External referencing and pharmaceutical price negotiation*

Begoña Garcia Mariñoso[a], Izabela Jelovac[b], Pau Olivella[c]

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Abstract

External referencing (ER) imposes a price cap for pharmaceuticals based on prices of identical products in foreign countries. Suppose a foreign country (F) negotiates prices with a pharmaceutical firm while a home country (H) can either negotiate prices independently or implement ER based on the foreign price. We show that country H prefers ER if copayments in H are relatively high. This preference is reinforced when H's population is small. Irrespective of relative country sizes, ER by country H harms country F. Our model is inspired by the wide European experience with this cost containment policy. Namely, in Europe, drug authorization and price negotiations are carried out by separate agencies. We also explore the extension where authorization and price negotiation take place in a single agency.

Keywords: Pharmaceuticals, external referencing, price negotiation.

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[a] Comisión del Mercado de las Telecomunicaciones, c. de la Marina, 16-18, 08005 Barcelona, Spain. E-mail: bgmarinoso@cmt.es

[b] University of Lyon, Lyon, F-69003, France; CNRS, UMR 5824, GATE, Ecully, F-69130, France; ENS LSH, Lyon, F-69007, France. E-mail. jelovac@gate.cnrs.fr

[c] Corresponding author. Department of Economics and CODE. Universitat Autònoma de Barcelona, Edifici B, 08193 Bellaterra, Barcelona, Spain. E-mail: pau.olivella@uab.es

1. Introduction

This paper aims at analyzing the incentives for a country to engage in external referencing for pharmaceuticals as opposed to directly negotiating the drug's price with the firm. External referencing (ER) consists of a price cap for pharmaceuticals, based on prices of identical products in other countries.

With very few exceptions, most countries in the industrialized world have implemented ER at some point of time. Indeed, the policy is currently in place in all European countries except Denmark, Germany, the UK, and Sweden, where prices are determined by negotiations between government agencies and pharmaceutical firms. Although we offer a detailed account of the European experience in the next section, let us advance here that, in 2005, the sales of pharmaceutical products in European countries engaging in ER represented a 60% share of total EU pharmaceutical sales.[1] Puig-Junoy (2004) states that "the conditions on the EU market are in effect weakening the use of [cost-based price regulation] and giving more importance to the observed price in other European countries (external reference pricing)." (p. 163.) Heuer et al (2007) reach a similar conclusion from their formal empirical analysis. They explore whether countries engaging in ER suffer from delays in the launch of pharmaceutical products, a good proxy for the importance of ER. Despite the fact that they explore several cost-containment policies as explanatory variables (therapeutic value, cost-effectiveness, and so on), it is suggestive that the dummy variable for the presence of ER is the only explanatory variable that is significant at the 5% level. Finally, Windmeijer et al. (2006) measure the effects of the implementation of ER in the Netherlands. They show that this policy resulted in considerably lower prices in general.

These experiences raise the following questions: Why are some countries interested in engaging in ER rather than directly negotiating prices like in the UK or Germany? What is the influence of the ER policy on the reference countries and the pharmaceutical firms?

1 Source: OECD Health Data, July 2007. We have used total expenditures in millions of US dollars at exchange rate for the EU-19. There is no data for Austria, Belgium, Greece, Ireland and Poland. Since these are all ER countries, the percentage is actually larger.

To tackle these questions, we use a model where a pharmaceutical firm (simply "the firm" henceforth) sells a drug in two countries. To gather whether any demand size effects exist we assume that countries differ both in size and in the level of copayments. If a country engages in an ER policy, we say that this is the "home country", whilst we refer to the country whose price serves as reference as "foreign country". If no country engages in ER, then each country negotiates prices independently of the other. We refer to this situation as "independent price negotiations" (IPN henceforth). We assume that the firm is based on a third country, so that both the foreign and the home country will unambiguously benefit from any price decrease. We use the Generalized Nash Bargaining Solution (GNBS) to solve each negotiation problem.

