Strategic Experimentation in a Durable Goods Duopoly

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Abstract

A firm selling a new product of uncertain quality competes with an existing firm in a two-period game. Both firms and buyers learn the quality of the new product through experimentation. We consider durable goods : buyers are in the market for only one unit and may choose to delay their purchase.

The value of information of a buyer who would choose to wait is always negative. If the firms are capacity constrained, there is always experimentation independent on the priors on the new good's quality and products are purchased immediately. Both firms are however able to exploit the intertemporal competition to extract the buyer's informational surplus. Call options are a simple way for the new firm to induce a waiting behavior on the part of one of the buyer.

Resumen

Hay una empresa que vende un nuevo producto de calidad incierta y compite con una empresa ya existencte en un juego de dos etapas. Tanto las empresas como los compradores aprenden la calidad del nuevo producto a través de la experimentación. Consideramos productos duraderos: los compradores están en el mercado por una única unidad y pueden elegir retrasar su compra. El valor de la información de un comprador que escogería esperar es siempre negativo. Si las empresas tienen restricciones de capacidad, siempre hay experimentación independiente de la anterior calidad del bien nuevo y se compran los productos inmediatamente. Ambas empresas son, sin embargo, capaces de explotar la competencia intertemporal para extraer el excedente de información del comprador. Las opciones de compra son una forma sencilla de la nueva empresa para inducir un comportamiento de espera por parte de uno de los compradores.

1 Introduction

When a new product is introduced, uncertainty with respect to its quality prevails. Both buyers and sellers can be uncertain about the quality of the good they exchange. If past consumption provides public information on quality, buyers may adopt waiting strategies to learn from the current experimentation of other agents. The consumption date can thus be one of the strategic variables for consumers. In this paper, we propose to study the dynamic interaction between learning and strategic considerations in a durable goods duopoly.

We analyze these strategic behaviors in a two period game. Two firms with vertically differentiated products engage in price competition. One product has a known value while the other is new and its true quality is uncertain. Neither firms nor buyers know the true quality of this new product. On the demand side, two buyers with a unit demand enter the market in the first period. Buyers must consume the new product to learn its quality. Past consumption provides a signal on the quality of the new product available to all parties[2]. This informational leakage introduces an informational externality in the model. The date of consumption for buyers is thus a strategic variable. The interesting point about a delayed purchase is that a buyer expecting the good to be purchased by somebody else may choose to wait in order to benefit from added information. Buyers have therefore a two dimensional decision problem : the date of consumption and the choice of the product. This possibility of delaying consumption is important for firms because it creates an intertemporal competition, consumption in the first and in the second period being substitutes. By selling tomorrow, firms reduce the demand for today. The model we consider is a durable goods model. Such a possibility is not considered in the existing literature and is quite relevant for actual applications. One can think for instance of the introduction of a new and unknown computer

[2] Via an unmodelled process of word-of-mouth communication.

operating system or a new launcher of satellites.

Firms producing telecommunication satellites and buying launch services are an illustrative example of the model. In this high risk industry, the choice of the launch vehicule is particularly important and the introduction of a new launch vehicule, which is associated with uncertainty about its true reliability, raises some questions. Is it preferable for buyers to launch their satellites with a known vehicule instead of buying the new one? Will buyers prefer to adopt a waiting position and see how the new vehicule behaves? A buyer may prefer to wait if it thinks it can learn about the quality of the new vehicule by observing the launch of other satellites. The problem is that not all buyers can do that, a satellite has to go first. For the operators of the launch vehicules, there is a pricing problem. The new launch vehicule, whose probability of failure is not known, must post a price such that a satellite accepts to experiment.

We first determine the value of information for the different agents. We find that the value of information to a buyer who would choose to wait is always negative. Price competition allows firms to extract the buyer's informational surplus so that, ex ante, both firms value positively information and prefer to play a second period game in which they are informed.

Following the example of space industry, we first consider a market in which each firm is capacity constrained so that each firm can only sell one unit of the product in each period. We find that there is always experimentation independent on the priors on the new product quality. Both buyers want to experiment the new product but, because of capacity contraints, one buyer is rationed. The rationed buyer does not wait for information and purchases the established product in the same period. Even if this experimentation has no social benefit because no agents use it, current information affects prices. The information generated by experimentation results in higher prices today so that both buyers lose. Firms are able to exploit the intertemporal competition to extract the buyers' informational surplus without acquiring the information.

When both firms can satisfy the whole market in a single period, learning does not influence the game. The firm with the highest expected quality serve the entire demand in the first period. There is experimentation only if the quality of the new product is greater than the quality of the established one. Prices are not affected by the learning aspect in the game. Learning does not affect the game when the established firm only is also capacity constrained. On the contrary, when the new firm only has a capacity constraint, the established firm can prefer to concede the market to the new firm and sells one unit of its product rather than serving the whole demand if information has a sufficiently high value. By conceding the market, the established firm can extract the informational surplus of the rationed buyer which can not be done if it serves the whole demand in the first period.

The equilibrium in the model is characterized by a non waiting behavior and is clearly inefficient. Once the costs of experimentation are paid, it is obvious that waiting for the result of the experimentation and learning the quality of the product is efficient. We have envision wether the use of contracts by firms[3] could modify this non waiting behavior. Call options appear to be the adequate contract. We show that once the first buyer has purchased the new product, the new firm, if it is optimistic about its product quality, offers a call option to the rationed buyer. The rationed buyer then waits to purchase in the second period. If there is a good experimentation, the buyer exercises its option and purchases the new product. If the result of the experimentation is bad, the buyer refuses to exercise its option and purchases the established product. This type of contract, when it is offered by the new firm, enforces the intertemporal competition such that the established firm prefers to wait and engage in a second period competition rather than capture the buyer in the first period.

[3] As it is observed in the space industry for instance.

