

Intra-Firm Bargaining and Learning in a Market Equilibrium*

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Abstract

This paper introduces an agency relationship into a dynamic game with informational externalities. Two competing firms plan to launch a new product and in each firm headquarters bargain with its R&D division about the cost of developing this product. The development cost is the private information of R&D divisions and is correlated across the two firms. We find that the agency relationship creates an incentive for simultaneous launching of the product, even if this involves an inefficient delay. As the commitment power of the headquarters decreases, this incentive becomes stronger. The effect of competition is decomposed into two parts. Inter-period competition (from past and future sales) pushes firms towards launching the product simultaneously, while intra-period competition (from concurrent sales) does the opposite.

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1 Introduction

When thinking about launching a new product, a firm's management or headquarters may not be completely sure about how much it will cost to develop. The R&D division usually has a better idea about the development costs. However, it is unlikely that the division would provide such information for free; typically, it would inflate the costs. The decision of a competitor to introduce a similar product will provide information that the product is not "too expensive" to develop. Headquarters now have a better bargaining position vis-à-vis their R&D division. However, the competitor's headquarters, which face the same problem, may also decide to wait for the information. Natural questions then arise. *When is the product launched? Do firms launch the product simultaneously? What is the effect of the strategic behaviour of the R&D divisions? How does competition affect the equilibrium?*

The aim of this paper is to study the effect of the agency relationship in a dynamic game with informational externalities. Its crucial feature is that the information which is being released and learned is about strategic agents (divisions). These can influence what and when the uninformed parties (headquarters) learn. Agents' incentives are shaped by both current and expected future rents and, therefore, future information affects them even *before* it becomes known.

Learning about the agent from the experience of others but also providing information to them is a feature of many real-life situations. Consider a country opening up to foreign capital. When a foreign firm discusses a joint project (foreign direct investment) with a local firm, it does not know exactly what the cost will be. If local firms have similar technologies, the foreign firm can wait and have a better idea of local firms' characteristics by observing the experience of other foreign firms in this market. However, a late entry may not be as profitable as an early one. Another example is that of unions bargaining with firms. The firms are privately informed of their profits, their market prospects, etc. This information is correlated across firms in the same industry. Then, each union may delay the agreement in order to learn the outcome of negotiations in other firms. Waiting too long, however, can be costly as the suppliers and consumers may switch to other firms.

In our model, two identical firms, A and B , compete in a product market. In each firm, there are headquarters and an R&D division. The cost of the R&D of the product is the private information of the division; headquarters know only the

cost distribution. Each R&D division develops the product at most once during the relationship. The costs of the two R&D divisions are perfectly correlated.¹

There are two periods, and all participants share a common discount factor. The bargaining between headquarters and their R&D division proceeds à la Sobel and Takahashi (1983). In period 1, the headquarters offer a price they are ready to pay for the product development in that period. If the division accepts it, development takes place; the headquarters sell the good in the market, and the game ends for this firm. If the R&D division rejects the offer, the game moves to period 2. Headquarters then observe whether the other firm has introduced the product or not and make another offer to their division that it is free to accept or reject.

In any equilibrium, there is a cut-off level of cost at which a division is indifferent as to whether it accepts developing the product in period 1, or waiting for a second-period offer. Thus in period 1, by its decision each division reveals whether its cost is above or below this cut-off. Then, each headquarters have an incentive to delay the development of its own product in order to obtain information about the cost of development of the other R&D division and, because they are the same, the cost of development of its own R&D division. The delay is costly, however, because of discounting and because of competition between firms, as we discuss below.

The agency problem in our adverse selection environment means that the division may pretend to have higher costs than it actually has. Then, it may reject a profitable offer in period 1 if it expects a sufficiently higher offer in period 2. In order to see the effect of this strategic behaviour, we first consider the *benchmark setting* in which the division is non-strategic: it accepts any offer in period 1 that is higher than its costs. We then study the *full-commitment setting* in which the division is strategic (it can reject an offer above its costs in period 1), but the headquarters can commit to a two-period contract. We also look at the *no-commitment setting* in which the division is strategic and the headquarters can propose only one-period contracts.

In the absence of product market competition, the only feature of the contracting in each firm that is relevant for the other firm is the information generated in period 1, i.e., the cut-off level of cost. We look for the equilibria in these cut-offs. We find that there are only asymmetric equilibria (in pure strategies) in the benchmark setting, while there are only symmetric equilibria in the full and no-commitment settings. In the benchmark setting, having the same cut-offs implies that the two

¹The R&D divisions can be thought of as independent (exclusive) suppliers.

divisions will generate exactly the same information. Headquarters prefer then to have different cut-offs in order to learn more. When the divisions are strategic, in contrast, having the same cut-offs becomes useful as it puts the headquarters in the best position to limit the strategic behaviour of the divisions. If a division deviates from the equilibrium behaviour and rejects a first-period offer which is above its cost, the other division will still accept the same offer and, therefore, headquarters will detect the deviation and will not improve their offer in period 2.

More generally, we show that the sets of symmetric equilibria are always nested: the smallest is in the benchmark setting (it may be non-empty once competition is introduced) and the largest is in the no-commitment setting. In other words, the agency problem drives the firms towards symmetric behaviour. Moreover, when the contractual imperfections increase and only one-period contracts are available, there is more need to discipline the agents and the symmetric behaviour becomes even more likely. The strategic behaviour of the R&D divisions creates a coordination motive in headquarters' actions. Therefore, the internal structure of the firm and, in particular, the way the agency problem is solved cannot be studied in isolation.

Efficiency is affected by informational externalities via two effects. The first effect is a standard one: the possibility to learn in the future causes the headquarters to delay in the introduction of the new product, which harms efficiency.² The second effect is strategic and increases efficiency. Since offers in period 2 are made under better information, they give a lower rent to the division in period 2 and, therefore, the division becomes "softer", i.e., more likely to accept a given offer, in period 1. The second effect arises, obviously, only when the division is strategic. In the benchmark setting there is just the first effect, so informational externalities decrease efficiency. In the full-commitment setting, the strategic effect is crucial. In the autarky, i.e., when the firm is alone in the market, headquarters would commit to a take-it-or-leave-it offer in period 1 which is very inefficient.³ Information obtained from the other firm allows headquarters to revise their offer and to contract with high cost types in period 2. In the no-commitment setting, the strategic effect becomes less important as the headquarters revise their offer anyway and the autarky is relatively efficient. The standard effect is likely to dominate, as in the benchmark setting.

²We assume that firms make profits for any cost realization. Thus, any delay is inefficient and is due to rent extraction by the headquarters.

³This is a standard result in dynamic bargaining models. See, for example, Sobel and Takahashi (1983) and Hart and Tirole (1988).

Competition may take various forms and we allow for a great flexibility in the ways in which it affects firms' profits. We distinguish intra-period competition, that is, competition from concurrent sales, from inter-period competition, that is, competition from past sales and future sales.⁴ Competition from past sales reflects first-mover advantage: a second entrant in the market obtains smaller revenues than the first one. We find that inter-period competition pushes firms towards symmetric behaviour. For example, in the benchmark setting the competitive pressure may force firms to forego the benefits of more information and opt to make the same offers. The effect of intra-period competition is the opposite. Headquarters may choose to offer different contracts and tolerate some strategic play of the divisions in order to differentiate themselves and introduce the product in different periods.

The rest of the paper is organized as follows. Below we discuss the related literature. In Section 2 we introduce the model and find equilibria in the benchmark and the full-commitment settings assuming no competition. In Section 3 we introduce competition and analyze the effects of the four kinds of competition mentioned above. We study the no-commitment setting in Section 4. In Section 5 we consider alternative information structures. The first structure allows for imperfect correlation between the costs of the two divisions, while in the second the costs of a division are completely revealed if it develops the product in period 1, for example, through reverse engineering by the other firm. Section 6 concludes.

1.1 Related literature

The two most closely related papers are those of Gu and Kuhn (1998) and Drugov (2007). Gu and Kuhn (1998) study simultaneous bargaining of several firms with their unions. However, in order to simplify the model, they assume that the principal (union) can make an offer only once (but can choose when) and, therefore, the agent (firm) cannot be strategic.⁵ This setup roughly corresponds to our benchmark setting. In Drugov (2007) the agent can strategically reject the principal's offer in

⁴Note that under intra-period competition in period 2 and inter-period competition from future sales the second-period probability of development, i.e., the second-period cut-off, also becomes relevant for the other firm.

⁵In a related paper, Kuhn and Gu (1999) study the same game with the possibility of a strategic rejection, but impose a sequential order of moves and, therefore, the revelation of information is exogenous. The first bargaining occurs in the autarky, while the second starts with more information.

an anticipation of a higher rent in the future. The model there is quite different as there are only two types of agent, but the quantity produced is continuous. In both papers, the only cost of the delay is discounting. In this paper, besides discounting, the cost of the delay is also a disadvantage of not being the first in the market and, therefore, depends on the strategy of other players. In other words, both the benefits of the delay (learning the information revealed by others) and the costs of the delay (being late in the market) are fully endogenous and may vary in different equilibria.

There is an extensive literature on learning from competitors. It may be about a technology (see, for example, Reinganum (1989) and De Bondt (1997) for surveys of patent, or R&D, races) or about the market or demand characteristics as in Rob (1991), Décamps and Mariotti (2004) and others. The crucial difference is that, in this paper, the learning is about the agent (the R&D division) who is a strategic player. In models of the investment-under-uncertainty type as in Dixit and Pindyck (1994), better information in the future always delays the investment since it increases the payoff of investing in the future while the payoff of investing today is unchanged. In an agency model, better future information makes the agent softer both in the future and in the present, and may lead to more contracting in the present, i.e., a smaller delay (Drugov (2006), Fuchs and Skrzypacz (2008)).

Several recent papers such as Raith (2003), Golan, Parlour, and Rajan (2007) and Marin and Verdier (2008) study a general, or rather industry, equilibrium in which the agency problem inside firms and market competition interact and influence each other. We also make a step in this direction. These papers study models with moral hazard in which competition affects contracts inside firms through changes in the profits that the principal obtains from a given agent's action. In our model, the agency problem is adverse selection, and competition has a dual role of providing information about the agents' types and changing principal's profits from a given contract. However, the informational role of competition may be important in the moral hazard environment as well. Indeed, starting with Lazear and Rosen (1981) and Holmstrom (1982) comparing performance of different agents is known to provide additional information, if there are common shocks to agents' performance. Then, the dual role of competition seems natural independently of the type of the agency problem.

It is well known that the principal can use correlation among agents' types to extract rents (see Crémer and McLean (1985) and Shleifer (1985) for early papers).

We obviously use this insight but the present paper differs in two aspects. First, in our paper there are many "principal-agent" pairs and not a single principal.⁶ Second, we study a dynamic game which allows us to analyse delay in contracting. Several papers study an adverse selection problem with an exogenous signal about agent's type. This is precisely the first step in analysing our model, the signal being information revealed by the other firm (taken as given). Fuchs and Skrzypacz (2008) analyze an infinite-horizon bargaining model and show that the delay is non-monotonic in the likelihood of a signal that reduces informational asymmetry. In Drugov (2006), in a two-period model, we show a related result that the delay is non-monotonic in the quality of the signal (as Drugov (2007), it is a two-type model with continuous quantity). In Strausz (2006) the model is also dynamic but the agent has unlimited liability which is known to be crucial for Crémer-McLean mechanisms (together with risk neutrality). Other papers, such as Riordan and Sappington (1988), Demougin and Garvie (1991), Boyer and Laffont (2003) and Gary-Bobo and Speigel (2006), study a static adverse selection problem with an exogenous contractible signal.

2 The Model

2.1 Setup

Two firms, A and B , plan to introduce a new product into the market. This product has yet to be developed. In particular, in each firm, headquarters (the principal) negotiate with the R&D division (the agent) about the development of the product. There are two periods, and all parties share a common discount factor $\delta < 1$. Each R&D division may develop the new product only once, either in period 1 or in period 2. The two divisions have the same cost of development, θ , uniformly distributed on $[0, 1]$.^{7,8} They know θ , but headquarters know only its distribution. If the product is developed, the production costs are zero. In what follows we use the words "develop"

⁶Another early paper is Nalebuff and Stiglitz (1983) that discusses, mostly informally, the benefits of relative compensation in markets where firms have correlated costs. There, firms design contracts taking information from other firms as given.

⁷Assuming uniform distribution allows us to obtain closed-form solutions. Qualitative results do not depend on this assumption.

⁸We consider imperfect correlation in Section 5.1.

and "produce" interchangeably.

If a firm introduces the product in period 1, it obtains revenues of v_1 ; introducing the product in period 2 yields v_2 . In this Section, there is no competition so the revenues do not depend on the behaviour of the other firm (competition is analyzed in Section 3). Introducing the product in period 1 is more profitable, $v_1 \geq v_2$, since it may be sold for two periods (if the product is non-durable) or it may be used for two periods (if it is a durable good). Also, it is always efficient to develop the product, $v_2 \geq 1$. Therefore, if some types do not produce, this is only for rent-extraction reasons. Finally, we also assume that $v_1 \leq 2$ in order to avoid trivial cases.

The timing of the game is as follows. At the beginning of period 1 each headquarters propose a contract to their R&D division. If a division agrees to develop the product in period 1, it does so, headquarters earn v_1 and the game is over for that firm. If the division does not develop the product in period 1, both headquarters and the division observe whether the other firm has developed the product in period 1 (but they do not observe the contract between the other firm's headquarters and the division). Then headquarters make an offer in the beginning of period 2 which the division accepts or rejects. Production, transfers and selling of the good in the market, if any, take place and the game ends.

The agency problem in our adverse selection environment means that the division may pretend to have higher costs than it actually has. Then, it may reject a profitable offer in period 1 if it expects a sufficiently higher offer in period 2. In order to see the effect of this strategic behaviour, we first consider the *benchmark setting* in which the division is non-strategic: it accepts any offer in period 1 that is higher than its costs. It can also be interpreted as the headquarters committing to outsource the development of the product if the offer is rejected. We then study the *full-commitment setting* in which the division is strategic (it can reject an offer above its costs in period 1) and the headquarters can commit to a two-period contract (possibly conditional on the production decision of the other firm in period 1). In Section 4, we also look at the *no-commitment setting* in which the division is strategic and the headquarters can propose only one-period contracts.