In our main contribution we assume that, under IPN, countries are unable to threaten the firm with not authorizing the drug for sale in case of a negotiation failure. The only threat available to countries is that of not listing the drug for reimbursement. In other words, even if negotiations fail, the firm can still sell the drug at any price of its choice, but with no subsidy. This assumption is motivated by the fact that, in Europe, price-negotiating agencies have no role in the authorization of drugs. We therefore say that in Europe we are in a "weak threats" scenario. We elaborate this point further in the next section. However, as an extension, we also analyze a situation where agencies can threaten to ban the drug altogether when negotiations fail, which we refer to as "the tough threats scenario". Indeed, some countries outside Europe like Brazil or Canada are known to threaten firms with not authorizing drug sales if negotiations fail or if the firm does not accept ER.

In each of these two threat scenarios, we analyze how the commitment by a country to engage in ER affects the negotiations in the foreign (i.e., reference) country and ultimately determines the firm's total profit.

The main results of the paper are the following. First, under weak threats, an ER policy increases the negotiated foreign price, which harms the foreign country. Second, despite this price increase, the home country prefers ER to an independent price negotiation if the consumer copayment in the home country is relatively high. However, this preference diminishes as the demand size grows in the home country relative to the foreign country, although this preference never disappears. Third, when compared to the profits resulting from IPN, an ER policy brings an increase in the profits derived from the foreign country and a decrease in those derived from the home country. Finally, the second effect is strong enough so that overall profits decrease.

In the next section we offer some evidence that is consistent with these predictions.

As for the tough threats scenario, we show that our main insight –that the home country is benefited while the firm is harmed by ER– still holds. However, in contrast to the weak threats scenario, the negotiated price in the foreign country is unaffected by ER, so that ER does not affect the foreign country.

Before offering an intuitive explanation for our results, let us point out that it is not the aim of this paper to provide an explanation of why copayments differ form one country to the other. Certainly, we take copayments as given, carrying out our analysis for any possible configuration of copayments. Therefore, we are implicitly assuming that it takes time to change copayments, whereas prices are negotiated in a more agile and case-by-case basis. Since copayments are the prices actually borne by consumers, issues of social equity, insurance, consumer externalities, and even savings in administrative costs are present in the setting of copayments. Moreover, the experience in the EU is that copayments are generally not dependent on each drug and that at most we observe copayments for large groups of medications (say chronic versus acute treatments) set by law. Notice that, again because copayment is the price borne by the consumer, it is in the copayment negotiation where price discrimination by firms would play a decisive role. By taking copayments as given our analysis constitutes a necessary first step in a more ambitious agenda of analyzing the reimbursement system as a whole.

Let us now offer some intuition for our results. Take first the weak threats scenario. Under IPN, if negotiation fails in the foreign country the firm obtains the monopolistic profits in the foreign country's unsubsidized market (as the drug is delisted but not banned). Under ER, if negotiations fail in the foreign country the firm obtains the monopolistic profits in both the foreign and the home country. Hence ER raises the *status quo* payoff of the firm, thus raising the firm's implicit negotiation power *vis à vis* the foreign country. Notice that as the size of the home country increases, this effect is reinforced. This explains why ER becomes less and less attractive for the home country as its size becomes more important. The reason why this does not happen under tough threats (i.e., negotiations in the foreign country are unaffected by ER) is that the threat point in the home country negotiation is the same regardless of the presence or absence of ER. To see this, suppose that ER is absent. Then if negotiations in the foreign country fail, the drug is banned so the firm makes no profits. Suppose that ER is present. If negotiations in the foreign country fail, the drug is banned in both countries, so again the firm makes no profits.

Apart from the works by Windmeijer et al. (2006) and Heuer et al (2007) mentioned above, there are several empirical studies that analyze the impact of price regulation.[2] Unfortunately, more than exploring the effects of ER in isolation, most empirical studies aim to determining the effect of price controls in general. The empirical implication of our model (the effects of demand size, consumer copayment, and the separation of authorization and subsidization decisions) might serve as a guide for future empirical studies on the effects of ER as a cost control policy.

