduced by Harrington (1992). In this model, firms are uncertain about whether the products sold by both rivals are homogeneous or slightly different. This author found that firms tend to set the same price for fear of learning that the products are homogeneous.

Similarly, Harrington (1995) developed a two-period duopoly model with linear demand curves in which firms are unaware of the cross-price elasticity of demand. When the expected value of this parameter is sufficiently low, Harrington (1995) showed that the difference between the prices set by both competitors in period 1 is higher with demand uncertainty than with perfect information. The opposite occurs when the expected value of the cross-price elasticity of demand is sufficiently high.

Likewise, Keller and Rady (2003) proposed a similar model to that introduced by Harrington (1995), but they assumed that the cross-price elasticity of demand can change over time with an infinite horizon. When this parameter changes sufficiently often, Keller and Rady (2003) found that firms set different prices in order to learn the true value of the unknown parameter.

Another branch of theoretical literature, on the effects of demand uncertainty on firm´s pricing policies in oligopolistic markets, is referred to as *signal jamming* (Riordan 1985; Mirman, Samuelson and Urbano 1993; Bernhardt and Taub 2015). These authors analysed how firms make suboptimum decisions in order to conceal the value of an unknown parameter of the market demand curve from their rivals. The results show that, when firms cannot observe the level of demand, they will set a higher price with imperfect information than with perfect information so that their rivals believe that the demand is higher than it actually is.

The contribution of this paper to previous theoretical literature is threefold. First, in all papers mentioned, none of the firms in the market can observe a parameter of the market demand curve, and none of them has better information than the others. However, in certain real markets, some of the firms might have informational advantages. For this reason, we introduce asymmetric information in a Hotelling´s model in which only one firm knows the transportation cost. Those models with symmetric information usually obtain an equilibrium in mixed strategies. In this equilibrium, firms generate price dispersion by randomly setting their prices within a certain interval in order to produce *learning through experimentation*, but these models do not specify whether firms should increase or decrease their price to learn the unknown parameter. On the contrary, asymmetric information may give rise to an equilibrium in pure strategies. In this equilibrium, the informed firm needs to increase its price in order to produce *learning through experimentation*, whereas the uninformed firm needs to reduce its price. In our equilibria with pure strategies, price dispersion between firms can be measured as the difference between the prices set by both firms. However, in the equilibria in mixed strategies obtained with symmetric information, the difference between the prices set by both firms only represents a specific realization of that dispersion because firms randomly set their prices around an interval.

Second, unlike previous studies, which only analysed either *signal jamming* or *learning through experimentation,* in our model, the informed firm may choose a short-run suboptimum price not only to hide its private information, but also to allow its rival to learn the unknown parameter of the market demand curve. Thus, we study the interaction between *signal jamming* and *learning through experimentation*.

Third, although previous literature has analysed the effects of *signalling* or *screening* on a wide range of economic situations[1], those models only studied one of those phenomena.

However, in our model, not only will the informed firm be able to use *signalling* to convey its private information, but also the uninformed firm will be able to design a mechanism in order to make its rival reveal its private information. Hence, both *signalling* and *screening* are possible in our model.

This article is organized as follows. The next section describes the model. Later, section III will determine the conditions under which a pooling or a separating equilibrium arises and proves the uniqueness of our equilibrium outcomes when the demand *shock* may take values within such a wide interval that there is no learning through experimentation. Section IV analyses the equilibria obtained when the demand *shock* may only take values within a narrower interval and obtains the conditions under which there will be *learning through experimentation*. Section V summarizes the main conclusions. The Appendix includes all the proofs of the propositions and theorems obtained.

II. THE MODEL

At this point, we introduce the Hotelling model used. Assume that there is a line of unit length (say 1 mile) along which N consumers are uniformly distributed and that this market is supplied by two risk-neutral firms: firms 1 and 2. Firm 1 is located at the west end of town, whereas firm 2 is located at the east end and they cannot change their locations because they find it prohibitively expensive to do so. We define a consumer location in this market to be that consumer´s preferred product or style. Thus, "consumer x" is located distance x from the left-hand end of the market, where distance may be geographic in a spatial model or measured in terms of characteristics in the sense of product differentiation. Although consumers differ regarding which variant or location of the good is the best or ideal product, they are identical in that they assign the same reservation price V to their preferred product. Each consumer is assumed to buy a maximum of one unit of the product. As usual, if "consumer x" purchases a good that is not her ideal product, a utility loss or a cost equal to Rx will be incurred when good 1 is consumed, and a cost equal to $R(1-x)$ when good 2 is consumed, where $R = \{L, H\}$, and $H > L > 0$. In this set-up, R is the transportation cost[2] and can take only two values. This parameter represents the degree of product differentiation. Then, if "consumer x" buys good 1 at price p_t^1 in period t, there will be a consumer surplus of $V - p_t^1 - Rx$ and if good 2 is purchased at price p_t^2 in period t, there will be a consumer surplus of $V - p_t^2 - R(1-x)$. Of course, the good purchased will be that which offers the greatest consumer surplus provided that this is greater than zero. Both firms compete for customers by simultaneously setting prices in a stable market in two consecutive periods (i.e., we assume that R does not change over time). Each firm has a constant unit cost of production equal to c. It is assumed that V is substantially greater than the unit cost of production c. Moreover, the discount factor, which is δ, is the same for both firms and is common knowledge.

Let x^m be a marginal consumer who is indifferent to buying from firm 1 or firm 2 (i.e., she enjoys the same consumer surplus either way). Algebraically, this means that for consumer x^m

$$V - p_t^1 - Rx^m = V - p_t^2 - R(1 - x^m) \qquad (1)$$

This equation may be solved to find the location of the marginal consumer. This location is

$$x_t^m(p_t^1, p_t^2) = \frac{p_t^2 - p_t^1 + R}{2R} \qquad (2)$$

At any set of prices, p_t^1 and p_t^2, all the consumers to the left of x_t^m buy from firm 1 in period t. All those to the right of x_t^m buy from firm 2 in period t. Thus, x_t^m is the fraction of the market that buys from firm 1 and $(1 - x_t^m)$ is the fraction that buys from firm 2. If the total number of permanent consumers is N and they are uniformly distributed over the market space, the demand functions facing firms 1 and 2 in period *t* in any combination, (p_t^1, p_t^2), in which the entire market is served is

$$D_t^1(p_t^1, p_t^2) = \frac{(p_t^2 - p_t^1 + R)}{2R} N + \varepsilon_t^1 \quad (3)$$

$$D_t^2(p_t^1, p_t^2) = \frac{(p_t^1 - p_t^2 + R)}{2R} N + \varepsilon_t^2 \quad (4)$$

where ε_t^1 and ε_t^2 are specific and independent demand shocks with a uniform distribution function. In particular, the distribution of each ε_t^j is $U(-\bar{\varepsilon}, \bar{\varepsilon})$ for $j = \{1,2\}$, where $\bar{\varepsilon}$ is greater than zero. $\bar{\varepsilon}$ and $-\bar{\varepsilon}$ represent the maximum value and the minimum values that the demand shock can take. These demand shocks might represent temporary consumers, such as tourists arriving at the city in each period. For example, ε_t^1 would represent those tourists who stayed in period *t* at those hotels to the left of x_t^m, whereas ε_t^2 would represent those tourists who stayed in period *t* at those hotels to the right of the marginal consumer. If the Hotelling´s line represented the proportion of attributes preferred by each consumer rather than a spatial location, the interpretation of those random shocks would be similar.

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 1 (the informed one) can observe R, but firm 2 (the uninformed one) cannot. It is common knowledge that the prior probability of R being equal to *L* is ϕ.

Firms´ information in period 2. Before choosing its price in period 2, each firm observes the prices chosen in period 1, p_1^1, p_1^2, and its own quantity sold in that period, but neither of the firms can observe its rival´s quantity sold in period 1[3].

The following sections show the sequential equilibria of our game as defined by Kreps and Wilson (1982). A sequential equilibrium for our signalling game will be a triple of strategies and beliefs that satisfy the following conditions:

1. Sequential rationality: For each *R*, the informed firm should set prices in periods 1 and 2 that maximize its total profit given the prices set in periods 1 and 2 by the uninformed firm. Additionally, the uninformed firm should set prices in periods 1 and 2 that maximize its total profit given its posterior beliefs about the unknown parameter and the prices set by its rival.
2. Consistency: In the equilibrium path, the uninformed firm´s beliefs about the unknown parameter should be calculated using Bayes´s rule.

As there can be multiple sequential equilibria, we choose the unique undefeated equilibrium of our model using the refinement developed by Mailath, Okuno-Fujiwara, and Postlewaite (1993).

III. PRICING POLICIES WITHOUT LEARNING THROUGH EXPERIMENTATION

In this section, we will present firms´ pricing policies when the uninformed firm cannot learn the true value of the unknown parameter even though firms set a short-run suboptimal price in period 1. In this context, we identify two types of equilibria: a separating and a pooling equilibrium. Then, we will characterize the conditions under which one of those equilibria will be the unique equilibrium selected by the refinement introduced by Mailath et al. (1993).

