Informational spillovers and strategic launch delay of pharmaceutical drugs[1]

November 21, 2006

[1] **(Preliminary draft prepared for submission to the iHEA World Congress in Copenhagen, 2007. Please do not quote without the authors' permission)**

We thank Mario Pagliero, Pedro Pita Barros, Xavier Martínez-Giralt, Izabela Jelovac and the participants at the BEC workshop at the Universitat Autònoma de Barcelona, the XXX Simposio de Analisi Economico and the Jornadas de Economia Industrial for their comments and suggestions. The usual disclaimer applies. The authors acknowledge the financial support of the Fundación Banco Bilbao Vizcaya.

Abstract

This paper analyzes informational spillovers in the pricing of drugs, which occur as a result of sequential launching. With sequential launches and asymmetric information about the production and distribution costs of a drug, the acceptation of a price where the drug is first launched might reveal the firm's private information to subsequent players. Information spillovers can be avoided by simultaneous launching in all countries. However, we identify conditions under which the firm can use launch delay and the consequent existence of spillovers to commit to the rejection of low prices. These conditions are: (i) the unit subsidy of drugs varies across countries; (ii) one of the countries has a larger aggregate demand and/or the firm is sufficiently patient (iii) the prior that countries hold about the firm being low cost takes intermediate values. If these conditions hold, a firm will chose to delay launch in the country with larger consumer copayment.

1 Introduction

Several authors have studied the (sequential) launch decisions of a pharmaceutical firm that aims to sell its product in several countries. Danzon, Wang and Wang (2005) (DWW) henceforth) as well as Kyle (forthcoming) report the variety in international launch delays and empirically estimate their determinants. The common denominator of these empirical papers is the assumption that low prices in a country will spill-over to other countries due to external referencing and parallel imports.[1] The basic trade-off that the pharmaceutical firm is facing is the following. On the one hand, by delaying launch in a low-price country, say A, the firm is also delaying the (small but positive) profits that are to be derived from this country. On the other hand, by delaying launch, the firm avoids this low price to overspill into other countries. In addition, the losses due to profit delay are more important the larger A's market is. These arguments give rise to two testable hypothesis. First, delay should be more likely in countries with lower expected prices. Second, for the same expected price, delay should be less likely in large demand countries. Evidence corroborating these hypothesis is provided in these two empirical analyses.

Notice, however, that these arguments hinge on prices being exogenous. To empirically implement this assumption, DWW take the price of similar drugs that are already in the market as a proxy for expected price. Hence the exogeneity assumption is warranted if intra-brand competition is sufficiently stiff. Kyle, on the other hand, takes the intensity of price controls as a proxy for expected price. The stiffer price controls are, the lower the price one should expect. Despite of this, we aim to show that making prices endogenous throws additional light to entry decisions by pharmaceutical firms. In other words, our model provides additional testable implications that are relevant for both domestic and international policies.

[1]Kyle focuses on the effects of price controls at the country where the firm is located and where the firm has already launched its product, as a determinant of subsequent launching in foreign countries. Our emphasis is on the initial launching decisions by a firm.

We take quite an extreme step in the direction of making prices endogenous. Namely, we assume that countries are unable to commit ex-ante to the price that the firm will be able to obtain. Hence, prices are determined in each country as the ex-post optimal decision by the health agencies that regulate prices. Conceptually, the difference with Kyle is that while she assumes that the price controls are committed in advance, we assume that the agency in a specific country sets price controls once the firm has decided to launch in that country. Equivalently, form a theoretical point of view it is as if agencies are able to make take-it-or-leave-it offers to firms, but these offers are made after the firm has already decided its timing of launches.[2]

This rather extreme assumption would take us to marginal cost pricing in a perfect information world, which is incompatible with pharmaceutical firms recouping their large fixed R&D costs. However, one of the main contributions of our work is that of introducing asymmetric information in this pricing process. Namely, the pharmaceutical firm has private information on its production and distribution costs, which in turn implies that only she knows what an acceptable price is. In consequence, also agencies face a trade-off. On the one hand, if an agency insists in offering a very low price to a pharmaceutical firm, it may end up loosing the provision of the drug. This is beautifully illustrated by the following statement by Pfizer Chairman Hank McKinell, also reported by Kyle: "[w]e introduce our new products later and later on the French market, and if the government continues to put pressure on prices, there will be no more [new products]." On the other hand, if an agency offers a high price, it will secure provision, but will do so at a lower welfare. When this trade-off is resolved in the second alternative, the firm makes large variable profits, as price will exceed marginal cost. In consequence a portion of fixed costs will be recouped.[3]

[2] There is a technical reason for why we stick to take-it-or-leave-it offers by the agency. Since, as we will see, our model is one with asymmetric information, setting up a more sophisticated negotiation procedure woudl force us to resort to the tools of bargaining under asymmetric information, which usually suffer from extremely poor predictive power (see for instance Fudenberg, Levine and Tirole, 1985).

[3] Notice that since R&D costs are sunk, they would be irrelevant in any negotiations between the firm and the health authority. We further discuss this below.

Once an information asymmetry is introduced, new and interesting effects arise. First of all, low prices may overspill to other countries even in the absence of parallel imports or external referencing. The reason is simple, agencies that would make generous price offers and who observe the firm accepting a low price will update their beliefs about what an acceptable price is. Hence the title of our paper. Second, we prove that an agency's aggressivity in her price offers to the firm crucially depends on three factors, a static one and two dynamic ones, one backward looking and one forward looking. The static factor is given by its reimbursement policy. Namely, we prove that agencies in countries where consumer copayment is large (low reimbursement or low subsidy) tend, everything else equal, to be less aggressive in their price offers. The backward-looking dynamic factor is simple: we already mentioned that if an agency has observed a low price acceptation in a previous country it will update its beliefs and become aggressive. The forward looking factor is given by the aggressivity of the subsequent agencies that the firm will face. Let us explain this in some detail. By backward induction, suppose that the last agency (say that of country B) is not aggressive. This implies that the firm will receive a generous offer unless some updating has occurred. Then assume that the first-to-last agency (say that of country A) would be aggressive even in the absence of learning. The firm may want to reject a low price offer by A in order to pretend that only generous offers are acceptable for her. This implies that the agency in A will end up facing a harsher trade-off. Even if the firm is truly willing to accept low offers, low offers may trigger a "disguise" rejection. On top of this, it could be the case that in truth only high prices are acceptable to the firm. We prove that there exist parameter configurations on prior beliefs, copayments, relative country size, and firm's discount factor, such that even aggressive agencies end up making generous offers. This is the main finding of the paper. As a corollary, the firm will strategically choose to delay launch in the less aggressive countries, rather than launch in all countries simultaneously under such configurations.