Recent work introduces pricing in dynamic learning models with many agents. A first category of papers has studied pricing with learning on the demand curve. We can cite Aghion, Espinoza and Jullien (1993) or Mirman, Samuelson and Schlee (1994) who study a duopoly market in which firms learn about the demand by observing the volume of their sales. Harrington (1995) studies price-setting behavior in a context of a duopoly in which firms are uncertain about the degree of product differentiation. These papers present models where buyers are fully informed about the product.

My work is more closely related to a second category of papers studying two-sided learning models. The first paper which has introduced pricing in a two-sided learning model is by Bergemann and Valimaki (1996a). In this paper, there is only one buyer and therefore no informational externalities between buyers. Bergeman and Valimaki (1996b) also present an extension of the Bolton and Harris (1993) model of strategic experimentation by introducing pricing. They focus on how informational externalities affect the efficiency of the market. Finaly, Bergeman and Valimaki (1997) analyze the diffusion of a new product in a duopoly where buyers have heterogenous preferences. They concentrate on determining the path of firms' prices and the associated path of market share evolution. All these studies consider models in which one or several buyers have unit demand at each instant of time. They abstract from an intertemporal substitution by buyers.

This intertemporal pricing consideration is introduced in a two-sided learning model by Haritchabalet (1998) in a monopoly setting[4]. The monopoly setting does not allow to study the informational externalities between firms.

Second 2 introduces notations and present supply and demand of the market. We present an analysis of the value of information in section 3. The equilibria of the game are described for each type of industries in section 4. Section 5 presents

[4]See also Judd and Riordan (1994) or Schlee (1998) for studies of two-sided learning model in monopoly settings.

a discussion on the efficiency of the equilibria. Section 6 is devoted to the study of contracts. Conclusions follow.

2 The model

We consider a two period model where two firms with vertically differentiated products engage in price competition. The established firm E, supplies a product with known quality ρ. The new firm N, offers a product whose quality is initially unknown both to the buyers and the sellers. We assume that all participants hold the same prior $\tilde{\pi}$ on the expected value of this quality at the beginning of the game. A purchase of this product yields some information about product quality to all participants, information is publicly observable. The game is thus one of incomplete but symmetric information and no issues of asymmetric information arise. We consider a binary information structure. The message received can either be good or bad. We denote by q the probability of receiving a good message ; $(1-q)$ is the probability to receive a bad message. The receipt of any message leads to a revision of beliefs[5], the agents update their prior beliefs $\tilde{\pi}$ into posterior beliefs π_g and π_b where π_g (resp. π_b) is the conditional expectation of the new product quality given that the agents receive a good message (resp. a bad message). We can express the relation between the prior $\tilde{\pi}$, the message probability q and the posteriors π_g and π_b : $\tilde{\pi} = q\pi_g + (1-q)\pi_b \equiv E\pi_i$. Thus $\pi_b < \tilde{\pi} < \pi_g$: receiving a good message leads to optimism about the new product quality and, on the contrary, receiving a bad message results in more pessimistic beliefs on the quality of the new product. At the beginning of the game, the new product expected quality can be greater or lower than the established one, but we assume that $\pi_b < \rho < \pi_g$.

We study different types of industries : an industry in which firms can satisfy

[5]Since all market participants obtain the same information on the new product, they will hold the same posterior beliefs.

all the demand in a single period (the non-capacity constrained industry), an industry in which each firm can only sell one unit of the product in each period (the capacity constrained industry) and the intermediate configuration in which one firm only is capacity constrained (the semi-capacity constrained industry). The analysis of these different types of industries allows to compare structures in which buyers have the same experimentation problem to structure in which buyers are constrained to chose different actions.

The marginal production costs are identical and normalized to zero. The firms have the same discount factor β.

Prices are announced simultaneously at the beginning of each period : (p_1^N, p_2^N) and (p_1^E, p_2^E) denote the intertemporal pricing policies of firm N and firm E.

On the demand side, there are two buyers with unit demand. The utility of a purchase is defined as the expected quality of the product minus its price. A buyer will purchase the product if this utility is positive. Buyers have the same discount factor β. Each buyer acts strategically. Given current prices, available information and the other agent's decision, the buyer chooses between the new product, the established product or waits to accumulate its information and delays its purchase to the second period.

The buyers' decision problem in our model differs from existing problems in the previously quoted literature in one important aspect. Considering that buyers can delay their purchase is equivalent to consider that a purchase in the first period and a purchase in the second period are substitute. This intertemporal substitution modifies competition between firms in the sense that the demand for the product in the second period depends on the first period consumption.

Each player maximizes its expected return given the beliefs over the new product and the strategies of other players. Our equilibrium concept will be Subgame-Perfect Equilibrium. In case of ties between the new or the established product, a buyer chooses the product with the highest quality. Similarly, in case of ties between acting immediately and later, the buyer is assumed to prefer immediate purchase. In the capacity constrained industry, we assume an efficient rationing rule[6].

3 The Value of Information

We first determine the value of waiting for a buyer and for firms. When there is one buyer in the second period, price competition between firms makes the second period game similar to a static Bertrand pricing game in which firms offer different qualities. The firm with the highest quality sells. The equilibrium price is determined by the quality difference between the two products. Second period price competition depends on whether experimentation has occurred or not.

If there has been no experimentation in the first period, second period prices are given by $p_2^E = \max\{\rho - \tilde{\pi}, 0\}$ and $p_2^N = \max\{\tilde{\pi} - \rho, 0\}$. The buyer obtains a discounted utility equal to $\beta \min\{\tilde{\pi}, \rho\}$.

If there is experimentation in the first period, the second period game is either favorable to the new firm or favorable to the established one, depending on the result of the experimental purchase. With probability q, the outcome of the experiment is good and Bertrand competition gives : $p_2^E = 0$ and $p_2^N = \pi_g - \rho$. With probability $(1 - q)$, the agents receive a bad message and the second period prices are $p_2^E = \rho - \pi_b$ and $p_2^N = 0$. The expected discounted profits are equal to $\beta E \max\{\pi_i - \rho, 0\}$ for firm N and $\beta E \max\{\rho - \pi_i, 0\}$ for firm E. The expected discounted utility obtained by the buyer is equal to $\beta E \min\{\pi_i, \rho\}$.