There are two ways of generating learning through experimentation in this market. First, the informed competitor can set a sufficiently high price in period 1 given the optimum price set by its rival. Second, the uninformed firm can set a sufficiently low price in period

1 given the optimum price set by its rival. In both cases, as shown by equation (4), firm 2 will sell a greater quantity with a low transportation cost than with a high cost even if the random shock, ε, takes its minimum value, $-\bar{\varepsilon}$, in the former case and its maximum value, $\bar{\varepsilon}$ in the latter case. Therefore, the competitor which generates learning through experimentation needs to set a short-run suboptimal price in period 1 to do so and consequently, it will incur a cost in that period. When $\bar{\varepsilon} > \frac{(H-L)N\left[(\hat{R}-L)+\sqrt{(\hat{R}-L)(3\hat{R}+L)}\right]}{8L\hat{R}}$, the price that each firm should set in period 1 is so different from its short-run optimum price that no firm will want to assume that learning cost[4], where $\hat{R} = \phi H + (1-\phi)L$. In this section, we analyse a market in which $\bar{\varepsilon} > \frac{(H-L)N\left[(\hat{R}-L)+\sqrt{(\hat{R}-L)(3\hat{R}+L)}\right]}{8L\hat{R}}$ and there is no learning through experimentation.

Without learning through experimentation, when the transportation cost is low, the informed firm will have to choose whether to reveal its private information to its rival in period 1 by simply setting its short-run optimal price, or to hide that information from its rival by setting the price it would have set if the transportation cost had been high. Hence, there will be two potential candidates for equilibria in pure strategies[5]: a separating and a pooling equilibrium.

In our first result, we characterize both types of equilibria obtained in our model.

Proposition 1. When $\bar{\varepsilon} > \frac{(H-L)N\left[(\hat{R}-L)+\sqrt{(\hat{R}-L)(3\hat{R}+L)}\right]}{8L\hat{R}}$*, a separating or a pooling equilibrium may arise. In the separating equilibrium, the price set by the informed firm in period 1 will be* $p_1^{1B}(L) = c + \frac{L\hat{R}+LH}{2\hat{R}}$ *if* $R = L$ *and* $p_1^{1B}(H) = c + \frac{H\hat{R}+LH}{2\hat{R}}$ *if* $R = H$*, whereas the price set by the uninformed firm in period 1 will be* $p_1^{2B} = c + \frac{LH}{\hat{R}}$ *irrespective of the transportation cost. In period 2, the prices set by* *both firms will be* $p_2^{1Bf}(L) = p_2^{2Bf}(L) = c + L$ *if* $R = L$ *and* $p_2^{1Bf}(H) = p_2^{2Bf}(H) = c + H$ *if* $R = H$. *The uninformed firm´s beliefs in period 1 will be given by the following equation:*

$$\hat{\phi} = \begin{cases} 0 \; if \; p_1^1 \geq p_1^{1B}(H) \\ 1 \; if \; p_1^1 < p_1^{1B}(H) \end{cases} \qquad (5)$$

In the pooling equilibrium, the price set by the informed firm in period 1 will be $p_1^{1B}(H) = c + \frac{H\hat{R}+LH}{2\hat{R}}$*, whereas the price set by the uninformed firm will be* $p_1^{2B} = c + \frac{LH}{\hat{R}}$. *These prices will be the same, irrespective of the transportation cost. In period 2, the price set by the informed firm will be* $p_2^{1B}(L) = c + \frac{L\hat{R}+LH}{2\hat{R}}$ *if* $R = L$ *and* $p_2^{1B}(H) = c + \frac{H\hat{R}+LH}{2\hat{R}}$ *if* $R = H$, *whereas the price set by the uninformed firm will be* $p_2^{2B} = c + \frac{LH}{\hat{R}}$*, irrespective of the transportation cost. The uninformed firm´s beliefs in period 1 will be given by the following equation:*

$$\hat{\phi} = \begin{cases} \phi \; if \; p_1^1 \geq p_1^{1B}(H) \\ 1 \; if \; p_1^1 < p_1^{1B}(H) \end{cases} \qquad (6)$$

It is easy to understand the intuition of each equilibrium[6]. In the separating equilibrium, in period 1 the informed firm sets a low price ($p_1^{1B}(L)$) when the transportation cost is low and a high price ($p_1^{1B}(H)$) when the transportation cost is high. For this reason, after observing the price set by the informed firm, the uninformed one learns the transportation cost and both firms compete in period 2 by setting their optimal one-shot prices with perfect information. These prices are $p_2^{Bf}(L) = c + L$ *if* $R = L$ *and* $p_2^{Bf}(H) = c + H$ *if* $R = H$. Thus, if the price set by the informed firm in period 1 is high ($p_1^{1B}(H)$), the uninformed firm believes that the transportation cost is high ($\hat{\phi} = 0$). Nevertheless, if the price set by the informed firm is lower than $p_1^{1B}(H)$, its rival believes that the transportation cost is low ($\hat{\phi} = 1$).

In the pooling equilibrium, the informed firm will set a high price in period 1, $p_1^{1B}(H)$, whatever the true value of the transportation cost. For this reason, the uninformed firm does not learn the unknown parameter after observing the price set by its rival in period 1, that is, the posterior beliefs are equal to the prior beliefs in this equilibrium ($\hat{\phi} = \phi$). As a result, the uninformed firm will set the same high price in both periods, $p_1^{2B} = p_2^{2B}$, because its information does not change over time. However, in period 2 the informed firm will take advantage of its better information by setting its short-run optimum price for each value of the transportation cost, meaning that the price is $p_2^{1B}(L)$ if the transportation cost is low and $p_2^{1B}(H)$ if it is high.

Now, we can present one of our main results, which addresses the market conditions under which a pooling or a separating equilibrium arises.

Theorem 1. When $\bar{\varepsilon} > \frac{(H-L)N\left[(\hat{R}-L)+\sqrt{(\hat{R}-L)(3\hat{R}+L)}\right]}{8L\hat{R}}$, *there will be a value of the discount factor,* $\bar{\delta}$, *which increases with* ϕ, *such that the pooling equilibrium will be the unique undefeated equilibrium of the model, provided that* $\delta > \bar{\delta}$, *whereas the separating equilibrium will be the unique undefeated equilibrium of the model when* $\delta < \bar{\delta}$. *Additionally, there will be a value of the prior probability of a low transportation cost,* $\bar{\phi}$, *in such a way that when* $\phi > \bar{\phi}$, *the unique undefeated equilibrium will be the separating equilibrium, regardless of the discount factor.*

Figure 1 shows the regions in which there will be a pooling or a separating equilibrium, depending on ϕ and δ, when L=1 and H=2. This figure is the representation of $\bar{\delta}^B(\hat{R})$ from equation (A.10) as a function of ϕ when L=1 and H=2. The grey shaded area represents the values of ϕ and δ for which we obtain a pooling equilibrium ($\delta > \bar{\delta}$ and $\phi < \bar{\phi}$), whereas the blue shaded area represents the values of ϕ and δ for which a separating equilibrium arises ($\delta < \bar{\delta}$ or $\phi > \bar{\phi}$).

To understand this theorem, imagine that the transportation cost is low. In this case, the informed firm will have two options in period 1: revealing its private information by setting a low price ($p_1^{1B}(L)$ in the separating equilibrium), or concealing its information by setting a high price ($p_1^{1B}(H)$ in the pooling equilibrium). In the latter case, the informed firm will incur a cost in period 1 because its rival sets a lower price than the high price the informed firm has to set to conceal its information ($p_1^{2B} < p_1^{1B}(H)$). This cost of hiding information may be measured as the profit obtained by firm 1 in period 1 when it sets the low price, minus the profit made by that firm when it sets the high price (difference between equations (A.7) and (A.5)). Nevertheless, the informed firm will also obtain a higher profit in period 2 because its rival will set a higher price in that period (p_2^{2B} in the pooling equilibrium) than the price it would set if it knew that the transportation cost is low ($p_2^{2Bf}(L)$ in the separating equilibrium). This additional profit from hiding information can be measured as the profit made by firm 1 in period 2 when it sets the price of the pooling equilibrium, minus the profit made by that firm when it sets the price of the separating equilibrium (difference between equations (A.6) and (A.8)). Hence, the informed firm will find it profitable to conceal its private information in period 1 whenever its additional profit from doing so is greater than its cost (see inequality (A.9) in the appendix).