The paper is organized as follows. A description of the European experience with ER is provided in Section 2, where we contrast our predictions with some actual country cases. The model is described in Section 3. Section 4 provides the solution to the benchmark case in which each country negotiates the price with the pharmaceutical firm, independently of the other country. Section 5 introduces the possibility that one country adopt a weak-threats ER policy, and analyzes its effects. Section 6 extends the analysis to the tough-threats scenario. Section 7 concludes. All the proofs are in the appendix.

2. The European Experience

Let us now overview the many instances of ER that one can find in Europe.[3] These cases motivate our assumption that countries cannot threaten not to authorize drugs for sale if price negotiations fail or if the ER policy is rejected by the firm.

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[2] On the effects of regulation on price see, for instance, Danzon and Chao (2000a, 2000b). On the effects of regulation on launch delays see Danzon, Wang and Wang (2005) and Kyle (2007).

[3] There are countries outside Europe that also have implemented ER: Brazil (lowest price); Canada (median price); Japan, Korea, and Taiwan (average price).

Many countries in Europe have implemented ER. However, not only the policy details differ from country to country, but are also changed often. For instance, in Denmark, foreign prices were used to determine the reimbursement price for drugs with the same ATC-code, but this policy has been discontinued recently, and has been replaced by non-price controls. In Sweden, ER was discontinued in 2002. Hence, the situation is, to say the least, volatile and the examples given below are only valid as of the time of writing this section.

As for inter-country differences, some administrations use the prices of other countries to construct an average reference price, whereas others take as a reference the minimum price. Among the first ones, some use a large list of referenced foreign countries. Austria uses prices from Denmark, Finland, France, Germany, Greece, Italy, the Netherlands, Portugal, Spain, Sweden, and the UK. Finland adds to the previous list prices from Austria, Belgium, Ireland, and Norway. Also, among countries using average prices, others use prices from just a handful of countries. For instance, in the Netherlands, the maximum price for a drug is established as an average of the prices of the same drug in Germany, France, UK, and Belgium. In Switzerland, the drug price should not exceed the average of the prices in Germany, Denmark, the Netherlands and the UK. Other countries that take averages of other countries' prices are Austria, Belgium, Italy, Lithuania and Norway.

As mentioned, some countries take the minimum instead of the average price. France uses the lowest price among Austria, Belgium, Denmark, Finland, Germany, Greece, Italy, the Netherlands, Portugal, Spain, Sweden, and the UK. Other countries using the same method are: Bulgaria, Croatia, Czech Republic, Estonia, Greece, Hungary, Latvia, Poland, Portugal, Romania, ex-Serbia-Montenegro, Slovakia, and Slovenia.

In summary, out of all European Countries, only UK, Sweden, Germany, and Denmark do not currently have an ER policy.

Importantly for our model, there are reasons to believe that most European experiences correspond to the weak threats scenario. The reason is simple. In Europe, drug authorization and price negotiation are separate processes carried out by independent agencies, based on different criteria, and with different time horizons. As Heuer et al. (2007) point out, "[W]ith the introduction of the European Medicines Evaluation Agency (EMEA) in 1995, the EU Member States wanted to harmonize access to the pharmaceutical market" so that "[...] companies benefit from a larger market after authorization." (p. 2). As for Switzerland, a non-EU state, Paris and Docteur (2007) report that "to be launched on the Swiss market, pharmaceutical products have to be approved by the Swissmedic [...].This authorization is valid for 5 years." In contrast, "The Federal Office of Public Health (OFSP) regulates both inclusion in the positive list and pricing of reimbursed pharmaceuticals." The Swiss case is also interesting because the ER policy makes the threat explicit: according to the Health Insurance Law (1996) a 'positive list' of reimbursed pharmaceuticals was introduced. For a drug to be included in this positive list, its price should not exceed the average of the prices in Germany, Denmark, the Netherlands and the UK. This exactly corresponds to our weak-threats scenario. Equally explicit is the Spanish case. According to the Law 29/2006**,** the drugs that are subsidized by the National Health System are subject to ER, and in these cases the maximum producer price for drugs will be set taking into account "the average price of EU member states that are not subject to exceptional or transitory regimes of industrial property rights." (Art. 90).