To analyze how experimentation affects the second period price competition

[6] See Tirole (1988).

between firms we refer to the value of information for firms E and N. This value is, in expected and non discounted terms, the variation in each firm's profit due to an experimentation. As long as this value is positive, firms will be willing to sacrifice part of their short-run profit in order to acquire information. The values of information V_N and V_E for firms N and E are given by :

$$V_N = E\max\{\pi_i - \rho, 0\} - \max\{\tilde{\pi} - \rho, 0\}$$

and

$$V_E = E\max\{\rho - \pi_i, 0\} - \max\{\rho - \tilde{\pi}, 0\}$$

Using the fact that the function $\max\{x, k\}$ is a convex function of x, we obtain that information about the new product is positively valued for firm N and firm E. Both firms attach the same value for the information.

We can compute the value of information for the second period buyer V_B, defined by the difference between the second period expected utility when there is experimentation in the first period and the second period utility whithout experimentation in the first period. This value indicates the variation in the second period buyer's utility due to an experimentation. We obtain the following result.

Proposition 1 $V_B = -V_E = -V_N$

Proof : See the Appendix.

This result states that the game has a zero sum property between one firm and the second period buyer. If there is an experimentation in the first period, a good signal results in more optimistic beliefs on the new product quality. The willingness to pay for the new product increases. Bertrand competition however implies that the new firm can extract all this additional surplus from the buyer. We then have that $V_N = -V_B$. If the result of the experimentation is bad, beliefs on the new product quality are pessimistics. The willigness to pay for the established product increases. Bertrand competition implies that the established firm can extract all this additional surplus form the buyer and $V_E = -V_B$. In other words, buyers are information averse. The availability of information from other buyer's experimentation does not lead to a free rider problem between buyers since buyers prefer not to be informed. Thus buyers may not opt to wait to see how the market evaluates the new product. On the contrary, both firms value positively information. They may encourage buyers to experiment and wait for information. Information is however socially optimal since $V_N + V_E + V_B > 0$.

4 Short Term Pricing

We now express the profits of firms N and E as functions of first period prices p_1^N and p_1^E. These profits depend on the type of industry considered. We first present the most interesting case of the capacity constrained industry. The assumption of capacity constraints is relaxed at the end of this section.

4.1 The Capacity Constrained Industry

The following profit functions summarize the different paths which can be taken at the equilibrium in the capacity constrained game.

$$\Pi_E = \begin{cases} p_1^E + \beta \max\{\rho - \tilde{\pi}, 0\} & if\ \rho - p_1^E > \tilde{\pi} - p_1^N\ , \rho - p_1^E \geq 0 \\ & and\ \tilde{\pi} - p_1^N < \beta \min\{\rho, \tilde{\pi}\} \\ & \\ p_1^E & if\ \rho - p_1^E > \tilde{\pi} - p_1^N > \beta \min\{\rho, \tilde{\pi}\} \\ & \\ \beta E \max\{\rho - \pi_i, 0\} & if\ \rho - p_1^E < \tilde{\pi} - p_1^N, \tilde{\pi} - p_1^N \geq 0 \\ & and\ \rho - p_1^E < \beta E \min\{\rho, \pi_i\} \\ & \\ p_1^E & if\ \beta E \min\{\rho, \pi_i\} < \rho - p_1^E < \tilde{\pi} - p_1^N \\ & \\ \beta\rho & if\ \rho - p_1^E < 0\ and\ \tilde{\pi} - p_1^N < 0 \end{cases}$$

$$\Pi_N = \begin{cases} \beta \max\{\tilde{\pi} - \rho, 0\} & if\ \rho - p_1^E > \tilde{\pi} - p_1^N,\ \rho - p_1^E \geq 0 \\ & and\ \tilde{\pi} - p_1^N < \beta \min\{\rho, \tilde{\pi}\} \\ \\ p_1^N & if\ \rho - p_1^E > \tilde{\pi} - p_1^N > \beta \min\{\rho, \tilde{\pi}\} \\ \\ p_1^N + \beta E \max\{\pi_i - \rho, 0\} & if\ \rho - p_1^E < \tilde{\pi} - p_1^N,\ \tilde{\pi} - p_1^N \geq 0 \\ & and\ \rho - p_1^E < \beta E \min\{\rho, \pi_i\} \\ \\ p_1^N & if\ \beta E \min\{\rho, \pi_i\} < \rho - p_1^E < \tilde{\pi} - p_1^N \\ \\ \beta \tilde{\pi} & if\ \rho - p_1^E < 0\ and\ \tilde{\pi} - p_1^N < 0 \end{cases}$$

Conditions $\rho - p_1^E > \tilde{\pi} - p_1^N \geq \beta \min\{\rho, \tilde{\pi}\}$ for instance, correspond to the case where buyers prefer to purchase in the first period from the established firm. Condition $\rho - p_1^E > \tilde{\pi} - p_1^N$ indicates that buyers prefer the established firm. If buyers wait, they will receive $\beta \min\{\rho, \tilde{\pi}\}$ by Bertrand pricing. When $\rho - p_1^E \geq \beta \min\{\rho, \tilde{\pi}\}$, they therefore prefer a purchase in the first period. Both buyers prefer a purchase from the established firm but, they can not choose the same product in the same period : one buyer is rationed. The rationed buyer then purchases the new product in the first period, which gives a greater utility than waiting.

We solve the profit maximization problem of the firms and obtain the following proposition.

Proposition 2 *In the capacity constrained industry, there exists a unique subgame perfect equilibrium such that both buyers make their purchase in the first period. One buyer purchases the new product, the rationed buyer purchases the established one.*

Proof : See the Appendix.