Now, we can understand the impact of a change in ϕ on the informed firm´s incentives to hide its information in period 1 when the transportation cost is low. For example, when the prior probability of a high transportation cost is greater (i.e., when ϕ decreases in Figure 1), the informed and uninformed firms will set higher prices in period 1 in the pooling equilibrium because $\frac{\partial p_1^{1B}(H)}{\partial \phi} < 0$ and $\frac{\partial p_1^{2B}}{\partial \phi} < 0$. As the difference between the prices set by both firms in period 1 does not change, the informed firm´s cost of concealing its information in the first period (difference between equations (A.7) and (A.5)) does not depend on ϕ. Additionally, firm 2 will set a higher price in period 2 when ϕ decreases because $\frac{\partial p_2^{2B}}{\partial \phi} < 0$. For this reason, the informed firm will be able to attract more customers from its rival by setting a low price, $p_2^{1B}(L)$, and its additional profit in period 2 from hiding its information (difference between equations (A.6) and (A.8)) will increase when ϕ decreases. As a result of the same cost in period 1 and the higher profit in period 2, the minimum discount factor to obtain a pooling equilibrium will be lower when ϕ decreases (equation (A.11) in the appendix shows that $\frac{\partial \bar{\delta}^B(\hat{R})}{\partial \phi} > 0$).

Nevertheless, when the prior probability of a low transportation cost is sufficiently high ($\phi>\bar{\phi}$), the uninformed firm will fiercely compete in periods 1 and 2 with a lower price. Consequently, the informed firm´s additional profit in period 2 (difference between equations (A.6) and (A.8)) will not be high enough to compensate the cost of hiding its information in period 1 (difference between equations (A.7) and (A.5)). For this reason, when $\phi>\bar{\phi}$, the separating equilibrium will always arise as shown in Figure 1.

Place Figure 1 about here

IV. PRICING POLICIES WITH LEARNING THROUGH EXPERIMENTATION

In this section we analyse our model when $\bar{\varepsilon} < \frac{(H-L)N\left[(\hat{R}-L)+\sqrt{(\hat{R}-L)(3\hat{R}+L)}\right]}{8L\hat{R}}$, that is, when there can be learning through experimentation in the market. Here, we restrict our attention to the region of the pooling equilibrium previously described and determine the conditions under which each firm has incentives to generate sufficient price dispersion in period 1, so that firm 2 becomes informed in period 2.

a) Informed firm´s incentives to produce learning through experimentation

We begin by considering the price that firm 1 has to choose in period 1 in order to make its rival learn the transportation cost, given the fact that firm 2 is setting its optimal price obtained in our pooling equilibrium. As shown by equation (4), if the price set by firm 1 is sufficiently higher than its rival´s price, the quantity sold by firm 2 will always be higher when $R = L$ than when $R = H$ even if ε_1^2 takes its extreme values. In this case, firm 2 will learn the value of *R* by observing its quantity sold in period 1. Hence, if firm 1 wants its rival to learn *R*, it will have to set a price in period 1, p_1^{1L}, so that the next condition is satisfied:

$$D_1^2(p_1^{1L}, p_1^{2B} | R = L, \varepsilon_1^2 = -\bar{\varepsilon}) = D_1^2(p_1^{1L}, p_1^{2B} | R = H, \varepsilon_1^2 = \bar{\varepsilon}) \qquad (7)$$

Then, the minimum price firm 1 has to choose in period 1, so that firm 2 becomes informed, is:

$$p_1^{1L} = c + \frac{LH}{\hat{R}} + \frac{4LH\bar{\varepsilon}}{(H-L)N} \qquad (8)$$

Therefore, firm 1 needs to create a sufficiently high price dispersion between firms in period 1 in order to generate learning in the market. The price given by equation (8) decreases with ϕ. In fact, when the prior probability of a low transportation cost increases, firm 2 will set a lower price in period 1 and consequently, firm 1 will not need to increase its price above its optimum price so much in order to create sufficient price dispersion in the market.

Now, we need to determine the values of $\bar{\varepsilon}$ under which there can be learning through experimentation in this model. It would be possible that the price set by firm 1 in period 1 in the pooling equilibrium reveals its private information to its rival when the transportation cost is high, in which case firm 1 would not need to manipulate its price in order to make its rival learn R and consequently, learning through experimentation will not be necessary. Specifically, if the price described in equation (8) were lower than the price set by firm 1 in the pooling equilibrium when $R = H$, firm 1 would not need to set a short-run suboptimum price in order to make its rival learn the transportation cost. Hence, in order to introduce learning through experimentation in the model, we assume that $p_1^{1L} = c + \frac{LH}{\hat{R}} + \frac{4LH\bar{\varepsilon}}{(H-L)N} > p_1^{1B}(H) = c + \frac{H\hat{R}+LH}{2\hat{R}}$, which is equivalent to $\bar{\varepsilon} > \frac{(H-L)(\hat{R}-L)N}{8L\hat{R}}$. If $\bar{\varepsilon} > \frac{(H-L)(\hat{R}-L)N}{8L\hat{R}}$, firm 1 will need to choose a suboptimal decision in the one-period game in order to produce learning in the market. In other words, firm 1 will incur a cost in period 1 in order to produce learning in the market.

In the previous section, the presence of ε_1^2 prevents firm 2 from learning the transportation cost merely by observing its quantity sold in period 1. For example, imagine that firm 1 sets a higher price than its rival in period 1. According to equation (4), given a quantity sold by firm 2, there will be a value of ε_1^2, which gives rise to that quantity sold when $R = L$, and a value of ε_1^2, which gives rise to the same quantity sold when $R = H$. As the distribution of this random shock is uniform, both values of ε_1^2 are equally likely and for this reason, the quantity sold provides no new information on R. Unlike in the previous section, we will now assume that $\bar{\varepsilon} < \frac{(H-L)N\left[(\hat{R}-L)+\sqrt{(\hat{R}-L)(3\hat{R}+L)}\right]}{8L\hat{R}}$ so that there can be learning through experimentation.

Additionally, we assume that firm 1 will sell a positive quantity when it sets the price given by equation (8). If we substitute R with H, p_t^1 with the price described in equation (8) and p_t^2 with p_1^{2B} in the demand equation (3), we obtain the expected quantity sold by firm 1 in period 1 when it sets the price that produces learning and its rival sets the price of the pooling equilibrium, which is $E(q_1^{1L}|R = H) = \frac{(H-L)N-4L\bar{\varepsilon}}{2N(H-L)}$. As the denominator is always positive, this quantity sold will be positive whenever the numerator is positive, that is, whenver $\bar{\varepsilon} < \frac{(H-L)N}{4L}$. As $\frac{(H-L)N}{4L} < \frac{(H-L)N\left[(\hat{R}-L)+\sqrt{(\hat{R}-L)(3\hat{R}+L)}\right]}{8L\hat{R}}$, there might be learning through experimentation whenever the following assumption is satisfied:

A.1. $\frac{(H-L)(\hat{R}-L)N}{8L\hat{R}} < \bar{\varepsilon} < \frac{(H-L)N}{4L}$.

The next proposition depicts firm 1´s incentives to make its rival learn the unknown parameter, given that firm 2 is behaving in period 1 as shown by the pooling equilibrium described by proposition 1. In that pooling equilibrium, when $\mathrm{R} = \mathrm{L}$, firm 1 hides the true value of the transportation cost from its rival. For this reason, when $\mathrm{R} = \mathrm{H}$, firm 1 needs to set the price described by equation (8) to produce learning and proposition 2 shows the conditions under which this happens.

Proposition 2. Under assumption A.1, when $R = H$, there will be two values of the prior probability of a low transportation cost, ϕ_1, ϕ_2, and a value of the discount factor, $\bar{\bar{\delta}}$, which depends on ϕ, such that firm 1 will produce learning through experimentation in period 1 if, and only if $\phi_1 < \phi < \phi_2$ and $\delta > \bar{\bar{\delta}}$. When $R = H$ and firm 1 produces learning through experimentation, the price set by firm 1 in period 1 is $p_1^{1L} = c + \frac{LH}{\hat{R}} + \frac{4LH\bar{\varepsilon}}{(H-L)N}$, whereas the price set by firm 2 will be $p_1^{2B} = c + \frac{LH}{\hat{R}}$. In period 2, the price set by both firms is the same and is equal to $p_2^{Bf}(H) = c + H$.

Figure 2 helps us to understand the intuition behind this result. This figure shows the regions described by this proposition when *H=2*, *L=1* and $\bar{\varepsilon} = 1.5$ for relevant values of ϕ. The blue line represents the minimum discount factor so that firm 1 wants to generate learning in the market for each value of ϕ ($\bar{\bar{\delta}}(\hat{R})$ in equation (A.17)), whereas the red line describes the minimum discount factor needed to obtain the pooling equilibrium ($\bar{\delta}^B(\hat{R})$ in equation (A.10)), which is a copy of the line represented in figure 1. The blue line decreases with ϕ. In fact, when ϕ decreases, it means that firm 2 is more confident of a high transportation cost in period 1 and then, it will set a higher price because $\frac{\partial p_1^{2B}}{\partial \phi} < 0$. As a result, this price will be closer to the price set by firm 1 in period 1 in the pooling equilibrium ($p_1^{1B}(H)$) when the transportation cost is high. For this reason, the informed competitor will need to deviate by more from that short-run optimal price in period 1 in order to create sufficient price dispersion. Thus, the profit lost from generating learning in period 1 (difference between equations (A.14) and (A.12)) increases, which explains why the minimum discount factor for firm 1 to have incentives to generate learning increases when ϕ decreases, that is, $\frac{\partial \bar{\bar{\delta}}(\hat{R})}{\partial \phi} < 0$.