We can use some of these European experiences to illustrate our predictions and to check their consistency with reality. As for the role of copayments, our prediction is that countries with relatively high copayments should be more prone to engage in ER. Using data for the year 2005, copayments in France and Spain (two external referencing countries) can be as high as, respectively, 37% and 40% of the price. In contrast, Germany and UK –who do not engage in ER–, have a cap on copayment around 10 Euro. Hence, our prediction is consistent for mildly expensive medications in these countries.

Another important prediction of our model is that under ER and weak threats, the home country's preference for ER over independent negotiations diminishes as its own relative size grows, although it never disappears. The fact that Germany and UK do not engage in ER while many small countries do is consistent with this prediction. For instance,[4] the Spanish population over that of Germany and UK in 2005 was,

[4] Source: OECD Health Data, July 2007.

respectively, 53% and 72%. A less evident case is that of France, whose population in that same year was 74% and 101% over Germany and UK, respectively. The fact that both Denmark and Sweden have abandoned ER does however run against our results.

We recognize that there may be other factors that condition price negotiations for a given reimbursement policy, like the prevalence of a given disease or risk mix (say population age), the lobbying activity of the pharmaceutical industry, and so on. Nevertheless, we believe that our analysis offers insights on the direction of the effects of an ER policy. The fact that the reference country could be harmed constitutes one of the main results of our analysis. This policy externality suggests the pharmaceutical pricing policies should be internationally coordinated.

3. The Model

The players in this game are a pharmaceutical firm and the health authorities of two countries, H (home country) and F (foreign country). We refer to these players as the firm and the agencies. The firm sells a drug in both countries. It holds a patent for the drug in both countries and produces at no variable cost.[5]

Both agencies operate a positive list of reimbursed pharmaceuticals. If the drug is listed for reimbursement in country *i*, patients pay a fixed and exogenous copayment C_i, as long as price is above copayment. If the price is below the copayment we assume that the out-of-pocket payment Z_i, i = F, H, is the price itself (i.e., there are no taxes). Formally,

$$Z_i = Min\{C_i, P_i\},\ i = \text{F, H}.$$

The difference between the price and the copayment, $P_i - C_i$, if positive, is reimbursed by the agency to the firm. If the drug is not listed for reimbursement then the patients pay the full price of the drug: P_i.

[5] The assumption that variable costs are negligible can be sustained empirically. Moreover, our analysis can be extended to situations with constant returns to scale. Having a positive marginal cost would only involve more complicated calculations, while in essence the results would be the same.

We assume that aggregate demand in country F is given by $D(Z_F)$, with $D'(Z_F) < 0$, $D''(Z_F) \leq 0$. Note that by assuming that copayments are fixed, demand is independent of the price as long as the price is above the copayment. Aggregate demand in country H is $KD(Z_H)$. In other words, country H is a K-replica of country F, with $K > 0$ but not necessarily larger than one. We say that country H has size K while country F has size 1.

We denote by P^M the monopoly price. In other words, P^M maximizes $PD(P)$. Notice that P^M is the same for both countries (and therefore independent of country size) due to two assumptions: zero variable costs (and in general due to constant returns to scale gross of sunk costs), and country H being a K-replica of country F.

The following assumption reflects another asymmetry between the two countries.

Assumption 1. *If the drug is listed for reimbursement in both countries, patients pay less in country F than in country H, and they pay less than the monopoly price, P^M, in both countries. In other words: $C_F < C_H < P^M$.*

As we will see, H would never implement ER if $C_F > C_H$. Note also that if $C_i > P^M$, this is tantamount to the drug being delisted.