At equilibrium, both buyers want to purchase the new product, and this experimentation choice is independent of the expected quality of the new product.

Since firm N is capacity constrained, one buyer is rationed. This buyer does not wait for the result of the experimentation and purchases the established product in the same period. Equilibrium prices are given by $p_E^{1*} = \rho - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B$ and $p_N^{1*} = \tilde{\pi} - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B$. The information generated by experimentation today results in higher prices today so that both buyers lose, even if the agents do not wait for information. The intertemporal competition between selling today and waiting for information allows firms to extract today the informational surplus of buyers without acquiring the information.

Once the first buyer has experimented in the first period, firm E can wait for information and receive a profit equal to $\Pi_E = \beta \max\{\rho - \tilde{\pi}, 0\} + \beta V_E$. Firm E can also sell to the rationed buyer in the first period by proposing a price $p_1^E = \rho - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B$ such that the rationed buyer prefers not to wait. The established firm waits for information if $p_1^E < \beta \max\{\rho - \tilde{\pi}, 0\} + \beta V_E$, which is equivalent to $\rho < \beta\rho + \beta V_B + \beta V_E$. Since $V_B + V_E = 0$ from Proposition 1, we obtain that once one buyer experiments, the established firm always prefers to sell in the first period when $\beta < 1$[7].

In a model without learning, the firm with the highest expected quality would sell one product in the first period, the other firm would sell to the rationed buyer in the same period. Learning has important effects in this model. Even if the quality of the established product is greater than the quality of the new product, firm E always concede the market to the new firm for the first buyer. The reason for that is that both firms are able tu use the intertemporal competition to extract the buyers' informational surplus and increase first period prices.

[7]It must be noted that the established firm prefers to capture the rationed buyer in the first period as long as its discount factor is greater or equal than the buyer discount factor.

4.2 Relaxing the Capacity Constraints

Assume now that both firms can satisfy the demand in a single period. Both buyers are now going to choose the same action since they have the same experimentation problem. Therefore, either both buyers purchase in the first period or they both purchase in the second period.

Proposition 3 *In the non-capacity constrained industry, there exists a unique subgame perfect equilibrium such that both buyers purchase the product with the highest expected quality in the first period.*

Proof : See the Appendix.

Equilibrium prices are given by $p_E^{1*} = \max\{\rho - \tilde{\pi}, 0\}$ and $p_N^{1*} = \max\{\tilde{\pi} - \rho, 0\}$. The equilibrium is not affected by the learning aspect in the game and it would be the same if the quality of both products were known. Since both buyers choose the same action, the second period game with an informed buyer can never be reached. Therefore, learning does not influence neither the behavior of firms, nor the behavior of buyers. In the non-capacity constrained industry, there does not exist any interaction between learning and strategic considerations. At equilibrium, there is experimentation if the expected quality of the new product is greater than the quality of the established product.

When the new firm has a capacity constraint only, the established firm can attract the rationed buyer after an experimentation, as explained previously. The established firm faces then the following trade off. On the one hand, if one buyer experiments, the established firm can extract the informational surplus from the rationed buyer. The price at which the firm sells this good is $p_E^{1*} = \rho - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B$. On the other hand, if the expected quality of the new product is lower than the quality of the established one, the established firm can sell two units of good in the first period at a price $p_E^{1*} = \rho - \tilde{\pi}$. If information has a sufficiently high value, the established firm prefers to concede the market for the first buyer to recover the informational surplus of the rationed buyer. If the value of information is not sufficient, the established firm sells to both buyers.

Proposition 4 *Assume that firm N is capacity constrained.*

Define

$$\hat{q} = \frac{\rho - \pi_b + (\beta - 1)\pi_b}{2(\pi_g - \pi_b) + \beta(\pi_b - \rho)}$$

Then, if $q \geq \hat{q}$, one buyer experiments and the rationed buyer purchases the established product in the first period ;
if $q < \hat{q}$, both buyers purchase the established product in the first period.

When the established firm is capacity constraint, the new firm sells to both buyers if the expected quality of its product is greater than the quality of the established one. Else, the new firm sells to the rationed buyer in the first period. As in the non-capacity constrained game, since the second period game where agents are informed can never be reached, learning does not affect the game.

5 Efficiency

In this model, we focus on a notion of ex ante efficiency[8]. We define an efficient equilibrium as an equilibrium which maximizes the social surplus of the game, that is the value of the product.

First, since information is socially optimal, it is efficient to wait for information once the costs of experimentation are paid. Second, assuming that there exists waiting, efficiency requires experimentation whenever current costs of experimentation are outweighed by future gains.

[8]See Holmstrom and Myerson (1983).

When the expected quality of the new product is lower than the quality of the established one, experimentation is costly. For values of $q \leq (\rho - \pi_b)/(\beta\pi_g - \beta\rho + \pi_g - \pi_b)$, the efficient alloaction requires that both products are sold by the established firm in the first period. If $q \geq (\rho - \pi_b)/(\beta\pi_g - \beta\rho + \pi_g - \pi_b)$, it is efficient to experiment and wait for information. When the expected quality of the new product is greater than the established product quality at the begining of the game, there is always gains to experiment and experimentation is efficient.

In the capacity constrained game, there is always experimentation and experimentation is excessive. This equilibrium contains another source of inefficiency due to the non-waiting behavior. The costs of experimentation are always paid, the gains of experimentation never obtained. The same inefficiency arises when the new firm is capacity constrained. Equilibrium exhibits also an excessive experimentation[9] and, as before, inefficiency increases with the non-waiting behavior.

In the non-capacity constrained game, there is experimentation only when the quality of the new product is greater than the quality of the established product. Experimentation is clearly insufficient. As before, the non waiting behavior increases inefficiency.