In figure 2, we have removed those regions in which ϕ is too low or too high. When the prior probability of a low transportation cost is below the region shown in this figure, in period 1 the uninformed competitor will set a price too close to that set by firm 1 in the pooling equilibrium because $\frac{\partial p_1^{2B}}{\partial \phi} < 0$. Then, firm 1 will have to deviate too much from its short-run optimal price in period 1 ($p_1^{1B}(H)$) in order to generate sufficient price dispersion and make its rival become informed. It means that the profit lost from generating learning in period 1 (difference between equations (A.14) and (A.12)) is higher than the additional profit obtained in period 2 (difference between equations (A.13) and (A.15)) and consequently, the informed firm will never find it profitable to generate learning through experimentation when ϕ is too close to zero. On the other hand, when the prior probability of a low transportation cost is above the region shown in Figure 2 ($\phi > \bar{\phi} = \phi_2$), the separating equilibrium will always be obtained, as shown in theorem 1, and no experimentation is necessary in period 1.

In figure 2, firm 1 will only have incentives to generate learning through experimentation whenever δ is above the blue line ($\delta > \bar{\bar{\delta}}(\hat{R})$). When δ is below the red line ($\delta < \bar{\delta}^B(\hat{R})$), the separating equilibrium will arise and no experimentation will be necessary. Thus, firm 1 will generate learning in the market when δ is above both curves ($\delta > max\{\bar{\bar{\delta}}(\hat{R}), \bar{\delta}^B(\hat{R})\}$).

Place Figure 2 about here

b) Firm 2´s incentives to produce learning through experimentation

Once again, let us assume that we are in the region of the pooling equilibrium described by Proposition 1. Next, we analyse the uninformed firm´s incentives to learn the true value of the transportation cost by setting a short-run suboptimal price in period 1, given that its rival is not generating learning in the market. To learn the unknown parameter, the price set by firm 2 must be sufficiently lower than its optimum price in period 1. In this way, firm 2 will generate sufficient price dispersion in the market. Then, since firm 1 is setting its price considered in the pooling equilibrium, $p_1^{1B}(H)$, the price set by firm 2 in order to learn the unknown parameter, p_1^{2L}, must satisfy:

$$D_1^2[p_1^{1B}(H), p_1^{2L}|R = L, \varepsilon_1^2 = -\bar{\varepsilon}] = D_1^2[p_1^{1B}(H), p_1^{2L}|R = H, \varepsilon_1^2 = \bar{\varepsilon}] \qquad (9)$$

Thus, the price that firm 2 has to set to learn the transportation cost in period 1 is:

$$p_1^{2L} = c + \frac{H(L+\hat{R})}{2\hat{R}} - \frac{4LH\bar{\varepsilon}}{(H-L)N} \qquad (10)$$

It is easy to see that assumption A.1 also forces the uninformed firm to set a lower price in period 1 than the price of the pooling equilibrium in order to learn R ($p_1^{2L} < p_1^{2B}$).

The next proposition analyses the conditions under which the uninformed firm will generate learning through experimentation in this oligopoly in the region of the pooling equilibrium, given the fact that the informed firm does not experiment. In the region of the separating equilibrium shown by theorem 1, the price set by firm 1 in period 1 reveals the true value of the unknown parameter and firm 2 does not need to experiment in the market.

Proposition 3. Under assumption A.1, there will be two values of the prior probability of a low transportation cost, ϕ^- *and* ϕ^+*, and a value of the discount factor,* $\underline{\delta}^{2L}$*, which depends on* ϕ*, so that firm 2 will generate learning through experimentation provided that* $\phi^- < \phi < \phi^+$ *and* $\delta > \underline{\delta}^{2L}$*. When only firm 2 produces learning through experimentation, the price set by firm 1 in period 1 is* $p_1^{1B}(H) = c + \frac{H\hat{R}+LH}{2\hat{R}}$ *and the price set by firm 2 is* $p_1^{2L} = c + \frac{H(L+\hat{R})}{2\hat{R}} - \frac{4LH\bar{\varepsilon}}{(H-L)N}$*. In period 2, the price set by both firms is the same and is equal to* $p_2^{Bf}(H) = c + H$*.*

The intuition of this proposition is easy to understand. On the one hand, firm 2 has to set a price below its short-run optimum price in period 1 to learn the transportation cost ($p_1^{2L} < p_1^{2B}$). Consequently, firm 2 incurs the cost of such a suboptimal decision in period 1 (difference between (A.24) and (A.20)). On the other hand, firm 2 will make a greater profit in period 2 when it learns the unknown parameter. This additional profit is measured as the difference between equations (A.21) and (A.27). Therefore, firm 2 will find it profitable to learn the demand parameter whenever the discounted additional expected profit in period 2 is greater than the cost in period 1, that is, whenever $\delta > \underline{\delta}^{2L}(\hat{R})$.

Now, let us explain why firm 2 fails to generate learning through experimentation when ϕ is too low or too high. A change in the prior probability of a low transportation cost will affect the uninformed firm´s profit and cost of learning as follows. Let us start analysing firm 2´s profit. The uninformed firm will only benefit from learning the transportation cost in period 2 when it is high. Otherwise, learning the transportation cost would increase competition in the market and reduce firms´ profits. Firm 2´s expected profit from learning will be equal to ϕ multiplied by the loss from learning the transportation cost when it is low, which is the difference between equation (A.21) when $\phi = 1$ and equation (A.26), plus $1-\phi$ times the profit from learning *R* when it is high, which is the difference between equation (A.21) when $\phi = 0$ and equation (A.25). Then, when the prior probability of a low transportation cost is close to 1, firm 2´s expected profit from learning would be too low and consequently, it will not generate learning.

Similarly, the uninformed firm´s cost of learning in period 1 also changes with ϕ. This cost of learning can be measured as the difference between equations (A.24) and (A.20). Specifically, when the prior probability of a low transportation cost is close to 0, the price set by firm 2 in period 1 in the pooling equilibrium is too close to its rival´s price in that equilibrium because $\frac{\partial p_1^{2B}}{\partial \phi} < 0$. Consequently, price dispersion without learning in period 1 is very low. For this reason, the uninformed firm will have to deviate from its short-run optimal price in period 1, p_1^{2B} , by much more to produce sufficient price dispersion in the market. This high deviation will increase the cost which the uninformed firm has to incur to learn R by too much, and once again, firm 2 will not want to generate learning.

c) Equilibrium outcomes with learning through experimentation

As shown by theorem 1, if the transportation cost is low and the values of the parameters of the model give rise to the pooling equilibrium, the informed firm does not want to reveal the true value of the transportation cost when it is low. In this scenario, we can obtain each firm´s incentives to experiment in the market. This is the purpose of our final result.

Theorem 2: *When assumption A.1 is satisfied, there will be two values of the prior probability of a low transportation cost,* ϕ_L *and* ϕ_H*, in such a way that the following results will be obtained. Firstly, our unique pooling equilibrium described in Proposition 1, in which neither firm will generate learning, will arise provided that* $\bar{\delta} < \delta < \bar{\bar{\delta}}$[7] *and* $\phi_L < \phi < \phi_H$*. Secondly, a unique equilibrium will be obtained,* *in which only firm 1 will generate learning through experimentation in period 1 provided that* $\bar{\bar{\delta}} < \delta < \underline{\delta}^{2L}$ *and* $\phi_L < \phi < \phi_H$. *Finally, when* $\delta > \underline{\delta}^{2L}$ *and* $\phi_L < \phi < \phi_H$, *there will be three types of equilibria: the equilibrium in pure strategies, in which only firm 1 generates learning, the equilibrium in pure strategies, in which only firm 2 generates learning, and an equilibrium in mixed strategies, in which both firms randomize in period 1 between their optimal prices with learning and their optimal prices without learning.*

The main conclusion is that the informed firm needs to be less patient to generate learning in the market than the uninformed one for the relevant values of the parameters ($\bar{\bar{\delta}} < \delta < \underline{\delta}^{2L}$). In fact, if the informed firm knows that the transportation cost is high, it will be guaranteed to make a greater profit in period 2 by deviating from its short-run optimal price in period 1. In fact, the difference between equations (A.13) and (A.15) is always positive. However, when the uninformed firm deviates from its short-run optimal price in period 1 to produce learning, it will make a greater profit in period 2 when the transportation cost is high, but it will make a lower profit if the transportation cost is low. As shown in the previous proposition, the drop in the profit made when the transportation cost is low is equal to the difference between equation (A.21) when $\phi = 1$ and equation (A.26). Similarly, the additional profit obtained by firm 2 in period 2 when the transportation cost is high is equal to the difference between equation (A.21) when $\phi = 0$ and equation (A.25). Thus, the uninformed firm´s uncertainty reduces its expected profit in period 2 and, for this reason, the minimum discount factor to incentivize firm 2 to experiment in the market ($\underline{\delta}^{2L}$) is greater than the minimum discount factor to encourage firm 1 to experiment ($\bar{\bar{\delta}}$). Then, if $\delta > \underline{\delta}^{2L}$, each firm will have incentives to experiment in the market, given that its rival does not do so. As shown above, experimentation in the market is costly in period 1. For this reason, if one firm experiments in the market, its rival will not want to do so, given the positive externality generated by the firm that produces learning in period 1. Then, our game becomes a typical coordination game with two potential equilibria in pure strategies and an equilibrium in mixed strategies as shown in the previous theorem.