These arguments could be summarized as follows. By delaying launch in the country with a non-aggressive agency, the firm is able to make the following threat to the aggressive agency: "Even if you are quite sure that low a price is acceptable for me, if your price offer is not generous enough I will pretend, by rejecting, that only high prices are acceptable." In some instances the threat is sufficient to ensure generous offers in all countries.

We analyze the effects of relative country size and the firm's intertemporal discount rate We show that if the aggressive agency (say A) is located in a sufficiently more populated country than the other and/or the firm is sufficiently impatient then the above threat no longer serves as a mechanism to raise the price offers made by A. In this case, in equilibrium the firm does not implement any delays. Conversely, for a fixed firm's discount rate, we should observe delays when countries are of similar size or when the country suffering delay has a larger population. Simply, the above threat becomes extremely credible when the future countries are large. This goes counter the argument presented by the empirical papers referenced above, which argue that delay only occurs for small countries. Another lesson from our analysis is that relative country size and firm's impatience are intimately intertwined in the incentives to delay launch.

Perhaps surprisingly, country size has no bearing whatsoever on an agency's aggressivity in the absence of learning. In other words, only per-capita differences matter in the agency's trade-off. It is also worth noting that it is a necessary condition for strategic delay to occur that reimbursement policies differ from country to country. Without this, all countries are equally aggressive (or generous) in their price offers.

Notice that parameter values exist such that in equilibrium low cost firms make positive (variable) rents. In a more long run perspective, this explains why pharmaceutical firms have incentives to engage in costly R&D despite the fact that they may be facing take-it-or-leave-it price offers from health agencies. Lucky firms may come up with an efficient production technology. Our main assumption is that whether R&D was successful in this regard is not observable.

As an extension, we analyze the case where countries are able to commit their price controls ex-ante. We prove that if agencies are sufficiently impatient then a generous agency may be willing to commit ex-ante to a large price offer in order to avoid delay. This result is in line with the literature of behavior-based price discrimination, where it is shown that long term contracts are beneficial to the side of the market making take-it-or-leave-it offers.[4] From a normative point of view, our interpretation of this is that agencies should reconsider their design of long run pricing policies. From a positive point of view, we could explain this phenomenon by assuming that prior beliefs on what an acceptable price is be quite optimistic and/or the absence of large and non-aggresive countries.

Finally, let us argue why one cannot apply the conclusions stemming form our work to other non-health-related markets. It is hard to find examples of products satisfying two crucial characteristics of our framework of analysis: monopsony power (*de facto*) by health agencies and the presence of subsidies to consumption. Although the first is in common with the procurement literature, the second characteristic makes the pharmaceutical industry quite unique.

The paper is organized as follows. In Section 2 we outline the model. In Section 3 we characterize the scenario where strategic launch delay is present in equilibrium. In Section 4 we solve the model on all other scenarios and show that launch delay never occurs. In Section 5 we analyze several extensions. All the proofs are in the Appendix.

2 The model

The players of the game are two agencies ($i = A, B$), one for each country; and a multinational pharmaceutical firm which is based on a third country.

Production costs and impatience

The costs of producing Q units of the drug are given by $F+cQ$. The firm can be of two types, characterized by the constant marginal cost of production $c \in (\underline{c}, \overline{c})$ with $\underline{c} < \overline{c}$. Denote by b_0 the probability that both agencies assign,

[4] See the survey on BBPD by Fudenberg and Villas-Boas (2005).

a priori, to the firm having low marginal costs. We refer to b_0 as the prior belief. The firm discounts second period profits by a rate $0 < \delta < 1$ that is independent of type.

Consumer copayment scheme

We focus on a proportional reimbursement or copayment scheme.[5] Given a full price p, a consumer only pays $y = \gamma_i p$ with $0 \leq \gamma_i < 1, i = A, B$. We assume that the copayment is larger in country B, namely,

Assumption 1 $\gamma_A < \gamma_B$.

This assumption implies that for each given full price p, *individual* demand is larger in country A.

Demand and surplus

Consumers are homogeneous across countries. An individual consumer's demand function is D. That is, if a consumer in either country pays y per unit then her demand is $D(y)$. Let P be the inverse of D. The properties of the function D are the following.

Assumption 2 *(i)* $P(0) > \overline{c} > \underline{c}$*; (ii)* D *is strictly decreasing and concave (perhaps not strictly).*

Part (i) implies that the market is always viable. Part (ii) implies that demand is maximized when consumers pay zero, and that maximum demand is finite. We denote this maximum demand by $q^{\max} = D(0)$. Denoting by p the price that the firm obtains, the consumer demand in country i is $D(\gamma_i p)$.

In order to simplify the analysis we make the following very mild assumption.

Assumption 3 *Even if the low cost firm is not subsidized in a country, its preferred price in this country is not smaller than* $\underline{c}$*. Equivalently,* $\arg\max_p D(p)(p - \underline{c}) \geq \overline{c}$.

[5] For fixed copayment, results do not change qualitatively.

This assumption guarantees that if the low cost firm *is* subsidized then its preferred price is also at least $\overline{c}$. Formally

Lemma 1 *Define* $p^m(\gamma) = \arg\max_p D(\gamma p)(p - \underline{c})$. *Then* $p^m(\gamma) > \overline{c}$ *for all* $\gamma < 1$.

In general, the individual gross consumer surplus as a function of firm's price p and copayment rate γ is given by

$$GCS(p, \gamma) = \int_0^{D(\gamma p)} P(q)dq.$$

Net consumer surplus is given by

$$S(p, \gamma) = GCS(p, \gamma) - D(\gamma p)\gamma p.$$

We normalize the mass of consumers in country B to 1, and the mass of consumers in country A to k. Thus, for a given firm price p, the aggregate demand in country A is $kD(\gamma_A p)$ while the aggregate demand in country B is $D(\gamma_B p)$.