A strategy of each headquarters is a triple (p_1, p_2^y, p_2^n) (all offered in period 1 or not, depending on the setting), where p_1 is the price to be paid to the division if it develops the product in period 1, and p_2^y and p_2^n are the prices, conditional on whether the other division has produced or not, to be paid for the development in

period 2.⁹ We consider only pure strategies.¹⁰

The equilibrium concept is Perfect Bayesian Equilibrium. We solve the model in the following way. In period 1, a division is indifferent about producing or not producing when its type is the cut-off type, $\theta = s$. If $\theta < s$, the division strictly prefers to produce in period 1, while it strictly prefers not to produce if $\theta > s$. The information revealed by each firm after period 1 is a partition, whether the type is below or above s . Then, s summarizes all the information revealed by each firm after period 1 and, therefore, only s (which is the probability of production in period 1) is payoff-relevant for the other firm. In an equilibrium, any strategy (p_1, p_2^y, p_2^n) maps into a cut-off type s of that firm's division. The strategies of the two firms can then be characterized by reaction functions $s^A(s^B)$ and $s^B(s^A)$ and their intersections are equilibria. Since the two firms are (ex ante) identical, $s^A(s^B)$ and $s^B(s^A)$ are symmetric about the diagonal.

In each setting, we will first find the reaction function $s^A(s^B)$ (that is, we solve the problem of headquarters A) and then look for intersections with its inverse. We also find prices p_1, p_2^y and p_2^n offered by headquarters A to division A (that we do not mark with superscript "A" to keep notation simple as this does not create any confusion.)

2.2 The Benchmark

In the benchmark setting, the R&D divisions do not behave strategically. Facing an offer p_1 , division A accepts it if it is higher than its costs. Thus, the cut-off type is $s^A = p_1$.

After period 1, observing whether firm B has introduced the product or not, headquarters A learn if the division's costs θ are higher or lower than s^B (remember that the costs are perfectly correlated). There are two cases to consider depending on whether their first-period offer p_1 is higher or lower than s^B .

Start with the case $s^A \geq s^B$ that we call *case a* (for *above*). The information

⁹The fact that p_1 is not conditional on the behaviour of the other firm matters only if the division is strategic and it is justified by additional assumptions that we introduce in Section 2.3 on full commitment.

¹⁰Mixed strategies introduce a significant complication since the updated beliefs after observing (no) production by the other firm in period 1 are not truncated uniform. Also, a pure-strategy equilibrium always exists in our model.

generated by firm B is useless since, following a rejection of an offer in period 1, the headquarters learn that θ is higher than s^A which is more precise than the fact that θ is higher than s^B . Then, headquarters A act as if they were in the *autarky* (i.e., alone in the market) and solve the following problem¹¹

$$\begin{cases} \max_{p_1, p_2^n} \Pi_a^{BM} = (v_1 - p_1) p_1 + \delta (v_2 - p_2^n) (p_2^n - p_1) \\ \text{s.t. } s^B \leq p_1 \leq p_2^n \leq 1 \end{cases} \quad (1)$$

(superscript "BM" refers to the benchmark setting).

When p_1 and p_2^n are offered, with probability $p_1 = s^A$ the development takes place in period 1, in which case the profits are $v_1 - p_1$; with probability $p_2^n - p_1$ it takes place in period 2, in which case the profits are $\delta (v_2 - p_2^n)$. If division A rejects p_1 , the headquarters A never observe production in firm B and therefore p_2^y is irrelevant. The two prices are obtained from the first-order conditions of (1) unless the constraints $s^B \leq p_1, p_2^n \leq 1$ bind, that is,

$$p_1 = \min \left\{ \max \left\{ s^B, \frac{v_1 - \delta v_2 + \delta p_2^n}{2} \right\}, 1 \right\}, \quad (2a)$$

$$p_2^n = \min \left\{ \frac{v_2 + p_1}{2}, 1 \right\}. \quad (2b)$$

Consider now the case $s^A \leq s^B$ which we call *case b* (for *below*). In this case the information generated by firm B is useful since, following a rejection of a first-period offer $p_1 = s^A$, the headquarters learn if the costs of the divisions are in the interval $(s^A, s^B]$ or $(s^B, 1]$. The headquarters maximize¹²

$$\begin{cases} \max_{p_1, p_2^y, p_2^n} \Pi_b^{BM} = (v_1 - p_1) p_1 + \delta [(v_2 - p_2^y) (p_2^y - p_1) + (v_2 - p_2^n) (p_2^n - s^B)] \\ \text{s.t. } p_1 \leq p_2^y \leq s^B \leq p_2^n \leq 1. \end{cases} \quad (3)$$

From the first-order conditions and the constraints, the expressions for the three prices are

¹¹This is the setting of Sobel and Takahashi (1983).

¹²Note that, at $s^A = s^B$, (1) and (3) are identical.

$$p_1 = \min \left\{ \frac{v_1 - \delta v_2 + \delta p_2^y}{2}, s^B \right\}, \quad (4a)$$

$$p_2^y = \min \left\{ \frac{v_2 + p_1}{2}, s^B \right\}, \quad (4b)$$

$$p_2^n = \min \left\{ \frac{v_2 + s^B}{2}, 1 \right\}. \quad (4c)$$

The price offered when there was no production by firm B , p_2^n , does not depend on p_1 since the updated beliefs of the headquarters are that $\theta \in (s^B, 1]$, and therefore do not depend on p_1 .

Once the maximal profits Π_a^{BM} and Π_b^{BM} have been found using (2) and (4), respectively, we can find when s^A is above and below s^B and therefore characterize the optimal contract as a function of s^B . This is done in the next Lemma. We only characterize s^A in the text of the Lemma since it is enough to find equilibria. We give the complete characterization in the proof in the Appendix.

Lemma 1 *In the benchmark setting, there are two cases:*

1. If $\frac{v_1 + (2-\delta)v_2}{4-\delta} \geq 1$, there exists $\theta_1^{BM} \in \left(\frac{v_1 - \delta v_2}{2-\delta}, \frac{v_1 - \delta v_2 + \delta}{2} \right)$ such that

$$s^A = \begin{cases} \frac{v_1 - \delta v_2 + \delta}{2}, & \text{if } s^B \leq \theta_1^{BM} \\ \frac{v_1 - \delta v_2 + \delta s^B}{2}, & \text{if } s^B > \theta_1^{BM} \end{cases}$$

2. If $\frac{v_1 + (2-\delta)v_2}{4-\delta} < 1$, there exists $\theta_2^{BM} \in \left(\frac{v_1 - \delta v_2}{2-\delta}, \frac{v_1 - \frac{\delta}{2}v_2}{2-\frac{\delta}{2}} \right)$ such that

$$s^A = \begin{cases} \frac{v_1 - \frac{\delta}{2}v_2}{2-\frac{\delta}{2}}, & \text{if } s^B \leq \theta_2^{BM} \\ \frac{v_1 - \delta v_2 + \delta s^B}{2}, & \text{if } s^B \in \left[\theta_2^{BM}, \frac{v_1 + (2-\delta)v_2}{4-\delta} \right] \\ \frac{v_1 - \frac{\delta}{2}v_2}{2-\frac{\delta}{2}}, & \text{if } s^B \geq \frac{v_1 + (2-\delta)v_2}{4-\delta} \end{cases}$$

Proof. See Appendix. ■

The two cases are very similar. When s^B is small, s^A is larger than s^B and constant. We are in case a and the information is not used. At a higher $s^B = \theta_1^{BM}$ or $s^B = \theta_2^{BM}$, depending on case 1 or 2, s^A jumps down to $\frac{v_1 - \delta v_2 + \delta s^B}{2} < s^B$ (case b) and continues to be smaller than s^B for even higher s^B . See Figure 1 for a numerical

example.¹³ The most important feature of the optimal s^A is that it never equals s^B . Indeed, whenever $s^A = s^B$, it generates exactly the same partition of the division's type space and, therefore, the information from the other division is useless. The headquarters then prefer either to decrease s^A to be able to use the information from division B or to increase s^A up to the autarky level. Also note that s^A is the same at $s^B = 0$ and at $s^B = 1$ since there is no information actually revealed and, therefore, the autarky solution is implemented.

The two firms are identical; thus, the reaction function of firm B is the inverse of that of firm A . Then, in order to find equilibria we need to find intersections of the reaction curve $s^A(s^B)$ with its inverse, which is done in the next Proposition (the exact values of equilibrium points are given in the Appendix).

Proposition 1 *In the benchmark setting, there are only two equilibria and they are asymmetric.*

Proof. See Appendix. ■

In an asymmetric equilibrium, by definition, the first-period production in one firm, say, firm A , is higher than that in firm B , $s^A > s^B$. Then, when $\theta \in (s^B, s^A)$ only firm A introduces the product in period 1. In other words, with probability $s^A - s^B$, firm A is the "leader" and firm B is the "follower" introducing the product in period 2 with a positive probability. The strategy of firm B can be described as "wait and see" and it is more profitable than being the "leader" (see profits in Figure 1). Firm A , knowing that firm B will wait, has to act on its own and use the autarky solution. This asymmetric equilibrium exists despite the fact that the firms are ex ante identical and there is a place for both of them in the market.

Let us discuss the efficiency of the equilibria. Production is always efficient in our model since $v_1 \geq v_2 \geq 1$. For the same total production over two periods, it is more efficient to produce in period 1 than in period 2 since $v_1 > \delta v_2$. Second-period prices and, therefore, second-period production are weakly increasing in the first-period price (production). Then, efficiency increases with the first-period production, i.e., with s .

In an asymmetric equilibrium, the "leader" has a higher first-period production and, thus, is more efficient than the "follower". The behaviour of the "leader", as

¹³The only difference between the two cases is that the constraint $p_2^n \leq 1$ always binds in case 1, while in case 2 it does not bind when $s^B < \theta_2^{BM}$ and $s^B > \frac{v_1 + (2-\delta)v_2}{4-\delta}$.

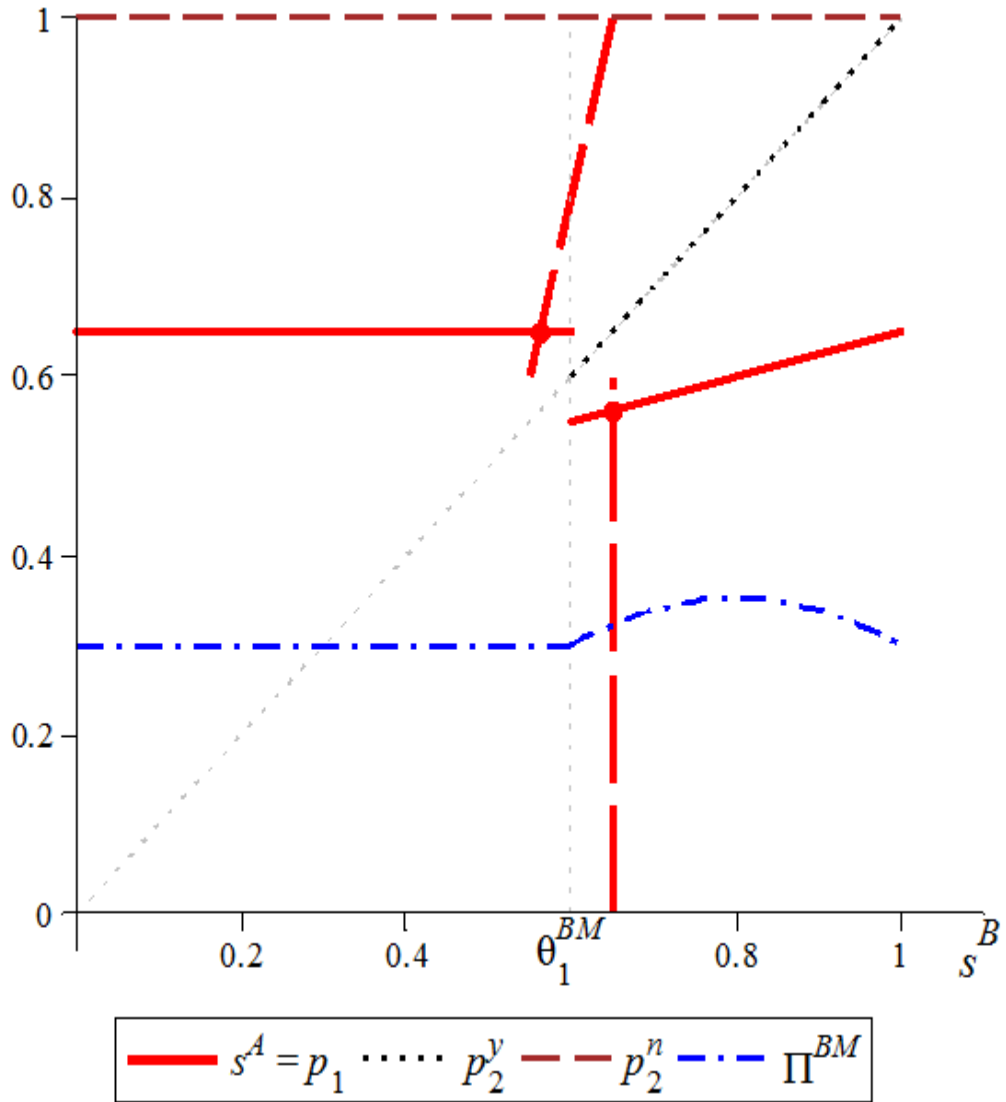


Figure 1: Prices and profits in the benchmark setting (case 1), $v_1 = 1.5$, $v_2 = 1.4$, $\delta = 0.5$. The long-dashed line is the inverse p_1 and its intersections with p_1 are (asymmetric) equilibria. For profits, the scale is adjusted.

we noted above, is the same as in the autarky, that is, when each firm acts on its own. The autarky is then more efficient since both firms would behave as "leaders". Indeed, informational externalities create an incentive to delay the production which is inefficient, though, privately optimal (the "follower" has higher profits than the "leader"). This is the only effect in the benchmark setting.¹⁴

2.3 Full commitment

In this Section, the R&D division is strategic: it agrees to develop the product in period 1 only if its rent is higher than its expected rent from waiting for period 2. The headquarters can commit to a two-period contract.