V. CONCLUSIONS

We analysed the interaction between signal jamming and learning through experimentation in a two-period duopoly game in which only one firm is completely informed about all the market conditions, whereas the other is unaware of the degree of product differentiation. Aghion et al. (1993) also explored learning through experimentation when firms are uncertain about the degree of product differentiation. Under their assumptions with symmetric information, information is always positively valued by firms, and for this reason, they concluded that firms always have incentives to experiment in the market, giving rise to price dispersion. However, under the same assumptions but with asymmetric information, we obtain that firms may negatively value information. In our model, new information may cause the uninformed rival to be more competitive, which would reduce both firms´ profits. A different demand specification may also allow firms´ information to be negatively valued; however, this was previously analysed by Harrington (1995) in a duopoly setting under symmetric information.

Furthermore, under symmetric information, Aghion et al. (1993) found that firms will randomly set different prices in period 1 around a certain interval because they obtained an equilibrium in mixed strategies. However, these authors do not prescribe whether each firm should increase or decrease its price in order to generate learning through experimentation. On the contrary, under asymmetric information, our model shows that the informed firm should increase its price in period 1 in order to generate learning through experimentation, whereas the uninformed firm should decrease its price. Finally, Keller and Rady (2003) found that price dispersion arises providing that firms´ products are close substitutes under symmetric information, whereas we obtained that firms have more incentives to increase price dispersion in the market when products are perceived to be neither too close substitutes nor too highly differentiated, that is, when $\phi_L < \phi < \phi_H$. Thus, asymmetric information may significantly change firms´ incentives to experiment in the market.

In our model, when the transportation cost is high, the informed firm might set suboptimally high price in the short-run as a signal of a high degree of product differentiation. Besides that, the uninformed firm may set a suboptimally low price in the short-run in order to learn the transportation cost. When the uninformed firm does not experiment in the market and sets its short-run optimal price, this price makes each type of informed firm set a different price in period 1, which allows the uninformed firm to know the true value of the transportation cost. As in a model of *screening*, the uninformed firm may use the price it sets in period 1 as a mechanism to make its rival reveal its private information through the price it sets in period 1. Thus, unlike previous theoretical research, this paper models a situation in which signalling and screening may interact with each other.

APPENDIX

Proof of Proposition 1. Separating equilibrium: In the separating equilibrium, both firms will compete in period 1 as in a one-shot game with asymmetric information because they know that they will compete with symmetric information in period 2. Solving this simple one-period game, we obtain the prices set by both firms in the Bayesian-Nash equilibrium of this game:

$$p_t^{2B} = c + \frac{LH}{\hat{R}} \quad \text{(A.1)}$$

$$p_t^{1B}(R) = c + \frac{R\hat{R}+LH}{2\hat{R}} \quad \text{(A.2)}$$

We propose a separating equilibrium in which both firms set the prices given in equations (A.1) and (A.2) in the first period. The price chosen by firm 1 depends on the transportation cost, *R*, and thus, it will reveal the true value of this parameter. Nevertheless, equation (A.1) shows that the uninformed firm´s optimal price cannot depend on *R*, because this firm sets its optimal price given its prior information. In this separating equilibrium, the uninformed firm will learn the true value of *R* in period 2 by observing its rival´s price set in period 1 and both firms will compete with full information. Thus, the optimal prices set by both firms in the second period will be $p_2^{1Bf}(R) = p_2^{2Bf}(R) = c + R$, which are the same as the optimal prices chosen by firms in a standard Hotelling model with complete information. To finish the description of our proposed separating equilibrium, we need to specify the uninformed firm´s posterior beliefs in period 2 after it has observed the price chosen by its rival in period 1. The next function defines the posterior probability of a low transportation cost, $\hat{\phi}$:

$$\hat{\phi} = \begin{cases} 0 \; if \; p_1^1 \geq p_1^{1B}(H) \\ 1 \; if \; p_1^1 < p_1^{1B}(H) \end{cases} \qquad \text{(A.3)}$$

This means that firm 2 will believe that $R = H$ whenever the price set by its rival in period 1 is greater than or equal to the optimal price for a high transportation cost. Likewise, if the informed firm sets a lower price, the uninformed one will believe that $R = L$.

<u>Pooling equilibrium</u>: We now describe our proposed pooling equilibrium, which consists of the following strategies. In the first period, firm 1 sets its optimal price in a one-period game for a high transportation cost irrespective of the true value of R (i.e., the price shown in equation (A.2) when *R*=*H*). However, as equation (A.1) shows, firm 2 will set its optimal price given its prior information. As the price set by firm 1 in the first period does not depend on *R*, it will keep firm 2 uninformed in period 2 and once again, equation (A.1) shows the price set by this uninformed firm in period 2 in this pooling equilibrium, $p_2^{2B} =$

p_1^{2B}, because the posterior probabilities are the same as the prior probabilities. Finally, firm 1 will take advantage of its better information in period 2; equation (A.2) shows the price set by firm 1 given the true value of R, $p_2^{1B}(R)$. The following equation describes the posterior probability function in this pooling equilibrium:

$$\hat{\phi} = \begin{cases} \phi \ if \ p_1^1 \geq p_1^{1B}(H) \\ 1 \ if \ p_1^1 < p_1^{1B}(H) \end{cases} \tag{A.4}$$

By construction, both proposed outcomes are sequential equilibria because each firm´s strategy is a best response to its rival´s strategy and firm 2´s beliefs are consistent with the Bayesian rule in equilibrium. QED.

Proof of Theorem 1. When $R = L$, firm 1 will have incentives to hide its private information from its rival in period 1 when its profit in the pooling equilibrium is higher than its profit in the separating equilibrium. Otherwise, the informed firm will reveal its private information in period 1. Thus, we need to compare the profits obtained by firm 1 in each type of equilibrium when the transportation cost is low.

<u>Pooling equilibrium</u>: When $R = L$, the expected profit made by firm 1 in period 1 is:

$$E\{\pi_1^1[p_1^{1B}(H), p_1^{2B}|R = L]\} = \frac{(H\hat{R}+LH)[LH+\hat{R}(2L-H)]}{8\hat{R}^2L}N \tag{A.5}$$

When $R = L$, firm 1´s expected profit in period 2 in the pooling equilibrium will be:

$$E\{\pi_2^1[p_1^{1B}(H), p_1^{2B}, p_2^{1B}(L), p_2^{2B}|R = L]\} = \frac{(LH+L\hat{R})^2}{8L\hat{R}^2}N \tag{A.6}$$

<u>Separating equilibrium</u>: When $R = L$, firm 1´s expected profit in period 1 in the separating equilibrium is:

$$E\{\pi_1^1[p_1^{1B}(L), p_1^{2B}|R = L]\} = \frac{(LH+L\hat{R})^2}{8L\hat{R}^2}N \tag{A.7}$$

In period 2, firm 2 knows that $R = L$ and both firms´ expected profits with perfect information are:

$$E\left\{\pi_2^1\left[p_1^{1B}(L), p_1^{2B}, p_2^{1Bf}(L), p_2^{2Bf}(L) | R = L\right]\right\} =$$

$$E\left\{\pi_2^2\left[p_1^{1B}(L), p_1^{2B}, p_2^{1Bf}(L), p_2^{2Bf}(L) | R = L\right]\right\} = \frac{L}{2} N \quad \text{(A.8)}$$

Thus, a pooling equilibrium will arise provided that:

$$E\{\pi_1^1[p_1^{1B}(H), p_1^{2B} | R = L]\} + \delta E\{\pi_2^1[p_1^{1B}(H), p_1^{2B}, p_2^{1B}(L), p_2^{2B} | R = L]\} >$$

$$E\{\pi_1^1[p_1^{1B}(L), p_1^{2B} | R = L]\} + \delta E\left\{\pi_2^1\left[p_1^{1B}(L), p_1^{2B}, p_2^{1Bf}(L), p_2^{2Bf}(L) | R = L\right]\right\} \quad \text{(A.9)}$$

Using equation (A.9), the minimum value of δ to obtain the pooling equilibrium is:

$$\bar{\delta}^B\left(\hat{R}\right) = \frac{\hat{R}^2(H-L)^2}{L^2(H^2+2H\hat{R}-3\hat{R}^2)} \quad \text{(A.10)}$$

Thus, when the discount factor is greater than the previous threshold, the pooling equilibrium will arise. Otherwise, the separating equilibrium will be obtained. From equation (A.10), we observe that the threshold obtained depends on $\hat{R}$, which depends on ϕ. We obtain:

$$\frac{\partial \bar{\delta}^B(\hat{R})}{\partial \phi} = \frac{2H\hat{R}(H+\hat{R})(H-L)^3}{L^2(H^2+2H\hat{R}-3\hat{R}^2)^2} \quad \text{(A.11)}$$

Since this derivative is greater than zero, the threshold increases with ϕ. Additionally, from equation (A.10), we obtain $\lim_{\phi \to 1^-} \bar{\delta}^B\left(\hat{R}\right) = +\infty$ and $\lim_{\phi \to 0^+} \bar{\delta}^B\left(\hat{R}\right) < 1$. Thus, there will be a threshold, $\bar{\phi}$, such that the pooling equilibrium will never arise when $\phi > \bar{\phi}$. Nevertheless, when $\phi < \bar{\phi}$, the pooling equilibrium will arise whenever $\delta > \bar{\delta}^B\left(\hat{R}\right)$.