Agencies' objective function

Agencies are risk neutral.[6] We define the agency's payoff as *per* individual and as a function of firm price and copayment rate. It is given by net consumer surplus minus government costs. That is, we are assuming that the agency's mandate is to maximize net consumer surplus minus the associated taxes. Hence, if a price p is accepted by the firm then the agency obtains

$$\begin{aligned} OF(p, \gamma) = S(p, \gamma) - p(1 - \gamma)D(\gamma p) = \\ GCS(p, \gamma) - D(\gamma p)\gamma p - p(1 - \gamma)D(\gamma p) = \\ GCS(p, \gamma) - pD(\gamma p). \end{aligned}$$

Note also that this objective function is not economic welfare as it does not

[6] Each agency deals with a large number of drugs. Under uncertain marginal costs, some price offers may be accepted and some may be rejected and in the end the agency only cares about average surplus generated.

include the firm's profits. To justify this, recall that we assume that the firm is not located in the country.[7] The properties of the objective function are given next. We express partial derivatives as subscripts.

Lemma 2 *For all* $0 < \gamma < 1$ *and* $p > 0$*, we have that* $OF_\gamma(p, \gamma) > 0$*.*

This implies that if the agency were to set the copayment, then γ would be chosen to be 1 and the consumers would bear the full brunt of price changes. However, we assume that the copayment in not chosen by the agency. For instance, suppose that it is the Parliament who chooses γ beforehand. If the Parliament has other motivations rather than mere financial costs and consumer surplus, intermediate values of γ will be legislated.[8] One could then ask why does the Parliament delegate the negotiation of the drug price to an agency. Following the usual delegation-as-commitment argument, the agency behaves more aggressively if its mandate includes cutting costs. In any case, we take the positive approach here as copayments below 100% are observed in reality.

Lemma 3 *For all* $0 < p < P(0)$ *and* $0 < \gamma < 1$*, we have that* $OF_p(p, \gamma) < 0$ *while* $OF_{p\gamma}(p, \gamma) > 0$*.*

That is, for p in the indicated region, *ceteris paribus* the agency always prefers lower prices. Intuitively, when price increases, this has three effects on the agency's objective function. First, the total government and consumer outlay on inframarginal consumers increases, a negative effect. However, as price increases total consumer copayment increases (for $\gamma > 0$) and hence demand decreases. This brings the other two effects on the agency: gross consumer surplus is reduced, again a negative effect, but fewer consumers need to be subsidized, a positive effect. The limit on p and the concavity of demand imply that the positive effect is not enough to compensate the other two.[9] The lemma also states that the absolute value of

[7] For altrnative interpretations of this assumption, see Jelovak, Garcia-Mariñoso and Olivella (2006).

[8] These could be equity or insurance considerations.

[9] Note that if the copayment is fixed the positive effect does not exist and all the remaining effects of the price increase on the objetive function are negative.

the effect of a price increase decreases with the copayment rate γ. This is due to the fact that as γ increases, the compensating positive effect gains importance, as the consumer is less isolated from the price increase. An important implication of the lemma is that, with full information, the agency would always offer the smallest acceptable price, i.e., the minimum average *variable* cost. In our set-up this coincides with the marginal cost.[10]

The next assumption states that, even if the drug was fully subsidized and the agency was to pay the maximum price $\overline{c}$, the agency would still benefit form the drug.

Assumption 4 $OF(\overline{c}, 0) > 0$.[11]

Given Lemma 2 and Lemma 3, assumption 4 implies that $OF(p, \gamma) > 0$ for any $p \leq \overline{c}$ and $\gamma \geq 0$.

From now on, denote the objective function of the agency in country j, $OF(p, \gamma_j)$, by simply $OF_j(p)$; for $j = A, B$.

Timing

The game has 3 or 5 stages depending on the firm's launching strategy, which is chosen in stage 1. Hence, launching may be simultaneous, sequential starting in A, or sequential starting in B. If launching is simultaneous, both agencies simultaneously make each a take-it-or-leave-it price p_i, $i = A, B$, and in that case in stage 3 the firm accepts or rejects each agency i's price offer. If the firm rejects agency i's offer, the firm does not receive authorization to sell the drug in country i. If the firm accepts i's offer, the drug is launched in country i and is included in this country's reimbursement list. If launching is sequential (say launch first in i and then in j), in stage 2 agency i makes the offer, in stage 3 the firm accepts or rejects, which is observed by firm j, in stage 4 agency j makes an offer, and in stage 5 the firm accepts or rejects.

[10] Hence, under symmetric information the country would never contribute to the financing of fixed R&D costs and would free ride on this investment.

[11] In the case of linear demand, this assumption implies that $P(0) > 2\overline{c}$, that is, the individual's maximum willingness to pay for the drug is at least twice the maximum unit cost, an extremely weak assumption for pharmaceutical drugs.

Beliefs and Price stakes

Agencies's prior beliefs on true costs are common. In the absence of any information, suppose for now that agency i thinks that an offer $p = \underline{c}$ will be accepted if and only if the firm is low cost whereas an offer $p_A = \overline{c}$ will be accepted by any firm. Then this agency will for sure dare to offer price $p = \underline{c}$ if $k \cdot b_0 OF_i(\underline{c}) > k \cdot OF_i(\overline{c})$. Notice that the previous comparison is independent of the size of k,and can be rewritten as

$$b_0 > \frac{OF_i(\overline{c})}{OF_i(\underline{c})},$$

where $\frac{OF_i(\overline{c})}{OF_i(\underline{c})} < 1$ by 3. Notice that the smaller the difference between $OF_i(\overline{c})$ and $OF_i(\underline{c})$ is, the larger and closer to1 is the ratio, and the less likely it is that the agency will dare to offer the low price $\underline{c}$ in the absence of new information. We say that an agency with a large ratio has "low price stakes" and that in consequence is not aggressive in its price offers. It turns out that an agency i's price stakes are inversely related to the copayment prevalent in country i. Formally.

Lemma 4 *Assumption 1 implies that* $OF_A(\overline{c})/OF_A(\underline{c}) < OF_B(\overline{c})/OF_B(\underline{c})$.

If $b_0 = \frac{OF_i(\overline{c})}{OF_i(\underline{c})}$ then agency i is indifferent between ensuring provision and risking a rejection. We make the following general tie-breaking assumption.

Assumption 5 *If an agency, given the ensuing game, is indifferent between ensuring provision by offering a price* p *and risking a rejection by offering price* $p' < p$*, the agency prefers to secure provision*

The next lemma is trivial but very useful.