6 Long Term Contracts

Assume now that firms can propose long term contracts. The aim of this section is to study how the equilibrium of the capacity constrained game and the semi-capacity constrained game are modified with contracts. In particular, we want to study if the introduction of contracts can induce a waiting behavior and, in this case, what is the form of the contract. We study two standard types of contracts :

[9] It can be easily checked that $\hat{q} \leq (\rho - \pi_b)/(\beta\pi_g - \beta\rho + \pi_g - \pi_b)$.

forwards[10] and call options[11].

6.1 Call options

We first present how a call option can be used by the new firm.

Let p_e be the premium of the call option and p_c^N be the exercise price.

The premium of a call option depends on the exercise price and vice versa. Usually, the exercise price is fixed and the premium is negotiated. Since we are interested in the modification of the equilibrium associated to the introduction of the call option, we prefer to fix the premium and compute the exercise price to simplify the interpretation of the results. We assume that $p_e = 0$.

The new firm will propose a call option only to the rationed buyer and only after an experimentation. If this contract is signed, the second period game is modified as follows. With probability q, the outcome of the experiment is good and the new firm, which has the highest quality, sells at the price p_c^N. With probability $(1-q)$, the agents receive a bad message and the buyer does not exercise its right. Since the buyer refuses to purchase the new product at a price $p_c^N > 0$, firm N announces a new price and the two firms engage in a Bertrand competition. Equilibrium prices are $p_2^E = \rho - \pi_b$ and $p_2^N = 0$.

The expected second period profit of the established firm, conditional on the event that it receives information on the new product remains the same

$$\beta E \max\{\rho - \pi_i, 0\}.$$

The expected second period profits of the new firm, conditional on the event that

[10] A forward contract is an agreement between a firm and a buyer to buy one unit of a good at a certain future time for a certain price. The specified price in the contract is the delivery price.

[11] The price in the contract is the exercise price. A call option gives the right to buy the good but the holder does not have to exercise this right which distinguishes options from forwards where the holder is obligated to buy the good. The buyer must pay to purchase a call option. The price of the call option, paid in the first period, is the premium of the option.

it receives information on the new product is given by

$$\beta q p_c^N.$$

The expected second period utility of the buyer who accepts the call option is therefore

$$\beta[q(\pi_g - p_c^N) + (1-q)\pi_b].$$

The modification in the profit of firm N and in the buyer's utility leads to a modification in the value of information for these two agents.

$$V_N = qp_c^N - \max\{\tilde{\pi} - \rho, 0\}$$

and

$$V_B = [q(\pi_g - p_c^N) + (1-q)\pi_b] - \min\{\rho, \tilde{\pi}\}.$$

When the new firm anounces a second period price conditionally on an experimentation in the first period, it actually commits to reduce its relative competitive position from $\pi_g - \rho$ to $\pi_g - p_c^N$, that is firm N commits to leave some surplus to the buyer. It therefore increases the value of information for the buyer without any changes in the value of information of the established firm and we obtain that $V_E + V_B \geq 0$. The game between the established firm and the second period buyer is no more zero sum. The total value of information is unchanged, firm N only transfers some value of information to the buyer. In other words, the new firm can enforce the second period price competition in order to avoid the monopoly position of the established firm and induce a waiting behavior.

We obtain the following results.

Proposition 5 *Define*

$$q^* = \frac{2\rho(1-\beta)}{\beta(\pi_g - \rho)}$$

Then, when both firms are capacity constrained,

if $q \geq q^*$, the new firm proposes a call option, one buyer experiments, the rationed *buyer purchases the option and waits for information ;*

if $q < q^*$, one buyer experiments and the rationed buyer purchases the established product in the first period.

When firm N is capacity constraint,

if $q \geq q^*$, the new firm proposes a call option, one buyer experiments, the rationed buyer purchases the option and waits for information

if $q^* > q \geq \hat{q}$, one buyer experiments and the rationed buyer purchases the established product in the first period ;

if $q < \hat{q}$, both buyers purchase the established product in the first period.

Proof : See the Appendix.

This proposition indicates that we can observe a waiting behavior if the prior on the good message probability is sufficiently high. When the new firm commits on a second period price, the exercise price is given by $p_c^N = \pi_g - \rho(1/\beta - (1-q)/q)$. The equilibrium profits are $\Pi_E = \beta \max\{\rho - \tilde{\pi}, 0\} + \beta V_E$ and $\Pi_N = \tilde{\pi}(1-\beta) + 2\beta q\{\pi_g - \rho(1/\beta - (1-q)/q)\}$.

For $q \leq q^*$, the new firm does not offer a call option and you can refer to the preceding section for the description of the equilibrium. It is therefore not always possible to implement efficient outcome at equilibrium with call options.

By commiting on a second period price, the new firm faces a trade-off, which can be described as follows. If the new firm does not offer the call option, it sells one product. The price posted for this product is a decreasing function of the value of information of the buyer. When the new firm offers a call option, it enforces the second period price competition and increases the value of information for the buyer, reducing the price posted in the first period. However, the new firm can now expect to sell a second unit of the product if the result of the experimentation is good. By offering this contract, the new firm increases its profit. The utility of both buyers increase whereas the profit of the established firm decreases.

We show in the proof of this proposition that the established firm can offer a call option only if the quality of its good is really greater than the expected quality of the new product.

6.2 Forward contracts

Assume now that the new firm proposes a forward contract. Let p_f be the price announced by the new firm for a purchase in the second period.

A buyer will accept this contract if the utility obtained by accepting the contract is greater than the utility obtained by delaying its purchase to the second period. The price p_f must verify : $\beta\tilde{\pi} - p_f \geq \beta E \min\{\rho, \pi_i\}$, which is equivalent to $p_f \leq \beta\tilde{\pi} - \beta E \min\{\rho, \pi_i\}$. The new firm will offer such a contract if its profit is greater than its profit without any contract, that is if $p_1^N + p_f \geq \tilde{\pi} - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B$. Using the relation $p_f \leq \beta\tilde{\pi} - \beta E \min\{\rho, \pi_i\}$, we obtain the following condition on the price p_1^N : we must have $p_1^N > \tilde{\pi}(1-\beta)$.