Unique undefeated equilibrium. In order to finish off the proof of theorem 1, we only need to prove that the unique equilibrium of our model will be the separating equilibrium when $\delta < \bar{\delta}^{B}(\hat{R})$ and the pooling equilibrium when $\delta > \bar{\delta}^{B}(\hat{R})$.

Since it is well-known that there are multiple sequential equilibria in signalling games, previous literature has proposed different criteria to restrict the off-the-equilibrium-path beliefs in order to obtain unique equilibria in the most relevant economic models[8]. Nevertheless, Mailath, Okuno-Fujiwara, and Postlewaite (1993) questioned previous refinements of sequential equilibria and suggested that a sequential equilibrium could be tested in the following way. Consider a message that is not sent in the equilibrium and suppose that there is an alternative sequential equilibrium in which a set of types of informed player choose the given message and prefer the alternative equilibrium to the proposed equilibrium. The test requires that the uninformed player´s beliefs at that action in the original equilibrium be consistent with this set. Mailath et al. (1993) stated that if the beliefs are not consistent, the second equilibrium defeats the proposed equilibrium, in which case they only choose the equilibria that are *undefeated* by any other equilibrium.

These authors demonstrated that the undefeated equilibrium coincides with the lexicographically undominated equilibrium in monotonic signalling games, which are games in which the uninformed player prefers to interact with the highest possible type of the informed player[9] and the informed player prefers that the uninformed player believes that he or she is the highest possible type. Since our game is monotonic, our undefeated equilibrium will coincide with the lexicographically undominated equilibrium, which can be obtained as follows. Imagine that there is an equilibrium for which there is a message which is outside that equilibrium path for a particular type of informed player, but this type sends that message at a second equilibrium and is better off at the second equilibrium than at the first one. If those types of informed player who are higher than the deviating type are at the second equilibrium, at least as well off as they are at the first, we say that the second equilibrium lexicographically dominates the first one. Likewise, if we find a type of informed player who is better off by sending his or her message specified at the second equilibrium than by sending his or her message at the first, but all the higher types of informed player are sending the same message at the second equilibrium as that sent at the first, we also conclude that the second equilibrium lexicographically dominates the first one regardless of whether those higher types are better off or worse off at the second equilibrium. Thus, an equilibrium is a lexicographically maximum sequential equilibrium (undefeated equilibrium) whenever there is no other equilibrium that lexicographically dominates it. We are going to use this concept to prove that our proposed separating equilibrium will be the unique undefeated equilibrium of this game when $\delta < \bar{\delta}^B(\hat{R})$, whereas our pooling equilibrium will be the unique undefeated equilibrium when $\delta > \bar{\delta}^B(\hat{R})$.

To simplify the exposition, we will call the informed firm which knows that $R = L$ the "low-cost firm", whereas the informed firm which knows that $R = H$ will be the "high-cost firm". First, we will prove that our separating equilibrium lexicographically dominates our pooling equilibrium when $\delta < \bar{\delta}^B(\hat{R})$. As shown above, when $\delta < \bar{\delta}^B(\hat{R})$, the low-cost firm is better off by choosing its strategy specified by the separating equilibrium, whereas the high-cost firm is choosing the same price in period 1 (its message) at both equilibria. Thus, the separating equilibrium dominates the pooling when $\delta < \bar{\delta}^B(\hat{R})$. As the opposite occurs when $\delta > \bar{\delta}^B(\hat{R})$, the pooling equilibrium dominates the separating when $\delta > \bar{\delta}^B(\hat{R})$.

It is easy to prove that no separating equilibrium other than ours is possible. In this model, an equilibrium will be separating whenever each type of informed firm sets a different price in period 1 and the posterior probability of L is equal to either zero or one. Then, another separating equilibrium might differ from ours because the prices chosen by each type of informed firm in period 1 are different or because the posterior probabilities are different. Obviously, a different set of prices chosen by each type of informed firm in period 1 cannot be an equilibrium when the posterior probabilities are the same as in our separating equilibrium. In fact, it would mean that some type of informed firm would be choosing a suboptimum strategy given its rival´s decisions. However, an alternative separating equilibrium might exist in which the low-cost firm chooses a different price in period 1 in order to appear to be a high-cost firm. If that strategy is successful, firm 2 will assume that the posterior probability of L is equal to zero when it observes the price chosen by the low-cost firm in that alternative equilibrium. Since this alternative equilibrium is a separating equilibrium, when firm 2 observes the price chosen by the high-cost firm, the posterior probability of L is equal to 1. If this were the case, the high-cost firm would be better off at our proposed separating equilibrium where firm 2 learns the true value of R. Thus, we have proven that any alternative separating equilibrium would be dominated by ours.

Finally, we prove that any alternative pooling equilibrium would be dominated by our pooling equilibrium. A set of strategies and beliefs would form a pooling equilibrium in this set-up whenever both types of informed firm set the same price in period 1 and the posterior probabilities at that equilibrium are the same as the prior probabilities. For example, imagine that there were an alternative pooling equilibrium in which both types of informed firm set a higher price in period 1 than the price we obtained. In this case, both types of informed firm would be better off at our pooling equilibrium. In particular, if the high-cost firm sets a higher price in period 1 than in the proposed equilibrium, it will be setting a suboptimal price and then, its profit in period 1 will be lower, whereas its profit in period 2 will be the same. Likewise, if the low-cost firm sets a higher price in period 1 than in the proposed equilibrium, it will be assuming a higher cost in period 1 to conceal its private information. However, the informed firm´s profit in period 2 cannot be greater than that obtained in our proposed pooling equilibrium because the latter is the maximum possible profit it can obtain at a pooling equilibrium given its rival´s decision. Thus, another pooling equilibrium in which both types of informed firm set a higher price in period 1 would be defeated by our proposed pooling equilibrium. Similarly, imagine that there were an alternative pooling equilibrium in which both types of informed firm set a lower price in period 1 than that obtained in our pooling equilibrium. If the high-cost firm sets a lower price in period 1 than in our equilibrium, this type of informed firm will be setting a suboptimal price in the first period, but it will not be able to increase its profit in period 2 because it is already obtaining its maximum possible profit in that period in our pooling equilibrium. As there are no higher types of informed firm than the high-cost firm in this model, it means that our pooling equilibrium dominates the alternative one.

Now, putting together all these arguments, we have proven that any other separating equilibrium would be defeated by ours, that any other pooling equilibrium would be defeated by ours and that our pooling equilibrium dominates the separating when $\delta > \bar{\delta}^B(\hat{R})$, whereas the opposite occurs when $\delta < \bar{\delta}^B(\hat{R})$. Thus, theorem 1 has been proven. QED. We use the same arguments to choose our unique equilibria with learning through experimentation, but we will not repeat them again to save space.

Proof of Proposition 2. We analyse the informed firm´s incentives to experiment in the market in the region of the pooling equilibrium described by theorem 1. Under assumption A.1, if $R = H$, firm 1 will produce learning in period 1 whenever the profit with learning is greater than the profit without learning. Next, we will compare these profits.