We make two following assumptions to ensure that, if headquarters want to use the information from the other firm, they have to delay the production until period 2. First, limited liability of the division: the rent earned by the division (payment it receives minus its true costs) is consumed in the same period and cannot be claimed back later even if the headquarters realize, after observing the other firm, that they have paid too much. Second, the credit (or cash) constraint of the division: headquarters have to cover the (claimed) costs of the division in the period when the development takes place. That is, the headquarters cannot order the development of the new product and pay for it later when there will be more information. These constraints imply that, at the beginning of period 1, headquarters propose a first-period price p_1 and a non-negative bonus to be paid later (conditional on future information). Moreover, only a division with costs below p_1 can accept this offer, and therefore, $s^A \leq p_1$. The bonus could be used to bring s^A closer to p_1 ; however, as we will see below, the full commitment solution involves $s^A = p_1$ and the optimal bonus is actually zero. Then, the contract offered by the headquarters at the beginning of period 1 is a triple (p_1, p_2^y, p_2^n) .

Once contracts have been offered (simultaneously and secretly) by the headquarters, each division decides whether to produce in period 1 or not; if it does not, it will be offered a pre-specified second-period price conditional on the production of the other firm. As in the benchmark setting, we first look for the optimal cut-off type

¹⁴In a different model, informational externalities could improve second-period production of all the firms, not only of the "follower". Then, there would be a trade-off between a higher delay of the "follower" and a better second-period production of the "leader".

of division A , s^A , taking the cut-off type of division B , s^B , as given. The equilibria are then obtained by finding intersections of $s^A(s^B)$ with its inverse.

Start with case a where $s^A \geq s^B$. If division A has costs $\theta \leq s^B$, it will produce in period 1. Indeed, it knows that, if it does not produce in period 1, the headquarters will learn that its costs are below s^B since division B will produce in period 1 and the second-period price p_2^y will satisfy $p_2^y \leq s^B \leq p_1$. Then, division A finds it optimal to produce in period 1.

The division with costs $\theta > s^B$ has a rent of $p_1 - \theta$ if it produces in period 1. If it does not produce, it will be offered a price $p_2^n \geq p_1$ since in period 1 the other division will not have produced either. Its rent will be $\delta(p_2^n - \theta)$. The cut-off type s^A is then

$$s^A = \frac{p_1 - \delta p_2^n}{1 - \delta}. \quad (5)$$

The problem of the headquarters is

$$\left\{ \begin{array}{l} \max_{p_1, p_2^n} \Pi_a^{FC} = (v_1 - p_1) s^A + \delta (v_2 - p_2^n) (p_2^n - s^A) \\ \text{s.t. } s^B \leq p_1 \leq p_2^n \leq 1 \text{ and (5).} \end{array} \right. \quad (6)$$

In case b , i.e., $s^A \leq s^B$, by a similar logic, the type which is indifferent between production in period 1 and in period 2 is $s^A \leq s^B$ given by

$$s^A = \frac{p_1 - \delta p_2^y}{1 - \delta}. \quad (7)$$

The headquarters' problem is

$$\left\{ \begin{array}{l} \max_{p_1, p_2^y, p_2^n} \Pi_b^{FC} = (v_1 - p_1) s^A + \delta [(v_2 - p_2^y) (p_2^y - s^A) + (v_2 - p_2^n) (p_2^n - s^B)] \\ \text{s.t. } p_1 \leq p_2^y \leq s^B \leq p_2^n \leq 1 \text{ and (7).} \end{array} \right. \quad (8)$$

The next Lemma simplifies further analysis. It says that the headquarters commit not to change their offer (unless there is evidence that the first-period price was unacceptable for the division). The reason is that the losses that occur because

the division delays its production outweigh the benefits of an additional production in period 2. This is the same reason as in Sobel and Takahashi (1983) and, more generally, in the bargaining literature where, for example, the seller, selling to a privately informed buyer, restricts sales to a single period.

Lemma 2 *In case a, $p_1 = p_2^n = s^A$. In case b, $p_1 = p_2^y = s^A$.*

Proof. For case a, plug (5) into Π_a^{FC} and differentiate it with respect to p_2^n to obtain

$$\text{sign} \left[\frac{\partial \Pi_a^{FC}}{\partial p_2^n} \right] = \text{sign} [2p_1 - 2p_2^n + v_2 - v_1].$$

As $v_1 \geq v_2$, the derivative is negative if $p_2^n > p_1$. Then, $p_2^n = p_1$ and, from (5), $s^A = p_2^n = p_1$.

Case b is proved analogously. ■

Note that in case b the second-period price when no firm produced in period 1, p_2^n , is ex post efficient: $p_2^n = \min \left\{ \frac{s^B + v_2}{2}, 1 \right\}$. The headquarters commit not to change their offer unless they receive a signal that the first-period offer was too low.

As the headquarters commit not to increase the (relevant) price in the future, the division accepts any offer above its costs. Then, the first-period price is also the division's type which is indifferent about producing in period 1 or 2. The next Lemma characterizes the optimal s^A . Figure 2 shows the optimal s^A , prices and profits.

Lemma 3 *In the full-commitment setting, there exists $\theta^{FC} < \frac{v_1}{2}$ such that*

$$s^A = \begin{cases} \frac{v_1}{2}, & \text{if } s^B \leq \theta^{FC}, \\ s^B, & \text{if } s^B \in [\theta^{FC}, \frac{v_1}{2}], \\ \frac{v_1}{2}, & \text{if } s^B \geq \frac{v_1}{2}. \end{cases}$$

Proof. Using Lemma 2, (6) becomes

$$\max_{p_1 \in [s^B, 1]} \Pi_a^{FC} = (v_1 - p_1) p_1$$

and the optimal price is $p_1 = \max \left\{ \frac{v_1}{2}, s^B \right\}$. (8) becomes

$$\max_{p_1 \leq s^B \leq p_2^n \leq 1} \Pi_b^{FC} = (v_1 - p_1) p_1 + \delta (v_2 - p_2^n) (p_2^n - s^B)$$

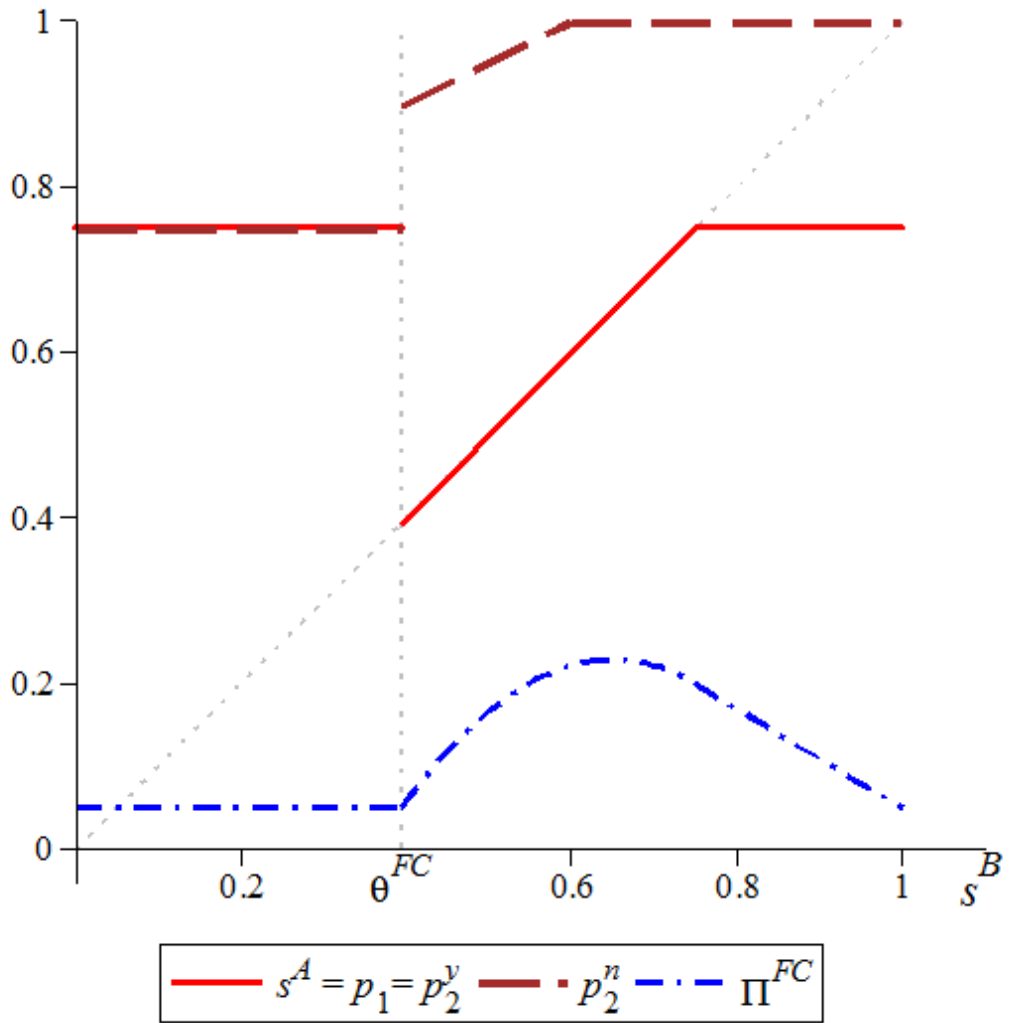


Figure 2: Prices and profits in the full-commitment setting, $v_1 = 1.5$, $v_2 = 1.4$, $\delta = 0.5$. For profits, the scale is adjusted.

and the optimal prices are $p_1 = s^A = \min \left\{ \frac{v_1}{2}, s^B \right\}$ and $p_2^n = \min \left\{ \frac{v_2 + s^B}{2}, 1 \right\}$.

Finally, $\Pi_a^{FC} < \Pi_b^{FC}$ for $s^B \geq \frac{v_1}{2}$, therefore, $\theta^{FC} < \frac{v_1}{2}$ and is found from the equality of profits in the two cases with the corresponding prices inserted. ■

The optimal cut-off s^A equals $\frac{v_1}{2}$, with the exception of the range $[\theta^{FC}, \frac{v_1}{2}]$ where it equals s^B . When $s^A = \frac{v_1}{2}$ and is above s^B , headquarters do not use the information. To use the information, the production has to be at most s^B . Thus, headquarters face a trade-off: to distort s^A downwards and to use information or not to distort s^A and to ignore information. When s^B becomes close enough to $\frac{v_1}{2}$, the distortion of s^A becomes relatively small and the benefits of information outweigh the losses due to the distortion. This happens at $s^B = \theta^{FC}$. Headquarters keep the distortion minimal, that is, $s^A = s^B$. In contrast to the benchmark setting, having $s^A = s^B$ is useful as it allows headquarters to detect the strategic rejection of p_1 . When s^B exceeds $\frac{v_1}{2}$, headquarters keep s^A undistorted at $\frac{v_1}{2}$ and still use the information.

Let us now turn to the equilibria of the game which are characterized in the next Proposition.

Proposition 2 *In the full-commitment setting, there is a continuum of symmetric equilibria in which both firms have the same production $s^A = s^B \in [\theta^{FC}, \frac{v_1}{2}]$. There are no other equilibria.*

All the equilibria are symmetric in the full-commitment setting. This means that the two firms always introduce the new product simultaneously, whether it be in period 1 or in period 2. The two firms generate the same information (the same partition) and headquarters use the information from the other firm to discipline their division. In the benchmark setting, there was no need for this and generating the same information was useless. Offering identical contracts, headquarters can detect strategic rejection of the contract in period 1, that is, rejection when the costs of the division θ are below p_1 , since in this case both divisions are supposed to accept the contracts and produce in period 1. Then, headquarters can contract with their division in period 2 when no firm produced before offering $p_2^n > p_1$ without a strategic response from the division in period 1. Indeed, as we see from (7), p_2^n does not affect s^A in case b .

These multiple symmetric equilibria can be ranked in terms of their efficiency. As we noted above, a higher first-period production, that is, a higher cut-off s , corresponds to a higher and earlier total production and, therefore, a higher efficiency.

Then, the "highest" symmetric equilibrium, in which $s^A = s^B = \frac{v_1}{2}$, is the most efficient one. In the autarky, each firm produces at the same level $s = \frac{v_1}{2}$ in period 1; however, headquarters commit to this take-it-or-leave-it offer and there is no production in period 2. Information obtained from the offer allows headquarters to offer a higher price p_2^n in period 2 without a possibility of strategic rejection of their offer in period 1. This is the strategic effect which increases efficiency. In the highest symmetric equilibrium informational externalities only improve contracting in period 2, as compared to the autarky. In other equilibria, they also cause a higher delay in period 1 which is a standard negative effect. Comparison with the autarky becomes then ambiguous.

A more efficient equilibrium is always associated with higher prices offered to the divisions which means higher rents for them. The profit-maximizing equilibrium is, however, an intermediate one as we can see in Figure 2. Then, in equilibria below the profit-maximizing one the headquarters, the divisions and consumers all want to move to a higher equilibrium. In equilibria above the profit-maximizing one, the preferences of the headquarters are opposed to those of divisions and consumers.