Notice that F and H have different aggregate demands for two reasons. One is country size. The other is that, as long as country prices are larger than copayments, even if an individual in F has the same demand function as another in H and even if factory prices are the same in the two countries, the latter individual will demand less due to the higher copayment.

The pharmaceutical firm aims at maximizing its joint profit from both countries, with $P_F D(Z_F)$ being profit in country F and $P_H KD(Z_H)$ being profit in country H.

We assume that, in each country i, copayments are exogenously set beforehand by some outside player (say the Government or the Parliament of this country). Hence, as explained in the introduction, we do not aim at studying what the optimal copayment

C_i should be. Therefore, the agency only bargains for low prices with firms in return for reimbursement rights. We believe this encompasses most real world cases.[6]

We assume that the agency is given the following mandate by the outside player: She should negotiate prices with the firm in order to maximize net consumer surplus minus the public costs of provision. Hence, the agency's objective function does not include the profits of the firm. We believe this assumption to be in accordance with reality, especially in countries with a few or small pharmaceutical firms. Another motivation might be that the outside player finds it beneficial to delegate the bargaining over price to a more aggressive negotiator.

Now, in a market of size K_i, with $K_i = \{1, K\}$, we define the net consumer surplus as:

$$K_i CS(Z_i) = K_i \left[\int_0^{D(Z_i)} D^{-1}(q) dq - Z_i \cdot D(Z_i) \right].^7$$

The objective function of the agency of a country of size K_i is:

$$K_i CS(Z_i) - K_i (P_i - Z_i) \cdot D(Z_i).^8$$

We model the negotiation process as a Nash bargaining game. We initially assume that the scenario is one with weak-threats. Namely, if negotiations fail in a country, the drug is not listed for reimbursement but the firm is allowed to market the product in that country. Of course, the firm will do so at the monopoly price, P^M. If the drug is

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[6] Some countries rely on the so-called "tiered pricing" whereby lower prices result in the drug enjoying a higher subsidy. Our model amounts to a very simple tiered pricing mechanism. As it will be explained below, negotiation failure results in the drug not being listed for subsidization. Hence, only two tiers are present: a subsidy $P - C_i$ or no subsidy at all.

[7] We consider the consumer surplus as a measure of health benefits as it is linked to the willingness to pay for the drug.

[8] Notice that, if $P_i < C_i$ then $Z_i = P_i$ and the objective function becomes $K_i.CS(P_i)$. Notice also that, if $P_i > C_i$ then $Z_i = C_i$ and the objective function of the agency is decreasing in C_i. Although we take copayments as exogenous, it is useful to understand why this is so. Suppose that one increases the copayment so that demand is reduced by one unit. This has a negative effect on gross consumer surplus equal to the original copayment, as the unit that is no longer sold was enjoyed by the marginal consumer. However, it also has a positive effect, as total expenditures (consumer plus government's) are reduced by the price. Since our premise was that copayment was below price, the assumed objective function increases. In consequence, if the agency was in charge of setting copayments, drug consumption would not be subsidized. However, as explained in the introduction, the outside player's preferences may be quite different from those of the agency.

not listed for reimbursement, there are no public expenses associated with subsidizing the drug and the objective function of the government reduces to $K_i CS(P^M)$, the value of the net consumer surplus at the monopoly price.

The following lemma will be useful later on. Consider the following function: $W(P) = PD(P) + CS(P)$. This function reflects the sum of (*per* capita) consumer and producer surplus in the absence of subsidy. Then:

Lemma 1. *The function W is concave and attains a maximum at P = 0.*

This lemma is very intuitive. Since marginal cost is assumed to be zero, the price that would maximize the sum of consumer and producer surplus is also zero.

Finally, the agencies of both countries have the same bargaining power, denoted by β. The bargaining power of the firm in either country is $1-\beta$.