Learning through experimentation. If firm 1 sets the price described by equation (8) and firm 2 sets its optimum price specified by the pooling equilibrium, the informed firm´s profit in period 1 is:

$$E\{\pi_1^{1L}[p_1^{1L}, p_1^{2B}|R = H]\} = \frac{LH[(H-L)N-4L\bar{\varepsilon}][(H-L)N+4\hat{R}\bar{\varepsilon}]}{2\hat{R}N(H-L)^2} \quad \text{(A.12)}$$

In period 2, firm 2 will know that $R = H$ and both firms will compete with full information. Then, the expected profit obtained in period 2 by firm 1 is:

$$E\left\{\pi_2^{1L}\left[p_1^{1L}, p_1^{2B}, p_2^{1f}(H), p_2^{2f}(H)|R = H\right]\right\} = \frac{H}{2}N \quad \text{(A.13)}$$

No learning through experimentation. In the region giving rise to the pooling equilibrium, if firm 1 sets its optimal price in period 1 rather than the price that produces learning, its expected profit when $R = H$ is:

$$E\{\pi_1^{1NL}[p_1^{1B}(H), p_1^{2B}|R = H]\} = \frac{H(L+\hat{R})^2N}{8\hat{R}^2} \quad \text{(A.14)}$$

In our pooling equilibrium, if $R = H$, the expected profit obtained by firm 1 in period 2 is:

$$E\{\pi_2^{1NL}[p_1^{1B}(H), p_1^{2B}, p_2^{1B}(H), p_2^{2B}|R = H]\} = \frac{H(L+\hat{R})^2N}{8\hat{R}^2} \quad \text{(A.15)}$$

The profits shown in equations (A.14) and (A.15) are exactly the same because both firms set the same prices in periods 1 and 2 in the pooling equilibrium when $R = H$.

Thus, when $R = H$, firm 1 will produce learning in period 1, whenever:

$$E\{\pi_1^{1L}[p_1^{1L}, p_1^{2B}|R = H]\} + \delta E\left\{\pi_2^{1L}\left[p_1^{1L}, p_1^{2B}, p_2^{1f}(H), p_2^{2f}(H)|R = H\right]\right\} >$$
$$E\{\pi_1^{1NL}[p_1^{1B}(H), p_1^{2B}|R = H]\} + \delta E\{\pi_2^{1NL}[p_1^{1B}(H), p_1^{2B}, p_2^{1B}(H), p_2^{2B}|R = H]\} \quad \text{(A.16)}$$

Using (A.16), we find that firm 1 will generate learning whenever:

$$\bar{\bar{\delta}}(\hat{R}) = \frac{\hat{R}-L}{3\hat{R}+L} - \frac{16L\hat{R}\bar{\varepsilon}}{(H-L)(3\hat{R}+L)N} + \frac{64L^2\hat{R}^2\bar{\varepsilon}^2}{(H-L)^2(\hat{R}-L)(3\hat{R}+L)N^2} \quad \text{(A.17)}$$

It is straightforward to verify that $\bar{\bar{\delta}}(\hat{R})$ is minimized with respect to $\bar{\varepsilon}$ when $\bar{\varepsilon} = \frac{(H-L)(\hat{R}-L)N}{8L\hat{R}}$ and is strictly increasing with $\bar{\varepsilon}$ in the interval described by assumption A.1. Furthermore, it is easy to verify that $\lim_{\phi \to 0^+} \bar{\bar{\delta}}(\hat{R}) = +\infty$. Thus, there will exist a threshold, $\phi_1 > 0$, such that $\bar{\bar{\delta}}(\hat{R}) > 1$ when $\phi < \phi_1$, which means that firm 1 never generates learning through experimentation if $\phi < \phi_1$.

When $\bar{\varepsilon} = \frac{(H-L)N}{4L}$, $\bar{\bar{\delta}}(\hat{R}) = \frac{(\hat{R}+L)^2}{(\hat{R}-L)(3\hat{R}+L)}$, which is its maximum possible value. In this case, $\bar{\bar{\delta}}(\hat{R}) > \bar{\delta}^B(\hat{R})$ when $\phi \to 0^+$, whereas the opposite will occur when $\phi \to 1^-$. Thus, if $\Delta\delta = \bar{\bar{\delta}}\left(\hat{R}\middle|\bar{\varepsilon} = \frac{(H-L)N}{4L}\right) - \bar{\delta}^B(\hat{R}) = \frac{(\hat{R}+L)^2}{(\hat{R}-L)(3\hat{R}+L)} - \frac{\hat{R}^2(H-L)^2}{L^2(H^2+2H\hat{R}-3\hat{R}^2)}$, this difference is positive when $\phi \to 0^+$ and negative when $\phi \to 1^-$. Moreover, this difference is strictly decreasing with ϕ and is a continuous function with respect to ϕ in any closed interval $[\phi^*, \phi^{**}]$ provided that $\phi^* > 0$ and $\phi^{**} < 1$. Then, using Bolzano´s theorem, there will be a unique value of ϕ, such that this difference is equal to zero. Using a similar argument, we conclude that for any value of $\bar{\varepsilon}$ within the relevant interval there will be a unique value of ϕ for which $\bar{\bar{\delta}}(\hat{R})$ is equal to $\bar{\delta}^B(\hat{R})$. Let us call ϕ^0 that value of ϕ. When $\phi > \phi^0$, $\bar{\bar{\delta}}(\hat{R}) < \bar{\delta}^B(\hat{R})$. Remember that when $R = H$, firm 1 will only need to generate learning through experimentation if $\delta > \bar{\delta}^B(\hat{R})$. Otherwise, the separating equilibrium will arise and firm 2 will learn the true value of R even if firm 1 sets its optimum price in period 1. Therefore, when $\phi < \phi^0$, firm 1 will generate learning if $\delta > \bar{\bar{\delta}}(\hat{R})$ and when $\phi > \phi^0$, firm 1 will generate learning if $\delta > \bar{\delta}^B(\hat{R})$. Then, abusing notation we can conclude that firm 1 generates learning through experimentation if $\delta > \bar{\bar{\delta}} = max\{\bar{\bar{\delta}}(\hat{R}), \bar{\delta}^B(\hat{R})\}$.

As shown by theorem 1, there will be a value of the prior probability of a low transportation cost, $\bar{\phi}$, such that when $\phi > \bar{\phi}$, the unique undefeated equilibrium will be the separating equilibrium irrespective of the discount factor, in which case the informed firm will not need to produce learning through experimentation. If we denote $\phi_2 = \bar{\phi}$, this concludes the proof of proposition 2. QED.

Proof of Proposition 3. Now, we need to compare firm 2´s profits with and without learning. Learning through experimentation. When $R = H$ and firm 2 sets the price shown in (10), its expected profit in period 1 is:

$$E\{\pi_1^{2L}[p_1^{1B}(H), p_1^{2L}|R = H]\} = \frac{H[(L+\hat{R})(H-L)N - 8L\hat{R}\bar{\varepsilon}][(H-L)N + 4L\bar{\varepsilon}]}{4\hat{R}N(H-L)^2} \quad \text{(A.18)}$$

When $R = L$, the expected profit obtained in period 1 by firm 2 when setting that short-run suboptimum price is:

$$E\{\pi_1^{2L}[p_1^{1B}(H), p_1^{2L}|R = L]\} = \frac{H[(L+\hat{R})(H-L)N - 8L\hat{R}\bar{\varepsilon}][(H-L)N + 4H\bar{\varepsilon}]}{4\hat{R}N(H-L)^2} \quad \text{(A.19)}$$

Thus, the expected profit obtained by firm 2 in period 1 with learning is:

$$E[\pi_1^{2L}] = \phi E\{\pi_1^{2L}[p_1^{1B}(H), p_1^{2L}|R = L]\} + (1-\phi)E\{\pi_1^{2L}[p_1^{1B}(H), p_1^{2L}|R = H]\} =$$

$$\frac{H[(L+\hat{R})(H-L)N - 8L\hat{R}\bar{\varepsilon}][(H-L)N + 4\hat{R}\bar{\varepsilon}]}{4\hat{R}N(H-L)^2} \quad \text{(A.20)}$$

In this case, firm 2 will learn the transportation cost in period 2 and its profit will be $E\{\pi_2^{2L}[p_1^{1B}(H), p_1^{2L}, p_2^{1f}, p_2^{2f}|R = L]\} = \frac{L}{2}N$ when $R = L$, whereas it will be $E\{\pi_2^{2L}[p_1^{1B}(H), p_1^{2L}, p_2^{1f}, p_2^{2f}|R = H]\} = \frac{H}{2}N$ when $R = H$. Therefore, firm 2´s profit in period 2 with learning will be:

$$E[\pi_2^{2L}] = \frac{\bar{R}}{2}N \quad \text{(A.21)}$$

where $\bar{R} = \phi L + (1-\phi)H$.