Lemma 5 *The ratio* $\frac{OF_i(\overline{c})}{OF_i(p)}$ *is increasing in* p *and is equal to 1 when* $p = \overline{c}$.

Posterior beliefs

Suppose that agency i has been approached first. Denote by $b_\alpha\,(p_i)$, $\alpha = R, A$, the subjective probability that $c = \underline{c}$ of agency $j \neq i$'s after observing, respectively, the acceptance ($\alpha = A$) or rejection ($\alpha = R$).

To simplify the exposition, we make the following assumption. It is proven to be without loss of generality in the Appendix.[12]

Assumption 6 *If a firm, given the ensuing game, is indifferent between accepting and rejecting an agency's price offer, the firm accepts with probability 1.*

Preliminary results and definitions

A preliminary lemma will prove to useful. It states that the inefficient type of firm is unable to derive any rents, irrespective of its launching decision and irrespective of the prior or posterior beliefs that agencies may have. Formally,.

Lemma 6 *Equilibrium prices are never above $\overline{c}$ and if any information is to be revealed, it must reveal that the firm has low costs.*

Next, we define an important threshold for a price offer. Intuitively, suppose that the firm has opted for a sequential launching strategy, and that the second agency is not aggressive in the absence of new information. The threshold is such that, any price on or above it will be acceptable by the firm even if this acceptation reveals that the firm has low costs, thus converting the second agency into an aggressive one. Notice that for the threshold to reveal information it must be below $\overline{c}$. As we will see, the following equation in p defines this threshold:

$$(p - \underline{c})kD(\gamma_A p) = \delta(\overline{c} - \underline{c})D(\gamma_B \overline{c}). \tag{1}$$

The term in the left hand side is the profit obtained by accepting the firm and thus foregoing second period profits. The right hand side is the present

[12] The argument that shows that this assumption is without loss of generality follows the usual reasoning for sequential games with continuous strategy sets. If the opposite was assumed, the previous player can obtain a strict gain by breaking the indifference at an arbitrarily small cost. But as this cost would have to be minimized subject to being positive, no solution exists. The argument in the appendix carefully looks at posterior beliefs along the game, as if these were zero for the type involved, the "strict gain" ceases to exist.

discounted value of profits in the second period if the second agency is not aggressive in the absence of new information. However, since the term in the right hand side is concave on p, the equation may yield more than one solution, or none, and even if one exists it is meaningless if it is larger than or equal to $\overline{c}$. The following lemma addresses these issues.

Lemma 7 *(1) Suppose first that $\delta/k < \frac{D(\gamma_A \overline{c})}{D(\gamma_B \overline{c})}$, a bound that is larger than 1. Then*

(i) Equation (1) yields a unique solution in the open interval $(\underline{c}, \overline{c})$. We refer to this solution as $\widetilde{p}_A$.

(ii) For prices different form $\widetilde{p}_A$, we have that

$$(p-\underline{c})kD(\gamma_A p)\begin{cases} > \delta(\overline{c}-\underline{c})D(\gamma_B \overline{c}) \text{ if } p > \widetilde{p}_A \\ < \delta(\overline{c}-\underline{c})D(\gamma_B \overline{c}) \text{ if } p < \widetilde{p}_A. \end{cases}$$

(iii) $\widetilde{p}_A$ can be made arbitrarily close to $\underline{c}$ by letting δ/k tend to zero.

(iv) $\widetilde{p}_A$ can be made arbitrarily close to $\overline{c}$ by letting δ/k tend to $\frac{D(\gamma_A \overline{c})}{D(\gamma_B \overline{c})}$.

(v) $\widetilde{p}_A$ is increasing in δ/k.

(2) Suppose now that $\delta/k \geq \frac{D(\gamma_A \overline{c})}{D(\gamma_B \overline{c})}$. Then there does not exist a solution to (1) in the open interval $(\underline{c}, \overline{c})$.

By substituting $\underline{c}$ by $\widetilde{p}_A$ in $\frac{OF_A(\overline{c})}{OF_A(\underline{c})}$, we obtain a new ratio $\frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)}$ that, by virtue of Lemmata 7 and 5, has the following properties.

Lemma 8 *(1) The ratio $\frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)}$ is increasing in δ/k, can be made arbitrarily close to $\frac{OF_A(\overline{c})}{OF_A(\underline{c})}$ by letting δ/k tend to zero, and can be made arbitrarily close to one if δ/k tends to $\frac{D(\gamma_A \overline{c})}{D(\gamma_B \overline{c})}$.*

(2) There exists $\delta/k < \frac{D(\gamma_A \overline{c})}{D(\gamma_B \overline{c})}$ such that $\frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)} = \frac{OF_B(\overline{c})}{OF_B(\underline{c})}$.

The properties of $\frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)}$ as a function δ/k are depicted in Figure 1 as a curve. This curve, together with the horizontal lines at $\frac{OF_A(\overline{c})}{OF_A(\underline{c})}$ and $\frac{OF_B(\overline{c})}{OF_B(\underline{c})}$, divide the space into four regions where the pair $(\delta/k, b_0)$ may lie. We will proceed by solving the game in each of these scenarios Intuitively, scenario 1, prior beliefs are extremely pessimistic. In scenario 2, beliefs are intermediate and either country A is relatively small or the firm is relatively patient. In scenario 3, beliefs are still intermediate but country A is either relatively large or the firm is relatively impatient. In scenario 4, prior beliefs are extremely optimistic. We will start with the second scenario, as we will prove that it is the only case where the firm engages in strategic launch delay.

[FIGURE 1 AROUND HERE]

Before solving the game, and in order to further simplify the analysis, we make the following assumption.

Assumption 7 *When forming its beliefs on the firm's true costs, neither agency takes into account the launch sequence.*

This assumption implies that posterior beliefs are only based on observed acceptation or rejection decision. The assumption could be justified by the existence of exogenous reasons for delayed launch, like regulatory uncertainty, inconclusive preliminary tests, and so on. In Section 5, we relax this assumption in several directions. The main insights of the paper remain valid.

3 The scenario with strategic launch delay

Suppose that the conditions for scenario 2 hold. Formally, suppose that

$$\frac{OF_A(\overline{c})}{OF_A(\underline{c})} < b_0 \leq Min\left\{\frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)}, \frac{OF_B(\overline{c})}{OF_B(\underline{c})}\right\}$$

We proceed by backward induction for each launching strategy, and then determine the optimal launching strategy.