If the quality of the new product is lower than the quality of the established product, the new firm does not offer a forward contract. Actually, the established firm can announce a strictly positive price p_1^E such that the new firm does not sell in the first period. The new firm can however propose a forward contract if its quality is really high.

Similarly, it can be shown that, as for the call option, the established firm proposes a forward contract only if its quality is really greater than the new product quality.

7 Conclusion

This paper analyzes the dynamic interactions between sellers and buyers behavior in learning environment on a product quality, taking into account an intertemporal substitution on part of buyers. This model is characterized by informational externalities : prices, the timing of actions and the revelation of information are all endogenous.

When both firms can satisfy all the demand in the short term, learning does not affect neither the behavior of firms, nor the behavior of buyers. This results in too little experimentation. When both firms can not satisfy all the demand in a single period, the equilibrium shows how firms can use capacity constraints and intertemporal competition to extract expected informational surplus without waiting for the information. We therefore obtain that the equilibrium is characterized by an excessive experimentation. This equilibrium contains an important inefficiency due to this non waiting behavior. Since information is socially optimal, there is always gain to wait for the information once the cost of experimentation are paid. The study of contracts is then interesting since we show that there exists a call option, proposed by the new firm which implements a waiting behavior. The new firm can propose this call option even if its product quality is lower than the established product quality, which distinguishes the call option from forward contracts proposed only when the quality of the new product is really high. The introduction of a call option by the new firm can therefore allow to suppress the inefficiency associated to the non waiting behavior.

Appendix

Proof of Proposition 1

We have that :

$$V_N = E\max\{\pi_i - \rho, 0\} - \max\{\tilde{\pi} - \rho, 0\}$$

$$V_E = E\max\{\rho - \pi_i, 0\} - \max\{\rho - \tilde{\pi}, 0\}$$

and

$$V_B = E\min\{\rho, \pi_i\} - \min\{\rho, \tilde{\pi}\}$$

First observe that $V_N = V_E$.

Second observe that $\min\{a, b\} = \{\max\{a, b\} - \max\{a - b, b - a\}\}$[12], we obtain

$$\begin{aligned} V_B &= E[\{\max\{\rho, \pi_i\}] - \max\{\rho - \tilde{\pi}, \tilde{\pi} - \rho\}\} \\ &\quad -\{\max\{\tilde{\pi}, \rho\} - \max\{\tilde{\pi} - \rho, \rho - \tilde{\pi}\}\} \end{aligned}$$

and then,

$$\begin{aligned} V_B + V_E &= E\{\max\{\rho - \pi_i, 0\} + \max\{\rho, \pi_i\} \\ &\quad - \max\{\rho - \pi_i, \pi_i - \rho\}\} \\ &\quad -\{\max\{\rho - \tilde{\pi}, 0\} + \max\{\tilde{\pi}, \rho\} - \max\{\tilde{\pi} - \rho, \rho - \tilde{\pi}\}\}. \end{aligned}$$

which is equivalent to

$$\begin{aligned} V_B + V_E &= E\{\min\{\rho - \pi_i, 0\} + \{\max\{\rho, \pi_i\}\} - \{\min\{\rho - \tilde{\pi}, 0\} \\ &\quad + \max\{\tilde{\pi}, \rho\}\} \end{aligned}$$

[12] If $a < b$, $\{\max\{a, b\} - \max\{a - b, b - a\}\} = b - (b - a) = \min\{a, b\}$. When $a > b$, $\{\max\{a, b\} - \max\{a - b, b - a\}\} = a - (a - b) = \min\{a, b\}$.

We finally obtain that

$$V_B + V_E = E\rho - \rho = 0.$$

□

Proof of Proposition 2

Assume that both firms are capacity constrained.

We can express the profits of firms N and E as a function of first period prices p_1^N and p_1^E.

$$\Pi_E = \begin{cases} p_1^E + \beta \max\{\rho - \tilde{\pi}, 0\} & if\ \rho - p_1^E > \tilde{\pi} - p_1^N\ , \rho - p_1^E \geq 0 \\ & and\ \tilde{\pi} - p_1^N < \beta \min\{\rho, \tilde{\pi}\} \\ \\ p_1^E & if\ \rho - p_1^E > \tilde{\pi} - p_1^N \\ & and\ \tilde{\pi} - p_1^N > \beta \min\{\rho, \tilde{\pi}\} \\ \\ \beta E \max\{\rho - \pi_i\} & if\ \rho - p_1^E < \tilde{\pi} - p_1^N, \tilde{\pi} - p_1^N \geq 0 \\ & and\ \rho - p_1^E < \beta E \min\{\rho, \pi_i\} \\ \\ p_1^E & if\ \rho - p_1^E < \tilde{\pi} - p_1^N \\ & and\ \rho - p_1^E > \beta E \min\{\rho, \pi_i\} \\ \\ \beta\rho & if\ \rho - p_1^E < 0\ and\ \tilde{\pi} - p_1^N < 0 \end{cases}$$

$$\Pi_N = \begin{cases} \beta \max\{\tilde{\pi} - \rho, 0\} & if\ \rho - p_1^E > \tilde{\pi} - p_1^N\ \ \rho - p_1^E \geq 0 \\ & and\ \tilde{\pi} - p_1^N < \beta \min\{\rho, \tilde{\pi}\} \\ \\ p_1^N & if\ \rho - p_1^E > \tilde{\pi} - p_1^N \\ & and\ \tilde{\pi} - p_1^N > \beta \min\{\rho, \tilde{\pi}\} \\ \\ p_1^N + \beta E \max\{\pi_i - \rho, 0\} & if\ \rho - p_1^E < \tilde{\pi} - p_1^N, \tilde{\pi} - p_1^N \geq 0 \\ & and\ \rho - p_1^E < \beta E \min\{\rho, \pi_i\} \\ \\ p_1^N & if\ \rho - p_1^E < \tilde{\pi} - p_1^N \\ & and\ \rho - p_1^E > \beta E \min\{\rho, \pi\} \\ \\ \beta\tilde{\pi} & if \rho - p_1^E < 0\ and\ \tilde{\pi} - p_1^N < 0 \end{cases}$$