3 Competition

In this Section, we introduce competition. We allow for a great generality parametrizing possible effects of competition in the following way. *Intra-period competition* arises when the two firms introduce new products in the same period. If this happens in period 1, each firm earns $\beta_1 v_1$, $\beta_1 \leq 1$, and if in period 2, each firm earns $\beta_2 v_2$, $\beta_2 \leq 1$. *Inter-period competition* arises when the two firms introduce their products in two different periods. Under competition from past sales, a firm suffers when it is the second to introduce the product and in this case its revenues decrease to $\gamma_p v_2$, $\gamma_p \leq 1$. The first firm then has a first-mover advantage. Under competition from future sales, the firm which first introduces the product suffers from the market's anticipation that the other firm will introduce the product later. Its revenues then decrease to $\gamma_f v_1$, $\gamma_f \leq 1$.¹⁵ We keep our assumption that it is always efficient to produce, that is, $\beta_1 v_1$, $\beta_2 v_2$, $\gamma_p v_2$ and $\gamma_f v_1$ are all greater than 1. A stronger competition means that revenues fall more and, therefore, it corresponds to a lower β_1 ,

¹⁵More precisely, its revenues become a combination of $\gamma_f v_1$ and v_1 weighted by the probability that the competitor will introduce the product in period 2.

etc.¹⁶

There are four possible effects of competition on the optimal cut-off type s^A : competition may increase or decrease s^A in case a (when s^A is above s^B) or in case b (when s^A is below s^B). It turns out that there is one-to-one correspondence between the four kinds of competition described above and these four effects. This is described in Table 1 below. We say that the set of symmetric equilibria *shrinks* if the interval of the values of s^B such that $s^A = s^B$ decreases. In some cases, this interval may even disappear and then there will be two asymmetric equilibria. When there are already no symmetric equilibria, the asymmetric ones become more asymmetric in the sense that the ratio $\frac{s^A}{s^B}$ goes further away from one. We also say that the set of symmetric equilibria *expands* to describe the opposite phenomenon.

Table 1: Effects of different kinds of competition

<i>Type of competition</i>	<i>Setting affected</i>	<i>Cut-off type s</i>	<i>Set of sym. eq.</i>
Intra-period 1, $\beta_1 \downarrow$	both BM and FC	decreases in case b	shrinks
Intra-period 2, $\beta_2 \downarrow$	both BM and FC	increases in case a ¹⁷	shrinks
Past sales, $\gamma_p \downarrow$	only BM	increases in case b	expands
Future sales, $\gamma_f \downarrow$	only BM	decreases in case a	expands

Table 1 should be interpreted in the following way. Each line describes the effects of one of the four kinds of competition. Consider, for example, the first line which corresponds to a stronger intra-period competition in period 1, i.e., a lower β_1 . It affects both the benchmark and full-commitment settings. It decreases the optimal cut-off type in case b (and does not affect it in case a). The set of symmetric equilibria shrinks.

Below, we start with inter-period competition from past sales and study it in some detail. In particular, we characterize optimal s^A in the benchmark setting and show that symmetric equilibria might appear. We summarize the results for the three other kinds of competition, providing intuition for their effects. Then,

¹⁶Note that competition affects the uninformed party. It can also affect the informed party, for example, when suppliers (with known costs) sell the input to downstream firms with unknown costs. The effects of competition would still be similar.

¹⁷Only in the benchmark setting.

we provide an example of how a standard model of competition (Hotelling's spatial model) translates into intra- and inter-period competition.

Finally, we show that, independently of the strength and the form of competition, symmetric equilibria exist for a larger range of parameters in the full-commitment setting than in the benchmark setting.

3.1 Inter-period competition from past sales

A stronger inter-period competition from past sales, or a bigger first-mover advantage, corresponds to a lower γ_p . It hurts firm A when firm A produces in period 2 while firm B has produced in period 1, that is, when $s^A < p_2^y \leq s^B$. Then, in case a , competition from past sales does not have any effect.

Consider case b and let us start with the benchmark setting. Problem (3) should be replaced by

$$\left\{ \begin{array}{l} \max_{p_1, p_2^y, p_2^n} \Pi_b^{BM} = (v_1 - p_1)p_1 + \delta [(\gamma_p v_2 - p_2^y)(p_2^y - p_1) + (v_2 - p_2^n)(p_2^n - s^B)] \\ \text{s.t. } p_1 \leq p_2^y \leq s^B \leq p_2^n \leq 1. \end{array} \right.$$

The only difference with (3) is that, when production takes place after that of the other firm, the revenues are multiplied by γ_p . As intuition suggests, a stronger competition (lower γ_p) decreases profits (apply envelope theorem). The prices become (compare with (4))

$$\begin{aligned} p_1 &= \min \left\{ \frac{v_1 - \delta \gamma_p v_2 + \delta p_2^y}{2}, s^B \right\}, \\ p_2^y &= \min \left\{ \frac{\gamma_p v_2 + p_1}{2}, s^B \right\}, \\ p_2^n &= \min \left\{ \frac{v_2 + s^B}{2}, 1 \right\}. \end{aligned}$$

We see that $p_1 = s^A$ decreases with γ_p and, therefore, a stronger competition from past sales (lower γ_p) will increase p_1 . A lower γ_p makes waiting until period 2 less attractive and therefore increases production in period 1.

Lemma 10 in the Appendix characterizes the optimal p_1 . In particular, compared to Lemma 1, a new case 0 appears: whenever $\frac{v_1+(2-\delta)v_2}{2\gamma_p v_2+2-\delta} \geq 1$, $s^A = s^B$ in some range. This obviously gives rise to symmetric equilibria that we did not observe before, in Section 2. See Figure 3.

The next Lemma characterizes equilibria in the benchmark setting.

Lemma 4 *In the benchmark setting, under inter-period competition from past sales, there are the following equilibria:*

0. *If $\frac{v_1+(2-\delta)v_2}{2\gamma_p v_2+2-\delta} \geq 1$, there is a continuum of symmetric equilibria in which both firms produce at the same level $s^A = s^B \in \left[\frac{v_1-\delta v_2+\delta}{2}, \frac{v_1-\delta\gamma_p v_2}{2-\delta} \right]$. There are no asymmetric equilibria.*

1,2. *If $\frac{v_1+(2-\delta)v_2}{2\gamma_p v_2+2-\delta} < 1$, there are only two equilibria and they are asymmetric.*

Proof. Analogous to the proof of Proposition 1. ■

Thus, under competition from past sales, symmetric equilibria appear whenever $\frac{v_1+(2-\delta)v_2}{2\gamma_p v_2+2-\delta} \geq 1$. A lower γ_p makes this condition easier to satisfy and it expands the interval $\left[\frac{v_1-\delta v_2+\delta}{2}, \frac{v_1-\delta\gamma_p v_2}{2-\delta} \right]$, where $s^A = s^B$, to the right. In the same spirit, a lower γ_p makes the asymmetric equilibria of cases 1 and 2 of the benchmark setting less asymmetric, in the sense that the cut-offs in the two firms in period 1 become closer to each other. Indeed, in these equilibria in one of the firms (say, A) the production is higher than that of firm B , $s^A > s^B$. Then, s^A is not affected by γ_p , while s^B decreases with γ_p . The ratio of the higher cut-off to the smaller one (from Lemma 10 in Appendix, case 1)

$$\frac{s^A}{s^B} = 2 \frac{v_1 - \delta v_2 + \delta}{(2 + \delta) v_1 - \delta v_2 (2\gamma_p + \delta) + \delta^2}.$$

increases in γ_p and, therefore, a lower γ_p moves it towards one. The same holds for case 2.

Consider now the full-commitment setting. There, the headquarters commit not to contract with the division in period 2 (unless the costs are revealed to be higher than the first-period price), and so when $s^A \leq s^B$, $s^A = p_1 = p_2^y$ (Lemma 2). Therefore, in the full-commitment setting, inter-period competition from past sales does not have any effect.

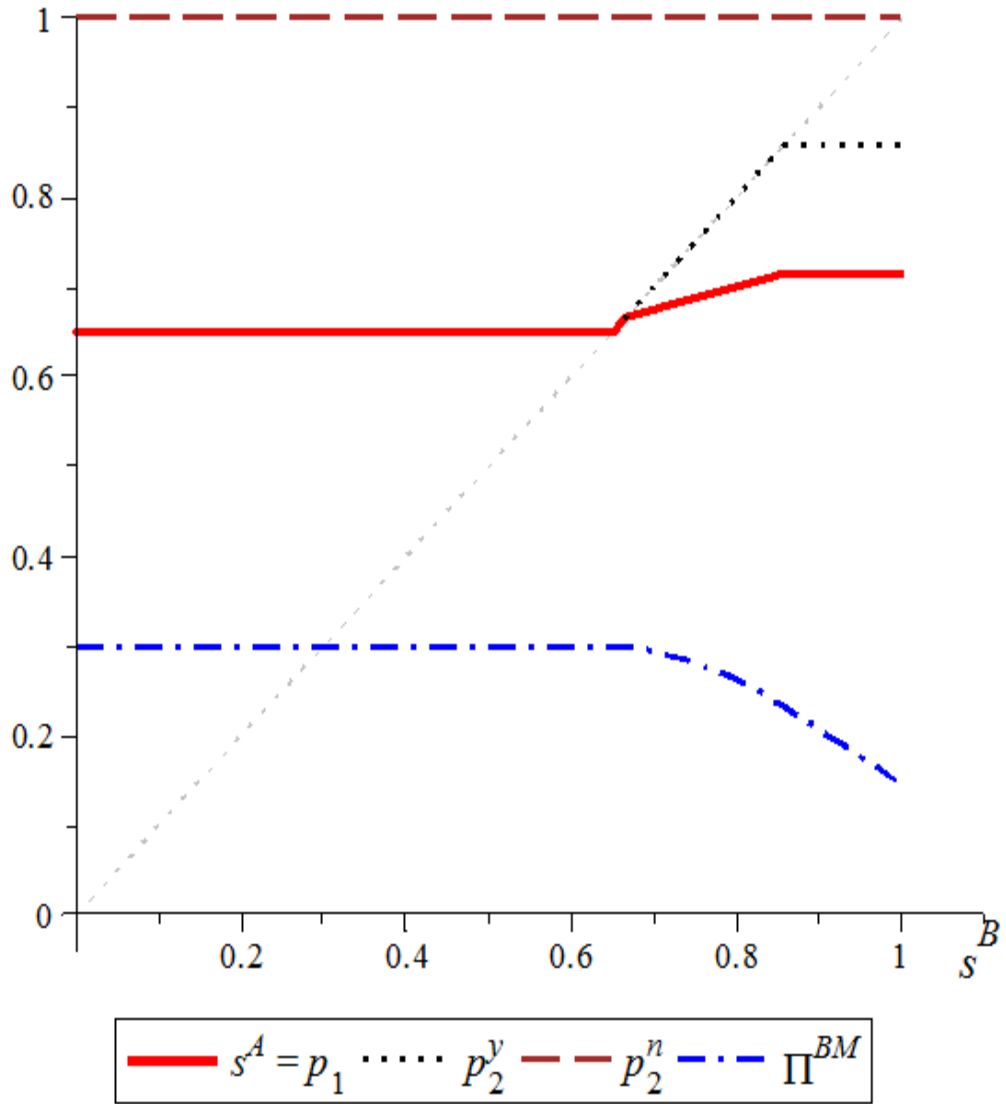


Figure 3: Prices and profits in the benchmark setting (case 0) under inter-period competition from past sales, $v_1 = 1.5$, $v_2 = 1.4$, $\delta = 0.8$, $\gamma_p = \frac{5}{7}$. For profits, the scale is adjusted.

The next Proposition summarizes the main effects of the competition from past sales.

Proposition 3 *A stronger inter-period competition from past sales (lower γ_p) increases the cut-off type s in case b and expands the range of symmetric equilibria to the right in the benchmark setting. It does not affect the full-commitment setting.*

3.2 Three other kinds of competition

3.2.1 Intra-period competition in period 1

Consider now intra-period competition in period 1. If both firms produce in period 1, they obtain only $\beta_1 v_1$ each, $\beta_1 \leq 1$. A stronger intra-period competition corresponds to a lower β_1 . It affects both the benchmark and the full-commitment settings.

In case a , the headquarters' profits in period 1, instead of $(v_1 - p_1) s^A$, become $(\beta_1 v_1 - p_1) s^B + (v_1 - p_1) (s^A - s^B)$, as if they were selling s^A units, and the first s^B of them at the price $\beta_1 v_1$ and the other $s^A - s^B$ at the price v_1 . The profits decrease when β_1 becomes smaller; however, the marginal profits are unaffected and, therefore, the optimal prices do not depend on β_1 .

In case b , in period 1 the headquarters obtain $(\beta_1 v_1 - p_1) s^A$ and therefore all prices and the cut-off type s^A should be adjusted downwards for v_1 becoming effectively $\beta_1 v_1$.

Consider the set of symmetric equilibria in the full-commitment setting. The lower end of the interval where $s^A = s^B$ is defined as the value of s^B , such that the autarky profits, i.e., when $s^A > s^B$, equal profits when $s^A = s^B$. From the discussion above, it is clear that β_1 has an identical effect on both profits and, therefore, the lower end of the interval where $s^A = s^B$ does not depend on β_1 . In the benchmark setting, the lower end of the interval $s^A = s^B$ is the autarky production that does not depend on β_1 .¹⁸ The upper end of the interval where $s^A = s^B$ is the optimal s^A when the constraint $s^A \leq s^B$ stops binding. It decreases since a lower β_1 decreases the optimal s^A . In both settings, the set of symmetric equilibria thus shrinks from the right.

¹⁸We implicitly assume that there is also competition from past sales (or future sales) under which symmetric equilibria in the benchmark setting may exist.

Symmetric equilibria may even cease to exist. Take, for example, the full-commitment setting. There, the interval where $s^A = s^B$ becomes $\left[\theta^{FC}, \frac{\beta_1 v_1}{2}\right]$.¹⁹ Then, if $\frac{\beta_1 v_1}{2}$ is smaller than θ^{FC} , there are no symmetric equilibria. Instead, two asymmetric equilibria appear in which in one firm the cut-off s equals $\frac{v_1}{2}$ and in the other $s = \frac{\beta_1 v_1}{2}$. The same may happen in case 0 of the benchmark setting.²⁰ Whenever symmetric equilibria do not exist, asymmetric equilibria arise with the same structure, as in cases 1 and 2 of the benchmark setting.

The next Proposition summarizes the effects of a lower β_1 .