3.1 Simultaneous launch

Suppose that the firm chose simultaneous entry in the past. In the last stage a low cost firm will accept any $p_J \geqslant \underline{c}$ and reject any $p_J < \underline{c}$, while a high cost firm will accept any $p_J \geqslant \overline{c}$ and reject any $p_J \geq \overline{c}$. Hence, given that

$\frac{OF_A(\overline{c})}{OF_A(\underline{c})} < b_0 \leq \frac{OF_B(\overline{c})}{OF_B(\underline{c})}$, A will offer $\underline{c}$ and B will offer $\overline{c}$ (even if $b_0 = \frac{OF_B(\overline{c})}{OF_B(\underline{c})}$, by Assumption 5), and both will be accepted The firm obtains instantaneous profits $(\overline{c} - \underline{c})D(\gamma_B \overline{c})$.

3.2 Delay launch in country A

Suppose now that the firm has decided to enter country B first, then country A. Since $\frac{OF_A(\overline{c})}{OF_A(\underline{c})} < b_0$, country A offers $\underline{c}$ even if no information has been revealed. If some information has been revealed, by Lemma 6 country A knows for sure that the firm has low costs ant therefore still offers $\underline{c}$. The firm accepts this offer. Therefore, when the firm is facing B's price offer, she knows that no matter what she does in the next period she will face an offer of $p_A = \underline{c}$. In consequence, a low cost firm will accept any $p_B \geqslant \underline{c}$ and reject any $p_B < \underline{c}$, whereas a high cost firm will reject any $p_B < \overline{c}$, as it was the last stage. However, since $b_0 \leq \frac{OF_B(\overline{c})}{OF_B(\underline{c})}$, B offers $p_B = \overline{c}$. The firm obtains $(\overline{c} - \underline{c})D(\gamma_B \overline{c})$, i.e., the same as with simultaneous entry.

3.3 Delay launch in country B

Since $b_0 \leq \frac{OF_B(\overline{c})}{OF_B(\underline{c})}$, the last agency B will offer $p_B = \overline{c}$ if no information has been revealed, and will offer $p_B = \underline{c}$ otherwise. Knowing this, if the low cost firm firm faces a price offer $p_A < \overline{c}$, she faces the trade-off addressed in the previous section. In other words, by Lemma 7, she will accept any $\overline{c} > p_A \geq \widetilde{p}_A$ and will reject any $p_A < \widetilde{p}_A$. A high cost firm of course will reject any such offer. Therefore, agency A faces the following trade-off: either secure provision by offering $p_A = \overline{c}$, or risk rejection of a lower price by offering $p_A = \widetilde{p}_A$. Since $b_0 \leq \frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)}$, then A prefers to offer $p_A = \overline{c}$. The firm obtains $(\overline{c} - \underline{c}) \left[kD(\gamma_A \overline{c}) + \delta D(\gamma_B \overline{c}) \right]$.

3.4 Comparisons

We already found that simultaneous launch and delaying launch in A yield the same profits, namely $(\overline{c} - \underline{c})D(\gamma_B \overline{c})$. The firm will prefer to delay launch in B if $(\overline{c} - \underline{c}) \left[kD(\gamma_A \overline{c}) + \delta D(\gamma_B \overline{c}) \right] > (\overline{c} - \underline{c})D(\gamma_B \overline{c})$, i.e., if $k > \frac{D(\gamma_B \overline{c})}{D(\gamma_A \overline{c})}(1 - \delta)$.

Since $\frac{D(\gamma_B \overline{c})}{D(\gamma_A \overline{c})} < 1$, both $\delta = 1$ and $k \geq 1$ are alternative sufficient conditions for launch delay. This is summarized in the next proposition.

Proposition 1 *The sufficient conditions for the firm to engage in launch delay are*
(i) $\frac{OF_A(\overline{c})}{OF_A(\underline{c})} < b_0 \leq Min\left\{\frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)}, \frac{OF_B(\overline{c})}{OF_B(\underline{c})}\right\}$*; and*
(ii) $k > \frac{D(\gamma_B \overline{c})}{D(\gamma_A \overline{c})}(1-\delta)$.

Intuitively, Condition (i) ensures that, in the absence of new information, agency is aggressive while agency B is not. (Use $\frac{OF_A(\overline{c})}{OF_A(\underline{c})} < b_0 \leq \frac{OF_B(\overline{c})}{OF_B(\underline{c})}$.) Now, by placing the non-aggresive agency B at the end, the firm is able to make the following threat to A: "If you dare to offer me a low price p just slightly above $\underline{c}$ because you are sufficiently sure that my costs are low, I will not accept it because accepting would reveal to agency B that my costs are low –thus rendering B aggressive– and you are not offering me much of a margin anyway." Given this threat, A cannot offer a such a low price offer. However, A can still offer an intermediate price $\widetilde{p}_A > \underline{c}$ that exactly compensates the firm for revealing its costs. However, A no longer compares sure provision at $\overline{c}$ with a likely provision at $\underline{c}$, but with a likely provision at $\widetilde{p}_A > \underline{c}$. Condition (i) also ensures that this new trade-off results in A opting for sure provision, as $b_0 \leq \frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)}$. Condition (ii) ensures that the costs of delaying launch are less than the benefits. The cost of launch delay is that the profits to be obtained in country B are delayed. The benefits are that the firm obtains positive profits from country A, whose agency would have offered $p = \underline{c}$ had launch been simultaneous. If the firm is patient ($\delta = 1$) the costs of delay disappear, hence launch delay is preferred for any k. If the firm is extremely impatient (δ close to zero), then the size of country A (where delay brings profits) should be at least equal the size of country B.

It is clear that condition (ii) is necessary to obtain strategic launch delay. We now show that conditions (i) and (ii) of the last proposition are not only jointly sufficient to have strategic launch delay, but also necessary. In order to do this, we need to solve the game in all the other three possible scenarios

4 The scenarios without strategic launch delay

We solve the game case by case, in order of difficulty, starting from the easiest scenario.