We compute the best response functions $BR_N(p_1^E)$ and $BR_E(p_1^N)$ of firms N and E to solve for the first period equilibrium prices.

$$\mathrm{B}R_E(p_1^N)\begin{cases} \in\,]\rho-\tilde{\pi}+p_1^N, \beta E\min\{\rho,\pi_i\}] & \text{if } p_1^N < (1-\beta)\tilde{\pi}-\beta E\min\{\rho,\pi_i\} \\ = \ \rho-\tilde{\pi}+p_1^N-\epsilon & \text{if } p_1^N > (1-\beta)\tilde{\pi}-\beta E\min\{\rho,\pi_i\} \end{cases}$$

$$BR_N(p_1^E)\begin{cases} \in\,]\tilde{\pi}-\rho+p_1^E, \beta\min\{\rho,\tilde{\pi}\}] & \text{if } p_1^E < (1-\beta)\rho-\beta\min\{\rho,\tilde{\pi}\}\} \\ = \tilde{\pi}-\rho+p_1^E-\epsilon & \text{if } p_1^E > (1-\beta)\rho-\beta\min\{\rho,\tilde{\pi}\}\} \end{cases}$$

Where $\epsilon \to 0$.

By confronting these two functions we obtain first that firm N announces $p_1^N = \tilde{\pi}-\beta\min\{\rho,\tilde{\pi}\}-\beta V_B-\epsilon$ and firm E announces $p_1^E = \rho-\beta\min\{\rho,\tilde{\pi}\}-\beta V_B$. With these prices, the first period buyer can obtain a utility equal to $\beta\min\{\rho,\tilde{\pi}\}+\beta V_B+\epsilon$ if it experiments which is superior to the utility obtained from a purchase to the established firm or from delaying its purchase to the second period. The follower has then the choice between a purchase to the established firm in the first period or a purchase in the second period. The follower chooses the action which gives the greater utility : the follower purchases the established product in the first period.$\square$

Proof of Proposition 3

Assume that both firms can supply the whole demand in each period.

We can express the profits of firms N and E as a function of first period prices p_1^N and p_1^E.

$$\Pi_E = \begin{cases} 2p_1^E & \mathit{if}\ \rho-p_1^E > \tilde{\pi}-p_1^N \\ & \mathit{and}\ \rho-p_1^E \geq \beta\min\{\rho,\tilde{\pi}\} \\ & \\ 2\beta\max\{\rho-\tilde{\pi},0\} & \mathit{if}\ \rho-p_1^E < \beta\min\{\rho,\tilde{\pi}\}, \\ & \mathit{and}\ \tilde{\pi}-p_1^N < \beta\min\{\rho,\tilde{\pi}\} \\ & \\ 0 & \mathit{if}\ \beta\rho-p_1^E < \tilde{\pi}-p_1^N \\ & \mathit{and}\ \tilde{\pi}-p_1^N \geq \beta\min\{\rho,\tilde{\pi}\} \end{cases}$$

$$\Pi_N = \begin{cases} 0 & if\ \rho - p_1^E > \tilde{\pi} - p_1^N \\ & and\ \rho - p_1^E \geq \beta \min\{\rho, \tilde{\pi}\} \\ & \\ 2\beta \max\{\tilde{\pi} - \rho, 0\} & if\ \rho - p_1^E < \beta \min\{\rho, \tilde{\pi}\}, \\ & and\ \tilde{\pi} - p_1^N < \beta \min\{\rho, \tilde{\pi}\} \\ & \\ 2p_1^N & if\ \rho - p_1^E < \tilde{\pi} - p_1^N \\ & and\ \tilde{\pi} - p_1^N \geq \beta \min\{\rho, \tilde{\pi}\} \end{cases}$$

We compute the best response functions $BR_N(p_1^E)$ and $BR_E(p_1^N)$ of firms N and E to solve for the first period equilibrium prices.

$$\mathrm{B}R_E(p_1^N) \begin{cases} \rho - \beta \min\{\rho, \tilde{\pi}\} & \text{if } p_1^N \geq \tilde{\pi} - \beta \min\{\rho, \tilde{\pi}\} \\ \rho - \tilde{\pi} + p_1^N - \epsilon & \text{if } \tilde{\pi} - \min\{\rho, \tilde{\pi}\} \geq p_1^N > \tilde{\pi} - \beta \min\{\rho, \tilde{\pi}\} \\ \rho - \min\{\rho, \tilde{\pi}\} & \text{if } \tilde{\pi} - \min\{\rho, \tilde{\pi}\} < p_1^N \end{cases}$$

$$BR_N(p_1^E) \begin{cases} \tilde{\pi} - \beta \min\{\rho, \tilde{\pi}\} & \text{if } p_1^E \leq \rho - \beta \min\{\rho, \tilde{\pi}\}\} \\ \tilde{\pi} - \rho + p_1^E - \epsilon & \text{if } \rho - \min\{\rho, \tilde{\pi}\} \geq p_1^E > \tilde{\pi} - \min\{\rho, \tilde{\pi}\} \\ \rho - \min\{\rho, \tilde{\pi}\} & \text{if } \rho - \min\{\rho, \tilde{\pi}\} < p_1^E \end{cases}$$

Where $\epsilon \to 0$.

By confronting these two functions we obtain first that firm N announces $p_1^N = \max\{\tilde{\pi} - \rho, 0\}$ and firm E announces $p_1^E = \max\{\rho - \tilde{\pi}, 0\}$.$\square$

Proof of Proposition 4

Assume that firm N is capacity constrained.