Proposition 4 *A stronger intra-period competition in period 1 (lower β_1) decreases the cut-off type s in case b and shrinks the range of symmetric equilibria from the right in both the benchmark and the full-commitment settings.*

3.2.2 Intra-period competition in period 2

Suppose now that there is intra-period competition in period 2. If both firms produce in period 2, they obtain only $\beta_2 v_2$ each, $\beta_2 \leq 1$. A stronger intra-period competition corresponds to a lower β_2 .

The crucial difference (and complication) of this kind of competition is that the profits of each firm are now affected not only by the other division's cut-off type s (in period 1), but also by its cut-off type in period 2 in the case where nobody produced in period 1 which is p_2^n . In other words, the strategy of each firm is now a two-dimensional vector (s, p_2^n) .

In the benchmark setting, intra-period competition in period 2 hurts profits in both cases a and b since in each there is some probability that none of the divisions produces in period 1. In case a , exposure to this kind of competition occurs whenever $\theta \in (s^A, \min\{p_2^{n,A}, p_2^{n,B}\}]$. Then, the desire to escape from this competition will

¹⁹Once β_1 is introduced, s^A becomes equal to $\frac{\beta_1 v_1}{2}$ in case b .

²⁰In particular, the condition that separates case 0 from cases 1 and 2 in the benchmark setting becomes

$$\frac{v_1 + (2 - \delta)v_2}{\frac{2v_1}{\delta}(1 - \beta_1) + 2\gamma_p v_2 + 2 - \delta} \geq 1.$$

(when $\beta_1 = 1$, we obtain the condition in Lemma 4).

Its left-hand side increases with β_1 ; therefore, a stronger competition (lower β_1) makes it more difficult to satisfy.

make headquarters A go for more production in period 1, that is, increase s^A . This implies the set of symmetric equilibria shrinks from the left. In case b , exposure to intra-period competition in period 2 occurs whenever $\theta \in (s^B, \min \{p_2^{n,A}, p_2^{n,B}\}]$. It does not depend on s^A and, therefore, the optimal s^A does not change. This implies that the upper end of the interval where $s^A = s^B$ is not affected. Symmetric equilibria may disappear in the benchmark setting since the interval $(\frac{v_1 - \delta v_2 + \delta}{2}, \frac{v_1 - \delta \gamma v_2}{2 - \delta}]$ may not exist once v_2 is decreased to $\beta_2 v_2$ at its lower end.

In the full-commitment setting, only case b is affected since in case a there is no production in period 2. In case b , the profits are not affected at the margin and, therefore, s^A still equals $\frac{v_1}{2}$ unless constrained by s^B . Then, $\theta^{FC} < \frac{v_1}{2}$ still exists since, even at the lowest possible value of $\beta_2 = \frac{1}{v_2}$, headquarters prefer to distort s^A downwards to s^B to be able to use the information if s^B is sufficiently close to $\frac{v_1}{2}$ (from below). Therefore, symmetric equilibria always exist in the full commitment setting.

The next Proposition summarizes the effects of a stronger intra-period competition in period 2.

Proposition 5 *A stronger intra-period competition in period 2 (lower β_2) shrinks the range of symmetric equilibria from the left in both settings and increases the cut-off type s in case a of the benchmark setting.²¹*

3.2.3 Inter-period competition from future sales

Finally, the revenues in period 1 may be hurt if the competitor is expected to sell in period 2. Suppose that firm A earns only $\gamma_f v_1$, $\gamma_f \leq 1$, in period 1 if firm B sells in period 2.

Under this kind of competition, as well as under intra-period competition in period 2, the profits of the headquarters of each firm are affected not only by the other division's cut-off type s (in period 1) but also by its cut-off type in period 2 in the case where nobody produced in period 1 which is p_2^n . In other words, the strategy of each firm is a two-dimensional vector (s, p_2^n) .

Case b in each setting is not affected as, there, firm A produces only if firm B does. In case a , when only firm A is to sell in period 1 (that is, when the costs of

²¹In the full-commitment setting, symmetric equilibria never disappear.

divisions are between s^B and s^A), the market knows that for types of the division lower than $p_2^{y,B}$, firm B will sell in period 2. We obtain immediately that the full-commitment setting is not affected at all since there $s^A = p_2^y$, that is, there is no production in period 2 by firm B if firm A produces in period 1.

In the benchmark setting, the profits in case a decrease. The effect on marginal profits, and therefore prices and s^A , depends on whether the constraint $p_2^{y,B} \leq s^A$ binds. If it binds, $p_2^{y,B} = s^A$, the market knows that the other firm will sell in period 2 and therefore, headquarters A get only $\gamma_f v_1$. Then, when computing s^A , we need to replace v_1 by $\gamma_f v_1$ in the expressions we had before. If it does not bind, $p_2^{y,B} = \frac{v_2 + s^B}{2}$, firm B sells in period 2 if the cost of the division is between s^B and $p_2^{y,B}$; it does not sell in period 2 if the cost of the division is between $p_2^{y,B}$ and s^A . Then, assume that firm A earns a weighted sum of revenues with and without future sales, that is, $\frac{v_1}{s^A - s^B} \left[(p_2^{y,B} - s^B) \gamma_f + s^A - p_2^{y,B} \right]$. Future sales still reduce marginal profits and production in period 1, though to a lesser extent than when $p_2^{y,B} = s^A$.

The next Proposition summarizes the effects of competition from future sales.

Proposition 6 *A stronger competition from future sales (lower γ_f) expands the range of symmetric equilibria to the left and decreases the cut-off type s in case a in the benchmark setting. It does not affect the full-commitment setting.*

3.3 Example: Hotelling's competition

We show here how Hotelling's model of horizontal differentiation translates into the intra- and inter-period competition described above. Consider a "linear city" of length 1 populated by consumers distributed uniformly across the city. Firm A is located at the left end of the city, while the firm B is located at the right end and consumers have transportation cost $c < \frac{2}{3}$ per unit of length. The (per period) valuation of each consumer is 1. The product is non-durable and, therefore, if a firm develops the product in period 1, it will sell it for two periods.²² Then, if a consumer located at x buys the product from firm A at price p , his utility is

$$u = 1 - p - xc.$$

²²Once the product has been developed, the production costs are zero.

If firm A is alone selling the product in the market and sets its price equal to p , it sells to consumers located below $\frac{1-p}{c}$. The price that maximizes its profits $p^{\frac{1-p}{c}}$ is $p = \frac{1}{2}$ and the resulting profits are $\frac{1}{4c}$.²³ Then,

$$v_1 = \frac{1}{4c} (1 + \delta) \text{ and } v_2 = \frac{1}{4c}.$$

When the two firms compete offering p_A and p_B , the consumer located at x^* such that $p_A + x^*c = p_B + (1 - x^*)c$ is indifferent between buying from firm A and firm B . Firm A maximizes $p_A x^* = p_A \frac{p_B - p_A + c}{2c}$ taking p_B as given. In the equilibrium, $p_A = p_B = c$ and each firm earns $\frac{c}{2}$. Then,

$$\begin{aligned} \beta_1 v_1 &= \frac{c}{2} (1 + \delta), \\ \beta_2 v_2 &= \frac{c}{2}, \\ \gamma_p v_2 &= \frac{c}{2}, \\ \gamma_f v_1 &= \frac{1}{4c} + \delta \frac{c}{2}. \end{aligned}$$

We can now find β_1 and other parameters:

$$\beta_1 = \beta_2 = \gamma_p = 2c^2 \text{ and } \gamma_f = \frac{1 + 2c^2\delta}{1 + \delta} > 2c^2.$$

Lower transportation cost c increases profits when the firm is a monopolist, v_1 and v_2 , since more consumers are served. In the competition case, lower c decreases profits since competition becomes more intense. Both effects lead to stronger intra- and inter-period competition, that is, lower β_1 and other parameters.

We can study the effect of a lower c in two steps. At the first step consider $\beta_1 = \beta_2 = \gamma_p = \gamma_f$ and increase γ_f at the second one. Suppose that v_2 is high enough so all the types produce after two periods, that is, $p_2^n = 1$. The first step is then equivalent to a proportional reduction in v_1 and v_2 and our previous characterization applies (Propositions 1 and 2). At the second step, inter-period competition from future sales is relaxed (γ_f increases). The equilibria in the benchmark setting become then even more asymmetric since the leader increases its first-period production while

²³If firms could choose their location, the monopolist would place itself in the middle of the interval and earn $1 - \frac{c}{2}$. All the qualitative results would still hold.

the follower does not change it (Proposition 6). The full-commitment setting is not affected since the two firms never produce sequentially.

3.4 Comparison of the equilibria in the benchmark and full-commitment settings

When competition is absent, there are only asymmetric equilibria in the benchmark setting (Proposition 1) and only symmetric ones in the full-commitment setting (Proposition 2). Then, trivially, the set of symmetric equilibria in the benchmark setting is contained in the set of symmetric equilibria in the full-commitment setting. Under competition, symmetric equilibria may appear in the benchmark setting (Lemma 4) or disappear in the full-commitment setting (Section 3.2.1). However, as we show below in Proposition 7, the sets of symmetric equilibria are still nested.

In order to simplify the exposition, we first prove Lemma 5. In its statement, the optimal s^A is meant.

Lemma 5 (i) *If $s^A = s^B$ in the benchmark setting, then $s^A = s^B$ in the full-commitment setting and the profits are the same in the two settings.*

(ii) *If $s^A \neq s^B$ (and $s^A < 1$) in either of the two settings, then profits in the benchmark setting are strictly higher than in the full-commitment setting.*

Proof. The proof is based on the fact that $\Pi^{BM} \geq \Pi^{FC}$ since the full-commitment solution is feasible in the benchmark setting. The equality is reached if and only if all the prices and production are the same.

(i) In the benchmark setting, $p_1 = s^A$ and $p_2^y \in [s^A, s^B]$. When the two cut-offs are the same, then $p_1 = p_2^y = s^A = s^B$ (and p_2^n is ex post optimal). In the full-commitment setting, $p_1 = p_2^y = s^A$ (Lemma 2). When the two cut-offs are the same, then $p_1 = p_2^y = s^A = s^B$ (and p_2^n is ex post optimal). Thus, prices and production are the same in the two settings and profits are the same as well.

(ii) Suppose $s^A > s^B$ in the benchmark setting, then $p_2^n > s^A$. In the full-commitment setting, in order to have the same s^A , headquarters set $p_1 = p_2^n = s^A$. The prices are different in the two settings and, therefore, the full-commitment profits are lower than the benchmark ones. If $s^A < s^B$, it is p_2^y which is different in the two

settings. If $s^A \neq s^B$ in the full-commitment setting, again, either p_2^n or p_2^y will be equal to p_1 while this is not the case in the benchmark setting. ■

The next Proposition presents the main result of this section.

Proposition 7 *The set of symmetric equilibria in the benchmark setting is contained in the set of symmetric equilibria in the full-commitment setting. Moreover, the inclusion is strict unless the set of symmetric equilibria in the full-commitment setting is empty.*

Once Lemma 5 is proven, the proof of Proposition 7 is simple and therefore omitted. Indeed, from Lemma 5(i) it immediately follows that any symmetric equilibrium in the benchmark setting is also a symmetric equilibrium in the full-commitment setting. The fact that the inclusion is strict follows from Lemma 5(ii). The intuition is the following. In the full-commitment setting, headquarters commit not to change the price in period 2 unless they learn from the other firm that the first-period offer was too low. As soon as $s^A \neq s^B$, this commitment is costly since types above s^A (in case *a*) or between s^A and s^B (in case *b*) are shut down. In the benchmark setting, contracting in period 2 is always ex post optimal. Hence, when the division is strategic, headquarters have an additional motive to set $s^A = s^B$.

Another way to state Proposition 7 is that the range of parameters for which there exists a symmetric (asymmetric) equilibrium expands (shrinks) when the setting is changed from the benchmark to the full commitment.

4 No commitment

In this Section, we analyse the no-commitment setting in which headquarters cannot commit to two-period contracts. To simplify the exposition, we assume away competition as we did in Section 2. We first derive the best response function $s^A(s^B)$ and then find the equilibria. After that we prove that the set of symmetric equilibria is larger in the no-commitment setting than in the full-commitment one. In other words, symmetric behaviour of the two firms is more likely the more severe are the contractual problems.

At the beginning of period 1 headquarters offer a first-period price p_1 .²⁴ If the

²⁴Under no commitment, headquarters cannot commit to future positive payments. The credit constrained assumed in Section 2.3 can then be relaxed.

division rejects the offer, headquarters offer p_2^y or p_2^n depending on whether the other firm produced in period 1 or not. These second-period prices are ex post optimal and higher than p_1 .

As in the full-commitment setting, the division is strategic, that is, it accepts the first-period offer only when it brings a higher rent than the expected rent in period 2. The cut-off type of the division which is indifferent as to whether it produces in period 1 or in period 2 is s^A given, as in the full commitment setting, by (5) and (7), respectively, depending on whether s^A is higher or lower than s^B . Now, however, second-period prices p_2^y and p_2^n are not announced in period 1 but expected to arise as ex post optimal in period 2.

The game is solved backwards. In period 2, headquarters choose the optimal p_2^n and p_2^y knowing that they face an R&D division with costs higher than s^A . In period 1, when deciding about p_1 and, thus, about s^A , the headquarters take into account that p_1 will affect second-period prices. They also take the behaviour of firm B , summarized by the cut-off type s^B , as given.

As in the benchmark and full-commitment settings, there are two cases to consider. Let us start with case a , $s^A \geq s^B$.

If p_1 is rejected by the division A , the fact that firm B has not produced either gives the headquarters A no information as $s^A \geq s^B$. Thus, in period 2 they maximize $(v_2 - p_2^n)(p_2^n - s^A)$ which gives

$$p_2^n = \min \left\{ \frac{v_2 + s^A}{2}, 1 \right\}. \quad (9)$$

Then, the problem of headquarters A in period 1 is

$$\begin{cases} \max_{p_1} \Pi_a^{NC} = (v_1 - p_1) s^A + \delta (v_2 - p_2^n) (p_2^n - s^A) \\ \text{s.t. } s^B \leq p_1 \leq 1, \text{ (5) and (9).} \end{cases} \quad (10)$$

When $s^A \leq s^B$ (case b), the headquarters' problem in period 1 is

$$\begin{cases} \max_{p_1} \Pi_b^{NC} = (v_1 - p_1) s^A + \delta [(v_2 - p_2^y) (p_2^y - s^A) + (v_2 - p_2^n) (p_2^n - s^B)] \\ \text{s.t. } p_1 \leq s^B, \text{ (7), } p_2^y = \min \left\{ \frac{v_2 + s^A}{2}, s^B \right\} \text{ and } p_2^n = \min \left\{ \frac{v_2 + s^B}{2}, 1 \right\}. \end{cases} \quad (11)$$

The next Lemma characterizes the optimal s^A . For a numerical example see Figure 4.