No learning through experimentation. When $R = H$ and both firms set their prices specified by the pooling equilibrium, firm 2´s profit in period 1 is:

$$E\{\pi_1^{2NL}[p_1^{1B}(H), p_1^{2B} | R = H]\} = \frac{LH(3\hat{R}-L)}{4\hat{R}^2} N \quad \text{(A.22)}$$

Similarly, when $R = L$ and there is no learning through experimentation, firm 2´s expected profit in period 1 is:

$$E\{\pi_1^{2NL}[p_1^{1B}(H), p_1^{2B} | R = L]\} = \frac{H[\hat{R}(H+2L)-LH]}{4\hat{R}^2} N \quad \text{(A.23)}$$

Hence, firm 2´s expected profit in period 1 without learning is:

$$E[\pi_1^{2NL}] = \phi E\{\pi_1^{2NL}[p_1^{1B}(H), p_1^{2B} | R = L]\} + (1-\phi) E\{\pi_1^{2NL}[p_1^{1B}(H), p_1^{2B} | R = H]\} = \frac{H\{\phi[\hat{R}(H+2L)-LH]+(1-\phi)L(3\hat{R}-L)\}}{4\hat{R}^2} N \quad \text{(A.24)}$$

In period 2, firm 2 continues to be uninformed and its profit is the same as that obtained in period 1 when $R = H$:

$$E\{\pi_2^{2NL}[p_1^{1B}(H), p_1^{2B}, p_2^{1B}(H), p_2^{2B} | R = H]\} = \frac{LH(3\hat{R}-L)}{4\hat{R}^2} N \quad \text{(A.25)}$$

Likewise, when $R = L$, firm 2´s profit in period 2 will be:

$$E\{\pi_2^{2NL}[p_1^{1B}(H), p_1^{2B}, p_2^{1B}(L), p_2^{2B} | R = L]\} = \frac{LH(3\hat{R}-H)}{4\hat{R}^2} N \quad \text{(A.26)}$$

Thus, firm 2´s expected profit in period 2 without learning will be:

$$E[\pi_2^{2NL}] = \phi E\{\pi_2^{2NL}[p_1^{1B}(H), p_1^{2B}, p_2^{1B}(L), p_2^{2B} | R = L]\} + (1-\phi) E\{\pi_2^{2NL}[p_1^{1B}(H), p_1^{2B}, p_2^{1B}(H), p_2^{2B} | R = H]\} = \frac{LH}{2\hat{R}} N \quad \text{(A.27)}$$

In conclusion, firm 2 will produce learning provided that:

$$E[\pi_1^{2L}] + \delta E[\pi_2^{2L}] > E[\pi_1^{2NL}] + \delta E[\pi_2^{2NL}] \tag{A.28}$$

Using (A.28), we find that firm 2 will learn R whenever δ is greater than this threshold:

$$\underline{\delta}^{2L}(\hat{R}) = \frac{16LH\hat{R}^2\bar{\varepsilon}^2 - 2H\hat{R}(H-L)(\hat{R}-L)\bar{\varepsilon}N}{(H-L)^2N^2(\bar{R}\hat{R}-LH)} \tag{A.29}$$

As $\lim_{\phi\to 1^-} \underline{\delta}^{2L}(\hat{R}) = +\infty$, $\lim_{\phi\to 0^+} \underline{\delta}^{2L}(\hat{R}) = +\infty$, there will exist two values of the prior probability of a low transportation cost, ϕ^- and ϕ^+, such that $\underline{\delta}^{2L}(\hat{R}) > 1$ when $\phi<\phi^-$ or when $\phi > \phi^+$. It is easy to see that $\underline{\delta}^{2L}(\hat{R})$ is a continuous function with respect to ϕ whenever $\phi \in (0,1)$ and that there is a unique value of ϕ that minimizes $\underline{\delta}^{2L}(\hat{R})$. Since the minimum value of $\underline{\delta}^{2L}(\hat{R})$ is lower than 1 when $\bar{\varepsilon}\epsilon\left(\frac{(H-L)(\hat{R}-L)N}{8L\hat{R}}, \frac{(H-L)N}{4L}\right)$, Proposition 3 has been proven. QED.

Proof of Theorem 2. As we have proven in the previous propositions, given the fact that firm 2 does not experiment in the market, firm 1 will generate learning whenever:

$$\delta > max\{\bar{\delta}, \bar{\bar{\delta}}\} \tag{A.30}$$

Furthermore, firm 2 will have incentives to generate learning through experimentation, given the fact that firm 1 fails to do so, whenever:

$$\delta > \underline{\delta}^{2L} \tag{A.31}$$

$\bar{\bar{\delta}}$ is a continuous increasing function of $\bar{\varepsilon}$ when assumption A.1 is satisfied and is equal to zero when $\bar{\varepsilon} = \frac{(H-L)(\hat{R}-L)N}{8L\hat{R}}$, $\forall\phi \in (0,1]$. Similarly, $\underline{\delta}^{2L}$ is a continuous increasing function of $\bar{\varepsilon}$ and is equal to zero when $\bar{\varepsilon} = \frac{(H-L)(\hat{R}-L)N}{8L\hat{R}}$, $\forall\phi \in (0,1)$.

In addition, when $\bar{\varepsilon}$ takes its minimum possible value, that is, when $\bar{\varepsilon} = \frac{(H-L)(\hat{R}-L)N}{8L\hat{R}}$, $\frac{\partial\bar{\bar{\delta}}}{\partial\bar{\varepsilon}} = 0$, but $\frac{\partial\underline{\delta}^{2L}}{\partial\bar{\varepsilon}} = \frac{2H\hat{R}(\hat{R}-L)}{(H-L)(\bar{R}\hat{R}-LH)N} > 0\ \forall\phi \in (0,1)$. Finally, since $\frac{\partial^2\underline{\delta}^{2L}}{\partial\bar{\varepsilon}^2} > \frac{\partial^2\bar{\bar{\delta}}}{\partial\bar{\varepsilon}^2}\ \forall\phi \in (0,1)$, $\underline{\delta}^{2L}$ increases faster with $\bar{\varepsilon}$ than $\bar{\bar{\delta}}$. Thus, $\bar{\bar{\delta}} < \underline{\delta}^{2L}\ \forall\phi \in (0,1), \forall\bar{\varepsilon}\epsilon\left(\frac{(H-L)(\hat{R}-L)N}{8L\hat{R}}, \frac{(H-L)N}{4L}\right)$. This statement proves what our theorem indicates for the relevant values of ϕ and $\bar{\varepsilon}$ considered in propositions 2 and 3. In particular, if $\bar{\delta} < \delta < \bar{\bar{\delta}}$, neither firm 1 nor firm 2 will generate experimentation and the pooling equilibrium will arise, if $\bar{\bar{\delta}} < \delta < \underline{\delta}^{2L}$, only firm 1 will experiment in the market, and when $\delta > \underline{\delta}^{2L}$, each firm will want to experiment in the market, given the fact that its rival does not. Nevertheless, given the fact that a firm is experimenting in the market, the other firm prefers not to experiment. Hence, when $\delta > \underline{\delta}^{2L}$, we have a typical coordination game in which there are three types of equilibria. Firstly, there are two equilibria in pure strategies in which only firm 1 or firm 2 experiments. Secondly, there is an equilibrium in mixed strategies in which firms 1 and 2 randomly experiment in the market, that is, with a certain probability, firms will choose their prices in period 1 defined by the pooling equilibrium, and with the complementary probability, firms will choose their prices in period 1 to produce learning. As shown in propositions 2 and 3, all the previous analyses are valid whenever $\phi_L < \phi < \phi_H$, where $\phi_L = max\{\phi_1, \phi^-\}$ and $\phi_H = min\{\phi_2, \phi^+\}$. Therefore, theorem 2 has been proven. QED.

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[1] Some of the recent applications of signalling and screening models to industrial economics, labour economics, finance and other fields can be found in Riley (2001)

[2] As shown by D´Aspremont et al. (1979), an equilibrium in firms´ location decisions does not exist when the transportation cost is linear and for this reason, they assumed quadratic transportation costs. As we will not analyse firms´ location decisions in this model, we will assume linear transportation costs, but the results with quadratic transportation costs are exactly the same.

[3] This observational assumption is the same as that considered by Aghion et al. (1993), but we assume that both specific demand shocks are statistically independent. For this reason, if each firm observes both quantities sold in period 1, the results obtained will be exactly the same. However, in the perfect correlation scenario considered by Aghion et al., the results shown in section IV will only be valid if each firm cannot observe its rival´s quantity sold in period 1, which is a plausible assumption in many real markets.

[4] See the final part of the online appendix, where we prove that the informed firm will never produce learning when $\bar{\varepsilon} > \frac{(H-L)N\left[(\hat{R}-L)+\sqrt{(\hat{R}-L)(3\hat{R}+L)}\right]}{8L\hat{R}}$.

[5] Since the uninformed firm´s profit function is strictly concave in relation to its chosen price, we can guarantee that this firm will never randomize and then we only have to focus on pure strategy equilibria.

[6] The appendix shows a summary of the proofs of all propositions and theorems because they are too long. For a full derivation of those proofs, see the online appendix.

[7] See the definition of $\bar{\delta}$, $\bar{\bar{\delta}}$ and $\underline{\delta}^{2L}$ in Theorem 1 and Propositions 2 and 3.

[8] For example, the intuitive criterion was proposed by Cho and Kreps (1987), whereas Banks and Sobel (1987) suggested two different criteria that they called divinity and universal divinity.

[9] In the classical model of the labor market, workers are the informed players because they know their productivity, whereas employers do not. In this example, we can arrange the types of the informed player according to his or her productivity. In our model, we consider that the informed firm has a greater type when the transportation cost is high than when it is low.