If the expected quality of the new product is lower than the quality of the established one, as shown before, the established firm can sell two units of its product at a price equal to the quality difference. In this case, the profit of the established firm is given by $2(\rho - \tilde{\pi})$. The new firm makes a zero profit. Assume now that the established firm concedes the market to the new firm and sell only to the rationed buyer. In this case, both firms can extract the informational surplus of buyers. The profit of the established firm is given by $\rho - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B$; the profit of the new firm is equal to $\tilde{\pi} - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B$.

The new firm prefers to concede the market to the new firm rather than sell to the two buyers if

$$\rho - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B \geq 2(\rho - \tilde{\pi})$$

which is equivalent to

$$\hat{q} \geq \frac{\rho - \pi_b + (\beta - 1)\pi_b}{2(\pi_g - \pi_b) + \beta(\pi_b - \rho)}.$$

Assume now that firm E is capacity constrained. The equilibrium of the game is the following. If the quality of the new product is greater than the quality of the established one, the new firm sells two units of the good. Equilibrium profits are equal to $2(\tilde{\pi} - \rho)$ for firm N, 0 form firm E. When the quality of the established product is greater than the expected quality of the new product. Firm N can sell to the rationed buyer. Equilibrium profits are given by $(\rho - \beta\tilde{\pi})$ for the established firm and $\tilde{\pi}(1 - \beta)$ for the new firm.$\square$

Proof of Proposition 5

Assume first that both firms are capacity constrained.

To observe at equilibrium that, after an experimentation, the established firm waits for information, the exercise price p_c^N must satisfy the following conditions :

1) the established firm must prefer to wait for information rather than capture the buyer in the first period, $\rho - \beta V_B < \beta\rho + \beta V_E$;

2) the profit of the new firm must increase, $p_1^N + \beta q p_c^N > \tilde{\pi} - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B$.

If the new firm does not commit on a second period price, the equilibrium indicates that the two buyers purchase in the first period and the equilibrium prices are given by $p_1^N = \tilde{\pi} - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B$ and $p_1^E = \rho - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B$.

Assume now that the new firm commits on a second period price p_c^N conditionally on an experimentation in the first period. It then modifies the value of information for the second period buyer. This value is given by $V_B = [q(\pi_g - p_c^N) + (1-q)(\pi_b - \rho)] - \min\{\rho, \tilde{\pi}\}$ which is a decreasing function of p_c^N.

As long as $p_1^E = \rho - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B$ will give to the established firm a greater profit than $\beta E \max\{\rho - \pi_i, 0\}$, the waiting behavior will not be an equilibrium. Therefore, if the new firm commits on a second period price, it will announce p_c^N such that $\rho - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B \leq \beta E \max\{\rho - \pi_i, 0\}$, that is :

$p_c^N \leq \pi_g - \rho(1/\beta - (1-q)/q)$.

It is easy to verify that this inequality holds as an equality at equilibrium and therefore

$$p_c^N = \pi_g - \rho(1/\beta - (1-q)/q).$$

Second, the new firm has to make a greater profit by commiting on a second period price :

$$\tilde{\pi} - \beta \min\{\rho, \tilde{\pi}\} - \beta V_B + \beta q p_c^N \geq \tilde{\pi} - \beta E \min\{\rho, \pi_i\}.$$

The values of q that satisifes the two preceding conditions induce a waiting behavior at equilibrium. Hence waiting occurs in equilibrium whenever :

$$q^* \geq \frac{2\rho(1-\beta)}{\beta(\pi_g - \rho)}.$$

Assume now that firm N only has a capacity constraint.

We must now insure that the established firm prefers to wait for the second period game rather than sell two units of its product in the first period. The following condition must also be satisfied :

$$2(\rho - \tilde{\pi}) \leq \beta\rho + \beta V_E.$$

which is eqivalent to

$$q \geq \frac{2(\rho - \pi_b) + \beta(\pi_b - \rho)}{2(\pi_g - \pi_b) + \beta(\pi_b - \rho)}$$

The new firm will offer a call option only if

$$q \geq q^* = \frac{2\rho(1-\beta)}{\beta(\pi_g - \rho)}.$$

We must now check that $q^* > \hat{q}$.

$q^* > \hat{q}$ is equivalent to

$$\beta(\rho - \pi_b)[\beta(\rho + \pi_b) - 2\pi_b] + 4\rho(1-\beta)(\pi_g - \pi_b) > 0$$

which is verifed. We now present the use of an option by the established firm when both firms are capacity constrained. Let p'_e be the premium and p_c^E the exercise price. We assume that $p'_e = 0$.

The established firm will propose an option only if the first buyer purchases its product in the first period. The second period game is then the following. If the exercise price is such that $\rho - p_c^E \geq \tilde{\pi} - p_2^N$, the second buyer will exerce its option. Otherwise, the second buyer purchases the new product. If the the established firm use an option, the exercise price then satisfies $p_c^E \leq \max\{\rho - \tilde{\pi}, 0\}$. The established firm proposes an option only if the expected quality of the new product is lower than the quality of its product.

To observe that the established firm proposes an option, prices must satisfies the following conditions

1) The profit of the established firm must increase, $p_1^E + \beta p_c^E \geq \rho - \beta\tilde{\pi} - V_B\beta$

2) The new firm must prefer not to sell rather than sell to the second buyer in the first period, $\tilde{\pi} - \beta(\rho - p_c^E) \leq 0$.

We obtain that the exercise price p_c^E is equal to $\rho - (1/\beta)\tilde{\pi}$.

A necessary condition for the established firm to propose an option is then

$$\tilde{\pi} + \tilde{\pi}(1+\beta) - \beta\rho - \beta V_B \leq 0.$$

This condition can be verified when the expected quality of the new product is strictly lower than the quality of the established product.

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