Lemma 6 *In the no-commitment setting, there exist $\theta_1^{NC} < \frac{v_1}{2}$, $\theta_2^{NC} > \frac{v_1}{2}$ and $\tilde{v}_2 \in \left(\frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, \frac{v_1 - \delta v_2}{2(1 - \delta)}\right)$ such that*

$$s^A = \begin{cases} \begin{cases} \min \left\{ \frac{v_1 - \delta v_2}{2(1 - \delta)}, 1 \right\}, & \text{if } 2 - v_2 \leq \tilde{v}_2 \\ \min \left\{ \frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, 1 \right\}, & \text{if } 2 - v_2 > \tilde{v}_2 \end{cases} & \text{if } s^B \leq \theta_1^{NC}, \\ s^B, & \text{if } s^B \in \left[\theta_1^{NC}, \min \left\{ \frac{v_1 - \delta v_2}{2(1 - \delta)}, \theta_2^{NC} \right\} \right], \\ \min \left\{ \frac{v_1 - \delta v_2}{2(1 - \delta)}, 1 \right\}, & \text{if } s^B \in \left[\frac{v_1 - \delta v_2}{2(1 - \delta)}, \theta_2^{NC} \right] \text{ (when this region exists)}, \\ \min \left\{ \frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, 1 \right\}, & \text{if } s^B \geq \theta_2^{NC}. \end{cases}$$

Proof. See Appendix. ■

The behaviour of the optimal response function s^A is similar to the full-commitment case. When s^B is small, s^A is higher and, therefore, the information coming from firm B is not used. Then, at $s^B = \theta_1^{NC}$, s^A falls and becomes equal to s^B as, in this way, headquarters use the information but keep the distortion to a minimum. For some range of s^B , s^A is equal to s^B . When s^B becomes close to one, there are three possibilities. First, s^A may continue to be equal to s^B for s^B up to one. Second, s^A may become constant, as in the full-commitment setting. Third, s^A may become constant and then fall down again at $s^B = \theta_2^{NC}$ to another level. The second jump at $s^B = \theta_2^{NC}$ is unique to the no-commitment setting.

The second case is illustrated in Figure 4. When s^A becomes lower than s^B , an increase in s^B causes headquarters to offer a higher p_2^y ; however, s^A stays constant. That is, headquarters suffer more and more from the inability to commit not to increase the second-period price.

Finding equilibria is again straightforward as there are only symmetric equilibria.

Proposition 8 *In the no-commitment setting, there is a continuum of symmetric equilibria in which headquarters in both firms set the same first-period price p_1 that results in the same production $s^A = s^B \in \left[\theta_1^{NC}, \min \left\{ \frac{v_1 - \delta v_2}{2(1 - \delta)}, \theta_2^{NC} \right\} \right]$. There are no other equilibria.*

As in the full-commitment setting, there are multiple symmetric equilibria and no asymmetric ones. The two firms always introduce the new product together, either in

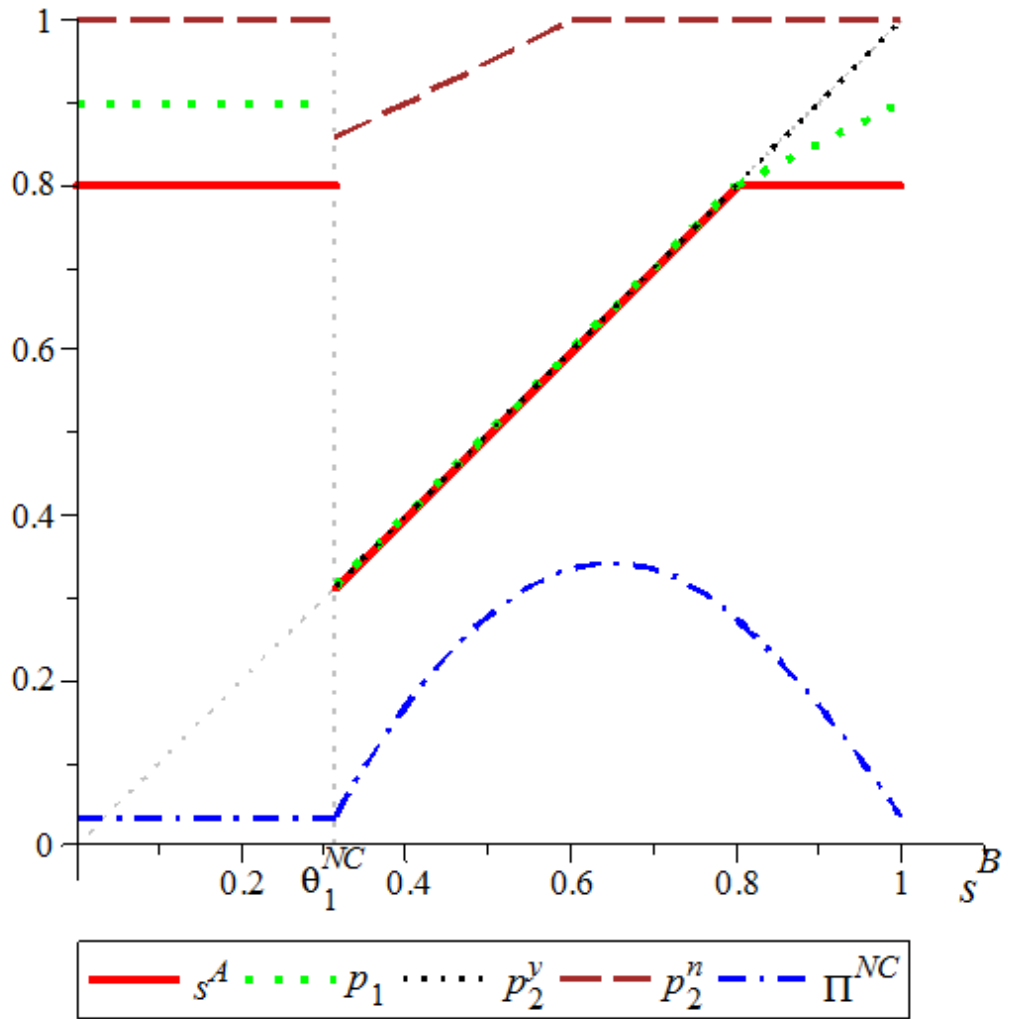


Figure 4: Prices and profits in the no-commitment setting, $v_1 = 1.5$, $v_2 = 1.4$, $\delta = 0.5$. For profits, the scale is adjusted.

period 1 or in period 2. They generate the same partition of the type space, i.e., the same information, and the headquarters use it to commit not to improve their offer, $p_2^y = p_1 = s^B$. The most efficient equilibrium is the "highest" symmetric equilibrium, that is, the one in which $s^A = s^B = \min \left\{ \frac{v_1 - \delta v_2}{2(1-\delta)}, \theta_2^{NC} \right\}$. The comparison with the autarky is ambiguous for two reasons. First, unlike the full-commitment setting, the autarky is relatively efficient since headquarters cannot shut down high cost types in period 2. Second, even in the highest equilibrium, first-period production may be greater or smaller than in the autarky.²⁵

We now show that the set of symmetric equilibria in the no-commitment setting is larger than the one in the full-commitment setting. For this, we use Lemma 7 which is similar to Lemma 5 and has a similar proof (omitted).

Lemma 7 (i) *If $s^A = s^B$ in the full-commitment setting, then $s^A = s^B$ in the no-commitment setting as well and the profits are the same in the two settings.*

(ii) *If $s^A \neq s^B$ (and $s^A < 1$) in either of the two settings, then profits in the full-commitment setting are strictly higher than in the no-commitment setting.*

The proof is based on the fact that $\Pi^{FC} \geq \Pi^{NC}$ since the no-commitment solution is feasible in the full-commitment setting. The equality is reached if and only if all the prices are the same.

Proposition 9 *The set of symmetric equilibria in the full-commitment setting is contained in the set of symmetric equilibria in the no-commitment setting. Moreover, the inclusion is strict unless the set of symmetric equilibria in the no-commitment setting is empty.*

From Lemma 7(i) it immediately follows that any symmetric equilibrium in the full-commitment setting is also a symmetric equilibrium in the no-commitment setting. The fact that the inclusion is strict follows from Lemma 7(ii). Intuitively, in the no-commitment setting, when p_1 is smaller than s^B , the headquarters cannot commit not to offer $p_2^y > p_1$. However, if p_1 is equal to s^B , it effectively commits the headquarters not to increase p_2^y as then $p_1 = p_2^y = s^B$. Thus, as compared to the full-commitment setting, there is an additional incentive for the headquarters to set $s^A = s^B$.

²⁵As in the full-commitment setting, a more efficient equilibrium is always associated with higher prices offered to the divisions which means higher rents for them. The profit-maximizing equilibrium is, however, an intermediate one as we can see in Figure 4.

5 Alternative information structures

In this Section, we consider alternative information structures. First, we study the setup where the costs of the two R&D divisions are independent with some probability, while still the same with a complementary probability. Second, we assume that, after development of the new product by one firm in period 1, the other can learn the exact development costs through reverse engineering. For ease of analysis and exposition, we assume, as in Section 2, that there is no competition.

5.1 Imperfect correlation of costs

Here, we relax the assumption that the costs of the two divisions are exactly the same. Suppose that the new product can be developed using one of two available technologies and in period 1 neither headquarters nor the division know if they use the same technology as their competitor. They only know that it is the same with probability λ . After period 1 they learn not only about the production of the other firm but also which technology it uses. Then, with probability λ the costs of the two divisions are the same, while with probability $1 - \lambda$ they are independent. In the latter case, the production of the other firm in period 1 does not reveal any information (but still may matter if there is competition). A higher λ is interpreted as more, or better, information being revealed by each firm in expectation.

When $s^A \geq s^B$ (case *a*), firm *A* does not use information it receives from firm *B*. Therefore, case *a* is not affected by λ .

Consider case *b* of the benchmark setting. Denote $p_2^{y,c}$ and $p_2^{n,c}$ the prices, conditional on the production of the other firm in period 1, offered by the headquarters in period 2, when the costs of the two divisions turn out to be the same, and p_2^i the price offered by the headquarters in period 2, when the costs of the two divisions are independent. Problem (3) becomes

$$\left\{ \begin{array}{l} \max_{p_1, p_2^{y,c}, p_2^{n,c}, p_2^i} \Pi_b^{BM} = (v_1 - p_1) p_1 \\ + \delta \left[\lambda ((v_2 - p_2^{y,c})(p_2^{y,c} - p_1) + (v_2 - p_2^{n,c})(p_2^{n,c} - s^B)) \right. \\ \left. + (1 - \lambda)(v_2 - p_2^i)(p_2^i - p_1) \right] \\ \text{s.t. } p_1 \leq p_2^{y,c} \leq s^B \leq p_2^{n,c} \leq 1, p_2^i \in [p_1, 1]. \end{array} \right. \quad (12)$$

It is intuitive, and can be easily shown, that $p_1 = s^A$ decreases with λ since more information makes waiting more profitable.²⁶ This implies that the set of symmetric equilibria shrinks from the right.

In the full-commitment setting, case *b*, the cut-off type s^A , instead of (7), becomes

$$s^A = \frac{p_1 - \delta [\lambda p_2^{y,c} + (1 - \lambda) p_2^i]}{1 - \delta}. \quad (13)$$

When $\lambda = 1$, the headquarters commit not to increase the price in period 2 (Lemma 2). For $\lambda < 1$, they have even fewer reasons to contract in period 2 and Lemma 2 extends to this case as well. That is, $p_1 = p_2^{y,c} = p_2^i = s^A$ and we obtain the same solution as the one characterized in Lemma 3. Then, when $p_1 = s^B$, profits increase with λ since a higher λ increases the chances that the costs of the division are known to be higher than s^B , in which case some production takes place in period 2. In case *a* the profits are unaffected by λ and, therefore, θ^{FC} increases with a lower λ . When $\lambda = 0$, no information is ever revealed by the other firm and $p_1 = \frac{v_1}{2}$ for any s^B , i.e., $\theta^{FC} = \frac{v_1}{2}$. This is the autarky solution.

In the no-commitment setting, the cut-off type s^A is also given by (13). Since there is no commitment to two-period contracts, at least p_2^i will be higher than p_1 and, thus, s^A will be lower than p_1 . There is now a strategic effect of more information:

$$\frac{\partial s^A}{\partial \lambda} = \frac{\delta}{1 - \delta} (p_2^i - p_2^{y,c}) > 0.$$

This is the precise sense in which the division becomes softer in bargaining in period 1 when more information is anticipated in the future. This effect calls for more production in period 1. The strategic effect is opposite to the direct effect that we observed in the benchmark setting where more information leads to more production after this information becomes available. It turns out that, in our model, the strategic effect is always the (weakly) dominating one. This result is the next Lemma.

Lemma 8 *In the no-commitment setting, more information increases production in period 1, $\frac{\partial s}{\partial \lambda} \geq 0$.*

²⁶If $p_2^i = p_2^{y,c} = \frac{v_2 + p_1}{2} < s^B$, then p_1 does not change with λ . Indeed, (12) becomes (3) that does not depend on λ .

Proof. See Appendix. ■

This implies that the set of symmetric equilibria expands to the right.

We summarize the main effects of more information in the next Proposition.