4.1 Scenario 1: Pessimistic agencies

Suppose that $b_0 \leq \frac{OF_A(\overline{c})}{OF_A(\underline{c})} < \frac{OF_B(\overline{c})}{OF_B(\underline{c})}$. If the firm enters simultaneously in both countries, it will face the most generous price offer possible (by lemma (6) from both: $p_A = p_B = \overline{c}$, as no information is revealed previous to the offer. It is obvious then that the firm cannot improve upon this by delaying launch in any of the countries.

4.2 Scenario 4: Optimistic agencies

Suppose that $b_0 > \frac{OF_B(\overline{c})}{OF_B(\underline{c})} > \frac{OF_A(\overline{c})}{OF_A(\underline{c})}$. No matter who the last confronted agency (or agencies, if entry was simultaneous) is, the agency will offer $p = \underline{c}$ if no information was revealed in the past. If some information is revealed, then by Lemma 6 agencies know that the firm has low cost, thus reinforcing the aggressive price offer. Therefore, no matter whether there is launch delay or not, the low cost firm never makes any rents in equilibrium, so it is indifferent between any sequence of launches. If one observes delay, it is not due to strategic reasons.

4.3 Scenario 3: Intermediate beliefs, impatient firm

The only remaining scenario is the one where, not only $\frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)} \leq \frac{OF_B(\overline{c})}{OF_B(\underline{c})}$, but also $\frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)} < b_0 \leq \frac{OF_B(\overline{c})}{OF_B(\underline{c})}$ (see Figure 1). Notice that $\frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)} < b_0$ implies $\frac{OF_A(\overline{c})}{OF_A(\underline{c})} < b_0$, by Lemma 8. Therefore, if launching is simultaneous then A offers $\underline{c}$ and B offers $\overline{c}$. Firm's profits are $(\overline{c} - \underline{c})D(\gamma_B \overline{c})$. If the firm launches in country B first, then the last agency A will again offer $\underline{c}$ without fearing a disguise rejection by the low cost firm. As agency B is not aggressive, she will offer $\overline{c}$ in order to secure provision (as $b_0 \leq \frac{OF_B(\overline{c})}{OF_B(\underline{c})}$). The firm makes the same profits as with simultaneous launch. Suppose, finally, that the firm launches in country A first. Since agency A knows that the firm will face a non-aggressive firm next period, agency A cannot offer a price below $\widetilde{p}_A > \underline{c}$, since this would indeed trigger a disguise rejection. Hence Agency A faces the same trade-off as in Scenario 2: she either secures provision by offering $\overline{c}$ or she risks rejection by offering the lower price $\widetilde{p}_A$. However, in contracts with Scenario 2, agency A does prefer to risk, since $b_0 > \frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)}$. Therefore, A offers $\widetilde{p}_A$, the firm accepts if it has low costs and rejects otherwise, country B learns the true costs of the firm, and therefore offers $\underline{c}$ if she observed an acceptation in the previous period. The firm makes profits equal to $(\overline{c} - \underline{c})kD(\gamma_A \overline{c})$.

Let us now compare the three launching strategies. By contradiction, suppose that strategic delay is observed. This can only happen if $(\widetilde{p}_A - \underline{c})kD(\gamma_A \widetilde{p}_A) > (\overline{c} - \underline{c})D(\gamma_B \overline{c})$. However, by definition of $\widetilde{p}_A$ we know that $(\widetilde{p}_A - \underline{c})kD(\gamma_A \widetilde{p}_A) = \delta(\overline{c} - \underline{c})D(\gamma_B \overline{c})$, which is smaller than $(\overline{c} - \underline{c})D(\gamma_B \overline{c})$ due to impatience ($\delta \leq 1$), so we have reached a contradiction.

A by-product of the above analysis is that, if some external factor implies that the firm must launch sequentially, e.g. the firm has a single negotiating agent, then we have just proven the following corollary.

Corollary

Under Scenario 3, if launch is restricted to be sequential the firm strictly prefers lunching in country B first to the reverse order.

It is then perhaps acceptable to say that in Case 3 one observes strategic launching, although not strategic delay as delay must occur for exogenous reasons.

5 Extensions

Our analysis remains valid even if one relaxes some of our assumptions, and allows us to discuss the issue of precommitment by agencies.

5.1 Relaxing Assumption 7

By assumption 7, the first agency approached does not use the order of launches as a signal. This is at odds with the fact that under the conditions of Proposition 1, a low cost firm prefers to enter country B first. We now relax this assumption and allow agencies to update their beliefs using this information. Let us refer to this updating as "sophisticated updating". Formally, denote by AB the event that country A is entered first. Then we have that the low cost strictly prefers this to any other launching strategy, so that $Prob(AB|c = \underline{c}) = 1$. In contrast, the high cost is indifferent among all launching strategies, as it always receives zero rents. Therefore $Prob(AB|c = \overline{c}) = Prob(BA|c = \overline{c}) = Prob(\text{simultaneous launch}|c = \overline{c}) = 1/3$. Hence, if B observes both AB and an uninformative acceptation of $p_A = \overline{c}$, B updates beliefs using Bayes' rule as follows:

$$Prob(c = \underline{c}|AB) = \frac{\Pr(AB|\underline{c})b_0}{\Pr(AB|\underline{c})b_0 + \Pr(AB|\overline{c})(1 - b_0)} = \frac{b_0}{b_0 + (1/3)(1 - b_0)} = \frac{3b_0}{2b_0 + 1}$$

which is larger than b_0 if $b_0 < 1$. Notice that A will conduct the same updating, as she only has observed the launch sequence. This implies that the condition (i) of Proposition 1 has to be re-evaluated. Namely, letting $H = Min\left\{\frac{OF_A(\overline{c})}{OF_A(\widetilde{p}_A)}, \frac{OF_B(\overline{c})}{OF_B(\underline{c})}\right\}$ and $L = \frac{OF_A(\overline{c})}{OF_A(\underline{c})}$, condition (i) becomes $L < \frac{3b_0}{2b_0+1} \leq H$, or equivalently,

$$\frac{L}{3 - 2L} < b_0 \leq \frac{H}{3 - 2H}.$$

Notice that the function $f(z) = \frac{z}{3-2z}$ is increasing in z. Therefore, if $H > L$, then $\frac{H}{3-2H} > \frac{L}{3-2L}$ as well. In other words, the interval of prior beliefs that entails launch delay does not disappear due to sophisticated updating, but shifts up and may shrink or expand depending on other parameter values. Namely, the interval expands if and only if $H > Max\{L, \frac{3-3L}{3-2L}\}$, where $Max\{L, \frac{3-3L}{3-2L}\} = L$ if $L > \frac{1}{2}(3 - \sqrt{3}) \cong 0.63397$. This is illustrated in Figure 2.