Proposition 10 *More information (higher λ)*

- (i) *decreases the cut-off type s in case b and shrinks the set of symmetric equilibria from the right in the benchmark setting;*
- (ii) *expands the set of symmetric equilibria to the left in the full-commitment setting;*
- (iii) *increases the cut-off type s in case b and expands the set of symmetric equilibria to the right in the no-commitment setting.*

The effects of higher λ are opposite whether the agent is strategic or not. A higher λ makes information obtained from the other firm more valuable. In the benchmark setting, this increases incentives of the headquarters to delay the production and to use information from the other firm. When the agent is strategic, this information can also be used for more efficient contracting in period 1, that is, even *before* it becomes available (strategic effect). In the no-commitment setting, this effects dominates. In the full-commitment setting, the take-it-or-leave-it offer made in period 1 does not depend on λ . However, whenever $s^A \leq s^B$, a higher λ increases the chances that the headquarters will learn that the first-period offer was too low and will make a better offer in period 2. Then, while s^A is not affected by λ in both cases a and b , profits in case b increase with λ and, therefore, the set of symmetric equilibria expands to the left (θ^{FC} falls).

5.2 Perfect learning

So far we have considered "contractual" learning, that is, the inference about the division's costs made after in period 1 was based solely on the equilibrium contracts. Often, however, competitors may learn the production costs of a product doing reverse engineering. Then, headquarters learn the exact cost of the division if the other firm has produced in period 1. This is why we call it *perfect learning*. After

no production in period 1, as before, headquarters learn only that the division's cost is above a certain cut-off. As in Section 2, consider the setup without competition.

Case *a* does not change under perfect learning since, here, firm *A* does not use the information revealed by firm *B*.

Consider case *b*. If the division does not accept producing at price p_1 , headquarters will learn its type and, therefore, will offer $p_2^y = \theta$ in period 2. The division will not get any rent and, thus, accepts any first-period price above its cost. That is, the cut-off type s^A equals p_1 in all three settings. Even when strategic, the division behaves "myopically" and the commitment ability of the headquarters no longer matters.

The problem of the headquarters is now

$$\left\{ \begin{array}{l} \max_{s^A, p_2^n} \Pi_b = (v_1 - s^A) s^A + \delta \int_{s^A}^{s^B} (v_2 - \theta) d\theta + \delta (v_2 - p_2^n) (p_2^n - s^B) \\ \text{s.t. } s^A \leq s^B \leq p_2^n \leq 1. \end{array} \right.$$

Solving it, we obtain

$$s^A = \min \left\{ \frac{v_1 - \delta v_2}{2 - \delta}, s^B \right\}, \quad (14a)$$

$$p_2^n = \min \left\{ \frac{v_2 + s^B}{2}, 1 \right\}. \quad (14b)$$

Since in case *a* perfect learning does not matter, our previous analysis applies for $s^B \leq \frac{v_1 - \delta v_2}{2 - \delta}$, in particular, the characterization of the cut-off type s^A in Lemmas 1, 3 and 6. For $s^B > \frac{v_1 - \delta v_2}{2 - \delta}$, the three settings become identical and the same $s^A = p_1 = \frac{v_1 - \delta v_2}{2 - \delta}$ is optimal in case *b*. This implies that $\frac{v_1 - \delta v_2}{2 - \delta}$ becomes the upper end of the interval where $s^A = s^B$. Since $\frac{v_1 - \delta v_2}{2 - \delta} < \frac{v_1}{2}$, the sets of symmetric equilibria shrink in the full-commitment and no-commitment settings. In the benchmark setting, symmetric equilibria exist only if inter-period competition is present. For example, under inter-period competition from past sales, (14a) becomes

$$s^A = \min \left\{ \frac{v_1 - \delta \gamma v_2}{2 - \delta}, s^B \right\}$$

and $s^A = s^B$ if $s^B \in \left[\frac{v_1 - \delta v_2 + \delta}{2}, \frac{v_1 - \delta \gamma v_2}{2 - \delta} \right]$, which is the same interval as before (Lemma 4, case 0). Therefore, perfect learning does not affect the set of symmetric equilibria.^{27,28}

The next Proposition summarizes the main effects of perfect learning.

Proposition 11 *Introduction of perfect learning shrinks the sets of symmetric equilibria from the right in the full-commitment and no-commitment settings.*

Under perfect learning, the sets of symmetric equilibria still increase with the severity of the agency problem as before (see Proposition 7). However, this result is now driven by case *a* where information is not used. In case *b*, the agency problem is the same across the three settings, and the sets of symmetric equilibria have the same upper endpoint.

6 Conclusion

This paper investigated informational externalities across intra-firm bargaining games in a market setting. We found that the agency relationship creates a coordination motive in headquarters' actions making simultaneous launching of a new product more likely. Each firm uses the information generated by the competitor to discipline its R&D division. This is done the best when the divisions are put in the same conditions, that is, when they face the same incentives to develop the product. When the agency problem becomes more severe, there are more benefits in limiting the strategic behaviour of the R&D division and firms tend to behave symmetrically even more. The effects of competition are very different depending whether it is intra- or inter-period. Inter-period competition penalizes firms when they launch the new product in different periods and, therefore, it is conducive for the simultaneous launching. Intra-period competition has an opposite effect since it pushes firms to differentiate and to launch the product in different periods.

This paper makes a step towards understanding the interactions between internal structure of firms and competition in an industry equilibrium. Competition plays

²⁷This is because at $s^B = \frac{v_1 - \delta \gamma v_2}{2 - \delta}$, when it becomes optimal to have $s^A < s^B$, the effect of perfect learning in terms of higher profits is still of the second order.

²⁸In cases 1 and 2 of the benchmark setting, perfect learning decreases θ_1^{BM} and θ_2^{BM} , respectively, since profits are higher under perfect learning in case *b* while remaining unchanged in case *a*.

a dual role since it affects both the costs and the benefits of solving the agency problem in any given way. The way the agency problem is solved then maps back into competition. We still have a very limited understanding of these interactions and general equilibrium effects, and more research is needed.

Appendix

Proof of Lemma 1. In case *a*, solve (2). Assume that $p_2^n = 1$, solve for p_1 and find the condition that $\frac{v_2+p_1}{2}$ is indeed larger than one. Then, assume that $p_2^n = \frac{v_2+p_1}{2}$ and find $p_1 = s^A$. This gives the following:

$$\begin{aligned}
\text{Case 1. if } \frac{v_1+(2-\delta)v_2}{4-\delta} \geq 1 : \\
p_1 &= \max \left\{ \frac{v_1-\delta v_2+\delta}{2}, s^B \right\}, p_2^n = 1, \\
\text{Case 2. if } \frac{v_1+(2-\delta)v_2}{4-\delta} < 1 : \\
p_1 &= \frac{v_1-\frac{\delta}{2}v_2}{2-\frac{\delta}{2}}, p_2^n = \frac{v_1+(2-\delta)v_2}{4-\delta}, \quad \text{if } s^B \leq \frac{v_1-\frac{\delta}{2}v_2}{2-\frac{\delta}{2}} \\
p_1 &= s^B, p_2^n = \frac{v_2+s^B}{2}, \quad \text{if } s^B \in \left[\frac{v_1-\frac{\delta}{2}v_2}{2-\frac{\delta}{2}}, 2-v_2 \right] \\
p_1 &= s^B, p_2^n = 1, \quad \text{if } s^B \geq 2-v_2
\end{aligned} \tag{15}$$

In case *b*, solving (4) in a similar way, we obtain that $p_2^n = \min \left\{ \frac{v_2+s^B}{2}, 1 \right\}$ and

$$\begin{aligned}
p_1 &= p_2^y = s^B, \quad \text{if } s^B \leq \frac{v_1-\delta v_2}{2-\delta} \\
p_1 &= \frac{v_1-\delta v_2+\delta s^B}{2}, p_2^y = s^B, \quad \text{if } s^B \in \left[\frac{v_1-\delta v_2}{2-\delta}, \frac{v_1+(2-\delta)v_2}{4-\delta} \right] \\
p_1 &= \frac{v_1-\frac{\delta}{2}v_2}{2-\frac{\delta}{2}}, p_2^y = \frac{v_1+(2-\delta)v_2}{4-\delta}, \quad \text{if } s^B \geq \frac{v_1+(2-\delta)v_2}{4-\delta}
\end{aligned} \tag{16}$$

We are now left to determine where the change from case *a* to case *b* occurs. We will need the following Lemma.

Lemma 9 (i) If $p_1 = s^B$ in both cases, the profits are the same. (ii) If $p_1 = s^B$ in one of the two cases and $p_1 \neq s^B$ in the other, then profits are higher in the latter.

Proof. (i) True by comparing (1) and (3) (for the latter case, $p_1 = p_2^y = s^B$). (ii) True since $p_1 = s^B$ is feasible in both cases. ■

We will say that p_1 (and the corresponding case) is *constrained* when $p_1 = s^B$ in this case. If only one case is constrained, the other is optimal. The change from case

a to case b occurs when either both are unconstrained, or both are constrained (so $p_1 = s^B$) and one case becomes unconstrained.

There are the following parameter ranges to consider.

Case 1. If $\frac{v_1+(2-\delta)v_2}{4-\delta} \geq 1$, up to $s^B = \frac{v_1-\delta v_2}{2-\delta}$ case a is unconstrained while case b is constrained. For $s^B \in \left(\frac{v_1-\delta v_2}{2-\delta}, \frac{v_1-\delta v_2+\delta}{2}\right)$ both cases are unconstrained and the cut-off θ_1^{BM} is found from the equality of Π_a^{BM} and Π_b^{BM} , given by (1) and (3), respectively, with the corresponding prices. For $s^B > \theta_1^{BM}$, case b is optimal.

Case 2. If $\frac{v_1+(2-\delta)v_2}{4-\delta} < 1$, then $\frac{v_1-\delta v_2}{2-\delta} < \frac{v_1-\frac{\delta}{2}v_2}{2-\frac{\delta}{2}}$, and therefore, up to $s^B = \frac{v_1-\delta v_2}{2-\delta}$ case a is unconstrained while case b is constrained; thus, case a is optimal. For $s^B \in \left(\frac{v_1-\delta v_2}{2-\delta}, \frac{v_1-\frac{\delta}{2}v_2}{2-\frac{\delta}{2}}\right)$ both cases are unconstrained and θ_2^{BM} is found from the equality of (1) and (3) with the corresponding prices. For $s^B > \theta_2^{BM}$, case b is optimal. ■

Proposition 1 *In the benchmark setting, there are only two equilibria and they are asymmetric:*

1. If $\frac{v_1+(2-\delta)v_2}{4-\delta} \geq 1$, in one firm the cut-off is $s = \frac{v_1-\delta v_2+\delta}{2}$ and in the other $s = \frac{(2+\delta)v_1-\delta v_2(2+\delta)+\delta^2}{4}$.
2. If $\frac{v_1+(2-\delta)v_2}{4-\delta} < 1$, in one firm the cut-off is $s = \frac{v_1-\frac{\delta}{2}v_2}{2-\frac{\delta}{2}}$ and in the other $s = \frac{(2+\frac{\delta}{2})v_1-2\delta v_2}{4-\delta}$.

Proof. Plug optimal second-period prices from (2) and (4) into (1) and (3), respectively. The profit function Π^{BM}

$$\Pi^{BM} = \begin{cases} \Pi_a^{BM}, & \text{if } s^A \leq s^B \\ \Pi_b^{BM}, & \text{if } s^A \geq s^B, \end{cases}$$

where Π_a^{BM} and Π_b^{BM} are given by (1) and (3), respectively, is a function of (s^A, s^B) only. While it is continuous in both arguments, it may not be quasiconcave in s^A . Then, the standard theorem for the existence of a pure-strategy Nash equilibrium (Theorem 1.2 in Fudenberg and Tirole (1991) due to Debreu (1952)) cannot be applied. Pure-strategy Nash equilibria still exist in our model and we prove their existence by construction.

Case 1. Denote $s^{B*} = \frac{v_1 - \delta v_2 + \delta s^B}{2}$ at $s^B = \frac{v_1 - \delta v_2 + \delta}{2}$, that is,

$$s^{B*} = \frac{(2 + \delta)v_1 - \delta v_2(2 + \delta) + \delta^2}{4}.$$

We need to show that s^{B*} is smaller than θ_1^{BM} . The necessary and sufficient condition for this is that, at $s^B = s^{B*}$, profits Π_a^{BM} are higher than profits Π_b^{BM} .

Let us first find the optimal prices and then compare profits. Note that the following inequalities hold:

$$\frac{v_1 - \delta v_2}{2 - \delta} \leq s^{B*} \leq \frac{v_1 - \delta v_2 + \delta}{2} \leq \frac{v_1 + (2 - \delta)v_2}{4 - \delta}.$$

Then, in the case where $p_1 \geq s^B$, $p_1 = \frac{v_1 - \delta v_2 + \delta}{2}$ and $p_2^n = 1$ (see (15)). If $p_1 \leq s^B$, then $p_1 = \frac{v_1 - \delta v_2 + \delta s^{B*}}{2}$, $p_2^y = s^{B*}$ and $p_2^n = \min\left\{\frac{v_2 + s^{B*}}{2}, 1\right\}$ (see (16)). At $s^B = s^{B*}$, $\min\left\{\frac{v_2 + s^{B*}}{2}, 1\right\} = 1$. Once these prices are plugged into Π_a^{BM} and Π_b^{BM} , the difference in profits is positive:

$$\Pi_a^{BM} |_{s^B=s^{B*}} - \Pi_b^{BM} |_{s^B=s^{B*}} = \frac{1}{64} \delta^2 (4 - \delta^2) (v_1 - \delta v_2 + \delta - 2)^2 > 0.$$

Case 2. Denote $s^{B*} = \frac{v_1 - \delta v_2 + \delta s^B}{2}$ at $s^B = \frac{v_1 - \frac{\delta}{2} v_2}{2 - \frac{\delta}{2}}$, that is,

$$s^{B*} = \frac{(2 + \frac{\delta}{2})v_1 - 2\delta v_2}{4 - \delta}.$$

We need to show that s^{B*} is smaller than θ_1^{BM} . The necessary and sufficient condition for this is that, at $s^B = s^{B*}$, profits Π_a^{BM} are higher than profits Π_b^{BM} .

Let us first find the optimal prices and then compare profits. Note that the following inequalities hold:

$$\frac{v_1 - \delta v_2}{2 - \delta} \leq s^{B*} \leq \frac{v_1 - \frac{\delta}{2} v_2}{2 - \frac{\delta}{2}} \leq \frac{v_1 + (2 - \delta)v_2}{4 - \delta}.$$

Then, in the case where $s^A \geq s^B$, $p_1 = \frac{v_1 - \frac{\delta}{2} v_2}{2 - \frac{\delta}{2}}$ and $p_2^n = \frac{v_1 + (2 - \delta)v_2}{4 - \delta}$ (see (15)). If $s^A \leq s^B$, then $p_1 = \frac{v_1 - \delta v_2 + \delta s^{B*}}{2}$, $p_2^y = s^{B*}$ and $p_2^n = \min\left\{\frac{v_2 + s^{B*}}{2}, 1\right\}$ (see (16)). At $s^B = s^{B*}$, $\min\left\{\frac{v_2 + s^{B*}}{2}, 1\right\} = \frac{v_2 + s^{B*}}{2}$. Once these prices are plugged into (1) and (3), the difference in profits is positive:

$$\Pi_a^{BM} |_{s^B=s^{B*}} - \Pi_b^{BM} |_{s^B=s^{B*}} = \frac{1}{16} \delta^2 (4 - \delta - \delta^2) (v_2 - 1)^2 \geq 0.$$

■

Lemma 10 *In the benchmark setting, under inter-period competition from past sales,*

0. If $\frac{v_1+(2-\delta)v_2}{2\gamma_p v_2+2-\delta} \geq 1$, s^A is

$$s^A = \begin{cases} \frac{v_1-\delta v_2+\delta}{2}, & \text{if } s^B \leq \frac{v_1-\delta v_2+\delta}{2} \\ s^B, & \text{if } s^B \in \left[\frac{v_1-\delta v_2+\delta}{2}, \frac{v_1-\delta\gamma_p v_2}{2-\delta} \right] \\ \frac{v_1-\delta\gamma_p v_2+\delta s^B}{2}, & \text{if } s^B \in \left[\frac{v_1-\delta\gamma_p v_2}{2-\delta}, \min \left\{ \frac{v_1+(2-\delta)\gamma_p v_2}{4-\delta}, 1 \right\} \right] \\ \frac{v_1-\frac{\delta}{2}\gamma_p v_2}{2-\frac{\delta}{2}}, & \text{if } s^B \geq \frac{v_1+(2-\delta)\gamma_p v_2}{4-\delta} \text{ (if } \frac{v_1+(2-\delta)\gamma_p v_2}{4-\delta} < 1) \end{cases}$$

1. If $\frac{v_1+(2-\delta)v_2}{2\gamma_p v_2+2-\delta} < 1 \leq \frac{v_1+(2-\delta)v_2}{4-\delta}$, there exists $\theta_1^{BM} \in \left(\frac{v_1-\delta\gamma_p v_2}{2-\delta}, \frac{v_1-\delta v_2+\delta}{2} \right)$ such that s^A is

$$s^A = \begin{cases} \frac{v_1-\delta v_2+\delta}{2}, & \text{if } s^B \leq \theta_1^{BM} \\ \frac{v_1-\delta\gamma_p v_2+\delta s^B}{2}, & \text{if } s^B \in \left[\theta_1^{BM}, \min \left\{ \frac{v_1+(2-\delta)\gamma_p v_2}{4-\delta}, 1 \right\} \right] \\ \frac{v_1-\frac{\delta}{2}\gamma_p v_2}{2-\frac{\delta}{2}}, & \text{if } s^B \geq \frac{v_1+(2-\delta)\gamma_p v_2}{4-\delta} \text{ (if } \frac{v_1+(2-\delta)\gamma_p v_2}{4-\delta} < 1) \end{cases}$$

2. If $\frac{v_1+(2-\delta)v_2}{4-\delta} < 1$, there exists $\theta_2^{BM} \in \left(\frac{v_1-\delta\gamma_p v_2}{2-\delta}, \frac{v_1-\frac{\delta}{2}v_2}{2-\frac{\delta}{2}} \right)$ such that s^A is

$$s^A = \begin{cases} \frac{v_1-\frac{\delta}{2}v_2}{2-\frac{\delta}{2}}, & \text{if } s^B \leq \theta_2^{BM} \\ \frac{v_1-\delta\gamma_p v_2+\delta s^B}{2}, & \text{if } s^B \in \left[\theta_2^{BM}, \frac{v_1+(2-\delta)\gamma_p v_2}{4-\delta} \right] \\ \frac{v_1-\frac{\delta}{2}\gamma_p v_2}{2-\frac{\delta}{2}}, & \text{if } s^B \geq \frac{v_1+(2-\delta)\gamma_p v_2}{4-\delta} \end{cases}$$

Proof. Proceeds in the same way as the proof of Lemma 1. ■

Proof of Lemma 6. As before, there are two possible cases depending on whether s^A is higher or lower than s^B . In each of these cases there are two subcases. We solve each subcase, write the combined solution for each case, and then characterize the (full) solution.

Start with case *a*, i.e., solving (10). There are two subcases. If $s^A \leq 2 - v_2$, then

$$\begin{aligned} p_1 &= \frac{(2-\delta)s^A + \delta v_2}{2} \\ p_2^n &= \frac{v_2 + s^A}{2}. \end{aligned}$$

We can reformulate the problem (10) as the one of choosing s^A

$$\max_{s^A \in [s^B, 2-v_2]} \frac{1}{2} \left[(2v_1 - (2-\delta)s^A - \delta v_2) s^A + \frac{1}{2} \delta (v_2 - s^A)^2 \right].$$

The solution is

$$s^A = \min \left\{ \max \left\{ s^B, \frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta} \right\}, 2 - v_2 \right\}.$$

If $s^A > 2 - v_2$,

$$p_1 = (1 - \delta) s^A + \delta$$

$$p_2^n = 1.$$

(10) becomes

$$\max_{s^A \in [\max\{2 - v_2, s^B\}, 1]} (v_1 - (1 - \delta) s^A - \delta) s^A + \delta (v_2 - 1) (1 - s^A)$$

and the solution is

$$s^A = \min \left\{ \max \left\{ s^B, \frac{v_1 - \delta v_2}{2(1 - \delta)}, 2 - v_2 \right\}, 1 \right\}.$$

Combining the two subcases, the optimal s^A is

$$s^A = \begin{cases} \min \left\{ \max \left\{ \frac{v_1 - \delta v_2}{2(1 - \delta)}, s^B \right\}, 1 \right\}, & \text{if } 2 - v_2 \leq \frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta} \\ \min \left\{ \max \left\{ \frac{v_1 - \delta v_2}{2(1 - \delta)} \text{ or } \frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, s^B \right\}, 1 \right\}, & \text{if } 2 - v_2 \in \left[\frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, \frac{v_1 - \delta v_2}{2(1 - \delta)} \right] \\ \min \left\{ \max \left\{ \frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, s^B \right\}, 1 \right\}, & \text{if } 2 - v_2 \geq \frac{v_1 - \delta v_2}{2(1 - \delta)} \end{cases}$$

However, the intermediate case $2 - v_2 \in \left(\frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, \frac{v_1 - \delta v_2}{2(1 - \delta)} \right)$ is not a separate case.

There is $\tilde{v}_2 \in \left(\frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, \frac{v_1 - \delta v_2}{2(1 - \delta)} \right)$ such that

$$s^A = \begin{cases} \min \left\{ \max \left\{ \frac{v_1 - \delta v_2}{2(1 - \delta)}, s^B \right\}, 1 \right\}, & \text{if } 2 - v_2 \leq \tilde{v}_2 \\ \min \left\{ \max \left\{ \frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, s^B \right\}, 1 \right\}, & \text{if } 2 - v_2 \geq \tilde{v}_2 \end{cases} \quad (17)$$

Consider now case *b*, that is, solve (11). The second-period price when the other firm did not produce in period 1, p_2^n , is

$$p_2^n = \min \left\{ \frac{v_2 + s^B}{2}, 1 \right\}.$$

To find s^A , consider again two subcases. If $s^A \leq 2s^B - v_2$, the prices are

$$p_1 = \frac{(2 - \delta) s^A + \delta v_2}{2}$$

$$p_2^y = \frac{v_2 + s^A}{2}.$$

The maximization problem (11) becomes (omit the last part that depends only on p_2^n)

$$\max_{s^A \leq 2s^B - v_2} \frac{1}{2} \left[(2v_1 - (2 - \delta)s^A - \delta v_2) s^A + \frac{1}{2} \delta (v_2 - s^A)^2 \right] \quad (18)$$

and the solution is

$$s^A = \min \left\{ \frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, 2s^B - v_2 \right\}.$$

If $s^A \geq 2s^B - v_2$, the prices are

$$\begin{aligned} p_1 &= (1 - \delta) s^A + \delta s^B \\ p_2^y &= s^B. \end{aligned}$$

The maximization problem (11) becomes (omit the last part that depends only on p_2^n)

$$\max_{s^A \in [2s^B - v_2, s^B]} (v_1 - (1 - \delta)s^A - \delta s^B) s^A + \delta (v_2 - s^B) (s^B - s^A) \quad (19)$$

and the solution is

$$s^A = \max \left\{ \min \left\{ s^B, \frac{v_1 - \delta v_2}{2(1 - \delta)} \right\}, 2s^B - v_2 \right\}.$$

Combining the two subcases, there is θ_2^{NC} such that the optimal s^A is

$$s^A = \begin{cases} s^B, & \text{if } s^B \leq \min \left\{ \frac{v_1 - \delta v_2}{2(1 - \delta)}, \theta_2^{NC} \right\} \\ \frac{v_1 - \delta v_2}{2(1 - \delta)}, & \text{if } s^B \in \left[\frac{v_1 - \delta v_2}{2(1 - \delta)}, \theta_2^{NC} \right] \text{ (when this region exists)} \\ \frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, & \text{if } s^B \geq \theta_2^{NC} \end{cases}$$

The cut-off θ_2^{NC} is found from the equality of (18) and (19) with the corresponding prices. If this equation does not have solutions, define θ_2^{NC} as being equal to one. Note that s^A jumps down at θ_2^{NC} .

Before we combine this case with the previous one, let us show that $\theta_2^{NC} > \frac{v_1}{2}$. To do this, we need that for $s^B \leq \frac{v_1}{2}$, profits (18) are smaller than profits (19). Consider (19). Since $\frac{v_1 - \delta v_2}{2(1 - \delta)} \geq \frac{v_1}{2}$, $s^A = \max \left\{ \min \left\{ s^B, \frac{v_1 - \delta v_2}{2(1 - \delta)} \right\}, 2s^B - v_2 \right\} = \max \left\{ s^B, 2s^B - v_2 \right\} = s^B$. Therefore, $s^A = p_1 = p_2^y = s^B$. By Lemma 3 (and its proof), this is also the full-commitment solution for $p_1 \leq s^B$. Then, profits (19) cannot be lower than profits (18) and are actually strictly higher since, in the latter case, $s^A = \min \left\{ \frac{v_1 - \delta v_2}{2 - \frac{3}{2}\delta}, 2s^B - v_2 \right\} < s^B$.

Finally, we need to find out at which s^B the change from case a to case b occurs. Denote it θ_1^{NC} . For $s^B \leq \frac{v_1}{2}$, if $s^A \geq s^B$, the no-commitment solution (17) is different from the full-commitment solution (see Lemma 3 and its proof). Therefore, $\Pi_a^{NC} < \Pi_a^{FC}$. If $s^A \leq s^B$, then the full and no-commitment solutions coincide (see the paragraph above), and therefore, $\Pi_b^{NC} = \Pi_b^{FC}$. But then θ_1^{NC} has to be smaller than its full-commitment counterpart, θ^{FC} . Note that

$$\theta_1^{NC} < \theta^{FC} < \frac{v_1}{2} < \theta_2^{NC}.$$

■

Proof of Lemma 8. The headquarters' problem is

$$\left\{ \begin{array}{l} \max_{p_1} \Pi_b^{NC} = (v_1 - p_1) s^A \\ + \delta \left[\lambda ((v_2 - p_2^{y,c}) (p_2^{y,c} - s^A) + (v_2 - p_2^{n,c}) (p_2^{n,c} - s^B)) \right. \\ \left. + (1 - \lambda) (v_2 - p_2^i) (p_2^i - s^A) \right] \\ \text{s.t. } p_1 \leq s^B, p_2^{y,c} = \min \left\{ \frac{v_2 + s^A}{2}, s^B \right\}, p_2^i = \min \left\{ \frac{v_2 + s^B}{2}, 1 \right\}, \\ p_2^i = \min \left\{ \frac{v_2 + s^A}{2}, 1 \right\}, \end{array} \right. \quad (13)$$

Replace $p_1 = s^A (1 - \delta) + \delta [\lambda p_2^{y,c} + (1 - \lambda)]$ so that the problem amounts to the choice of s^A . We need to show that $\frac{\partial^2 \Pi_b^{NC}}{\partial \lambda \partial s^A} \geq 0$. Differentiate Π_b^{NC} with respect to λ

$$\frac{\partial \Pi_b^{NC}}{\partial \lambda} \frac{1}{\delta} = (v_2 - p_2^{n,c}) (p_2^{n,c} - s^B) + (p_2^i - p_2^{y,c}) (p_2^i + p_2^{y,c} - v_2).$$

Then,

$$\frac{\partial^2 \Pi_b^{NC}}{\partial \lambda \partial s^A} \frac{1}{\delta} = \begin{cases} 0, & \text{if } p_2^{y,c} = p_2^i = \frac{v_2 + s^A}{2} \\ \frac{s^A}{2} & \text{if } p_2^{y,c} = s^B, p_2^i = \frac{v_2 + s^A}{2} \\ 0, & \text{if } p_2^{y,c} = s^B, p_2^i = 1 \end{cases}$$

■

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