[FIGURE 2 AROUND HERE]

5.2 Agency B's precommitment

A consequence of Proposition 1 is that under Scenario 2, agency B suffers from launch delay (if the very mild condition (ii) holds). In equilibrium agency B then obtains $\delta_B b_0 OF_B(\overline{c})$, where δ_B is this agency's discount rate.

Suppose that B was able to commit, before any launch decisions had been taken, to offer $p_B = \overline{c}$ even in the event that she learns that the firm has low costs. Then, even if the firm delays launch in country B, it is unable to threaten agency A with a disguise rejection. This implies that A will offer $\underline{c}$, and that the firm will obtain profits $(\overline{c} - \underline{c})D(\gamma_B \overline{c})$, the same ones as with simultaneous entry. The firm will be indifferent between simultaneous entry and entering country B first, as delaying launch in B would serve no purpose. In both cases agency B is able to advance its payoff $b_0 OF(\overline{c})$ one period. To conclude, the firm is hurt by B's precommitment if condition (ii) of Proposition 1 holds. Finally, agency A is now able to be aggressive without the fear of a disguise rejection, and agency A's payoff greatly increases, from $OF_A(\overline{c})$ to $OF_A(\underline{c})$. We take these results as possible explanations to the many commitment mechanisms that one observes in the real world. However, notice that the proposed commitment is to a high price aimed to advance launching. The main insight of our analysis is that this commitment also overspills to other countries.[13]

6 References

1. Garcia-Mariñoso, B. , Jelovac, I., and Olivella, P., (2006) Internationally based price regulation and price negotiation patterns. Mimeo Universite de Liege.

2. Danzon, P. and Towse, A. (2003) Differential Pricing for Pharmaceuticals: Reconciling Access, R&D and Patents, *International Journal of Health Care Finance and Economics*, 3, 183-205

[13] In line with our corollary, if firm must launch sequentially and under Scenario 3, it is country A that would gain by commiting to offering $\overline{c}$ if she is sufficedntly impatient and/or b_0 is sufificently large (namely, if $\delta_A b_0 OF(\underline{c}) < OF_A(\overline{c})$), which is consistent with the defintioon of Scenario 3 if $\delta_A < \frac{OF_B(\tilde{p}_A)}{OF_B(\underline{c})} < 1$.

3. Danzon, P., Wang, R. and Wang, L., "The Impact of Price Regulation on the Launch Delay of New Drugs." *Health Economics*, 14(3), 2005.

4. Danzon, P., The Economics of Parallel Trade." *PharmacoEconomics.* March 1998. 13(3):293-304.

5. Fudenberg, D., Levine, D., and Tirole, J. (1985) Infinite Horizon Models of Bargaining with one-sided Information, In Roth, A. (ed.) *Game Theoretic Models of Bargaining,* Cambridge University Press.

6. Fudenberg, D. and Villas-Boas, J.M. (forthcoming) Behavior-Based Price Discrimination and Customer Recognition, in T.J. Hendershott, (ed.) *Handbook of Economics and Information Systems,* Amsterdam:Elsevier

7. Kyle, M.K. (Forthcoming) Pharmaceutical Price Controls and Entry Strategies, *The Review of Economics and Statistics*, forthcoming.

8. OECD (2003): Health at a Glance, Paris.

9. Windmeijer, F., E. De Laat, R. VDouven, R. and Mot, E. (2003) Pharmaceutical Promotion and GP Prescription Behaviour, CPB working paper.

7 Appendix

Proof of Lemma 1 Notice that $\frac{d^2 D(\gamma p)(p-\underline{c})}{d^2 p} = (p-\underline{c})D''(\gamma p)\gamma^2 + 2D'(\gamma p)\gamma < 0$ since D' is negative and D'' is non-positive by Assumption 2. Therefore, $p^m(\gamma)$ is a singleton for all γ and satisfies the first order conditions. The implicit function theorem tells us that the sign of $\frac{dp^m(\gamma)}{d\gamma}$ is the same as the sign of $\frac{\partial^2 D(\gamma p)(p-\underline{c})}{\partial p \partial \gamma} = \frac{\partial D'(\gamma p)\gamma(p-\underline{c})+D(\gamma p)}{\partial \gamma} = D''(\gamma p)\gamma p(p-\underline{c})+D'(\gamma p)(p-\underline{c})+D(\gamma p)p$, which is negative again since $D'<0$ and $D'' \leq 0$. Therefore, since $p^m(1) \geq \overline{c}$ by assumption 3, we have that $p^m(\gamma) > \overline{c}$ for all $\gamma < 1$QED

Proof of Lemma 2

Differentiate OF with respect to γ:

$$OF_\gamma(p,\gamma) = \gamma p^2 D'(\gamma p) - p^2 D'(\gamma p) = -D'(\gamma p)(1-\gamma)\gamma p,$$

which is positive if $p > 0$ and $0 < \gamma < 1$.

Proof of Lemma 3

Differentiate OF with respect to p. Using $P = D^{-1}$,

$$\begin{aligned} OF_p(p,\gamma) &= \gamma p D'(\gamma p)\gamma - D(\gamma p) - pD'(\gamma p)\gamma = \\ & -D'(\gamma p)(1-\gamma)\gamma p - D(\gamma p). \end{aligned}$$

Take the derivative of the last expression with respect to γ to get the cross partial derivative

$$OF_{p\gamma}(p,\gamma) = -D''(\gamma p)(1-\gamma)\gamma p^2 - D'(\gamma p)(-1)\gamma p - D'(\gamma p)(1-\gamma)p - D'(\gamma p)p =$$
$$-D''(\gamma p)(1-\gamma)\gamma p^2 - D'(\gamma p)(-1)\gamma p - D'(\gamma p)(1-\gamma)p - D'(\gamma p)p =$$
$$-\left[D''(\gamma p)\gamma p^2 + 2pD'(\gamma p)\right](1-\gamma),$$

where $p > 0$, $D'' \leq 0$, $D' < 0$, and $0 < \gamma < 1$. This proves $OF_{p\gamma} > 0$. We can now use this result to state that an upper bound on OF_p is reached when $\gamma = 1$. Hence to prove $OF_p(p,\gamma) < 0$ it suffices to prove that $OF_p(p,1) < 0$. Now $OF_p(p,1) = -D(p)$, which is negative for $p < P(0)$.

Proof of Lemma 4. This is a direct implication of $\gamma_A < \gamma_B$.

Proof of Lemma 5

Define $Q(\gamma) = OF(\overline{c},\gamma)/OF(\underline{c},\gamma)$. Then $sign[Q'(\gamma)] = sign[OF_\gamma(\overline{c},\gamma) \cdot OF(\underline{c},\gamma) - OF(\overline{c},\gamma) \cdot OF_\gamma(\underline{c},\gamma)]$. Since $OF_p < 0$ by Lemma 3 we have $OF(\underline{c},\gamma) > OF(\overline{c},\gamma)$. By Lemma 2, $OF_\gamma > 0$. Therefore $sign[Q\prime(\gamma)] > 0$ if $OF_\gamma(\overline{c},\gamma) > OF_\gamma(\underline{c},\gamma)$. This is guaranteed since $OF_{\gamma p} > 0$ by Lemma 3.

Proof of Lemma 6 Notice that in the last stage any further update of information becomes irrelevant. Therefore, a low cost firm will accept any $p \geqslant \underline{c}$ and reject any $p < \underline{c}$ while a high cost firm will accept any $p \geqslant \overline{c}$ and reject any $p < \overline{c}$.[14] Assume, by contradiction, that $p > \overline{c}$. By lemma

[14] Here is where the part (a) of the last assumption is used.

3, the last agency(ies) i is(are) better off by deviating to $p' = p - \varepsilon$ for any sufficiently small but positive ε, contradiction. In consequence, in the first to last stage, the last agency(ies) will offer at most $p = \overline{c}$. This implies that in the last stage the high cost firm makes zero profits regardless of previous history and beliefs. If launch was simultaneous, we are done.

Now suppose that launch was sequential: first country i and then country j. We have already proven that p_j is at most $\overline{c}$. Now suppose, by contradiction, that i offers $p_i > \overline{c}$. We first prove that this offer will be accepted by any firm type. By rejecting, the firm will trigger an update of beliefs $b_R(p_i)$. The best that can happen to a firm is that these beliefs are zero, in order to obtain a price $\overline{c}$ by the last agency. Suppose then that $b_R(p_i) = 0$. A high cost firm obtains a present discounted value of zero: zero in the first period due to her rejection and zero the last stage since her mark-up is zero. If instead the high cost firm accepts, it obtains a positive (instantaneous) utility. Now suppose that the low cost firm rejects $p_i > \overline{c}$. Then, since we have just proved that a high cost firm would have accepted, we have that $b_R(p_i) = 1$, so the firm will facet $p = \underline{c}$ in the last stage and obtain zero profits. If instead the firm accepts the price offer, it cashes in $(p_i - \underline{c}) k_i D(\gamma_i \overline{c}) > 0$. Hence also the low cost firm prefers to accept the offer. This will also be true for $p' = p_i - \varepsilon$ for any sufficiently small but positive ε. This contradicts $p_i > \overline{c}$ being part of an equilibrium. To conclude, the maximum ever price that can be offered in this sequential game is $\overline{c}$.

If exactly price $\underline{c}$ is offered along the game, we know that the high cost firm is indifferent between accepting or rejecting. By Assumption 6, the firm will accept. Hence, if the low cost form rejects it, it will reveal that her costs are low and obtain zero profits in both stages. If it is accepted, it obtains a positive profit, since $(\overline{c} - \underline{c}) k_i D(\gamma_i \overline{c}) > 0$. Hence all firms accept a price offer of $\overline{c}$. Hence an acceptation of $p = \overline{c}$ reveals no information. Now suppose that some price strictly below $\overline{c}$ has been offered along the game. If it is accepted, it reveals that the firm has low costs, and we are done. If it is rejected, then no information is revealed. This completes the proof. QED.

Proof of Lemma 7

Define $g(p) = (p - \underline{c})D(\gamma_A p)$. Then (1) can be expressed as $g(p) = \frac{\delta}{k}(\overline{c} - \underline{c})D(\gamma_B \overline{c})$. In the proof of Lemma 1 we showed that $g(p)$ is concave and that it reaches a maximum at $p^m(\gamma) > \overline{c}$. This implies that $g(p)$ is increasing in the interval $[\overline{c}, \underline{c}]$. Moreover, $g(\underline{c}) = 0$ and $g(\overline{c}) =.(\overline{c} - \underline{c})D(\gamma_A \overline{c})$. Prove part (1). Suppose $\delta/k < \frac{D(\gamma_A \overline{c})}{D(\gamma_B \overline{c})}$. Then $g(\overline{c}) =.(\overline{c} - \underline{c})D(\gamma_A \overline{c}) > \frac{\delta}{k}(\overline{c} - \underline{c})D(\gamma_B \overline{c})$. This proves parts (i) and (ii). Part (iii) follows from the fact that $\frac{\delta}{k}(\overline{c} - \underline{c})D(\gamma_B \overline{c})$ can be made arbitrarily small by letting δ/k tend to zero and that $g(\underline{c}) = 0$. Part (iv) follows form the fact that $\frac{\delta}{k}(\overline{c} - \underline{c})D(\gamma_B \overline{c}) = D(\gamma_A \overline{c})(\overline{c} - \underline{c}) = g(\overline{c})$ if $\delta/k = \frac{D(\gamma_A \overline{c})}{D(\gamma_B \overline{c})}$. Part (v) holds because $g(p)$ is increasing in the interval $[\overline{c}, \underline{c}]$ and $\frac{\delta}{k}(\overline{c} - \underline{c})D(\gamma_B \overline{c})$ is increasing in δ/k Part (2). follows directly from $g(p)$ being increasing in the interval $[\overline{c}, \underline{c}]$ and the fact that $g(\overline{c}) =.(\overline{c} - \underline{c})D(\gamma_A \overline{c}) \leq \frac{\delta}{k}(\overline{c} - \underline{c})D(\gamma_B \overline{c})$ in this case. QED.

Proof of Lemma 8

Part (1) is a direct application of Lemma 7. Part (2) is a direct corollary of part (1) together with Lemma 4.

Proof of Proposition 1 This is proven in the text.