Throughout the text we denote $D^M = D(P^M)$, $CS^M = CS(P^M)$ and $\pi^M = P^M D^M$. We also denote $D_i = D(C_i)$, $D_i' = D'(C_i)$, $CS_i = CS(C_i)$ and $CS_i' = CS'(C_i)$ for *i* = *F*, *H*.

4. Independent Price Negotiations

Here we present our main benchmark case in which each country carries a price negotiation with the pharmaceutical firm, independently from the other country, and in the scenario with weak threats.[9] Therefore, $K_i \cdot CS^M$ and $K_i \pi^M$ constitute the disagreement payoffs of the agency and the firm, respectively.

The Nash bargaining problem for a country *i* of size $K_i = \{1, K\}$ is:

[9] This analysis heavily draws from Jelovac (2003).

Maximize
p_i

$$NB_{1i} = \beta \ln\{K_i[CS(Z_i) - (P_i - Z_i)D(Z_i) - CS^M]\} + (1-\beta)\ln\{K_i[P_i D(Z_i) - \pi^M]\}$$
$$= \ln[K_i] + \beta \ln[CS(Z_i) - (P_i - Z_i)D(Z_i) - CS^M] + (1-\beta)\ln[P_i D(Z_i) - \pi^M]$$

subject to: $Z_i = Min\{C_i, P_i\}$ (1)

It is worth noting that in the bargaining problem of any country, we assume that the agency places no value on the consumer surplus or the public expenses of the other country. Note also that the size of the country, K_i, only constitutes a level effect in this bargaining problem, and in consequence will not affect the final price. By solving (1) we obtain the following lemma.

Lemma 2. *When both countries independently negotiate the price with the firm, then (i) the resulting price in each country i, i = F, H is:*

$$P_i^* = (1-\beta)C_i + (1-\beta)\frac{CS_i - CS^M}{D_i} + \beta\frac{\pi^M}{D_i}, \quad (2)$$

(ii) This price is increasing in the level of copayment, C_i and decreasing in β, and

(iii) $P_i^* > C_i$ for all i = F, H.

The profits per capita in the bargaining solution in country *i* are:

$$\pi_i^* = P_i^* D_i = (1-\beta)C_i D_i + (1-\beta)[CS_i - CS^M] + \beta\pi^M$$

Note that these profits decrease in C_i, since: $\partial\pi_i^* / \partial C_i = (1-\beta)C_i D'_i < 0$. Since $C_F < C_H$ by Assumption 1, profits per capita are larger in country F.

Note that Part (i) of Lemma 2 implies the following equality:

$$(1-\beta)\left[CS_i - CS^M - (P^* - C_i)D_i\right] = \beta\left[P^* D_i - \pi^M\right]. \quad (3)$$

Equation (3) illustrates that the surplus generated by the negotiation above the disagreement point is split between the country and the firm in the proportion β to $1-\beta$, as usual in this type of problem.

In the bargaining problem, the disagreement point does not depend on the copayment C_i. Hence, the effect of the copayment on the negotiated price is only due to its effect on the surplus generated by the negotiation above the disagreement point. Let $S(C_i)$ denote this surplus, with:

$$S(C_i) = CS_i + C_i D_i - CS^M - \pi^M \,. \qquad (4)$$

Note that $S(C_i)$ is decreasing in C_i: $S'(C_i) = CS_i' + D_i + C_i D_i' = C_i D_i' < 0$.

As the copayment increases, there is less to be split between the two parties and the negotiated solution converges to the monopoly outcome. The public costs of the subsidy decrease, and the agency can afford higher negotiated prices. At the same time, as the copayment increases, there is less for the firm to gain by negotiating and hence it requires a larger price. This explains Lemma 2. The next is a direct corollary.

Corollary 3. *For any K_i and with independent negotiations, the negotiated price in the country with a large copayment exceeds the negotiated price in the country with a small copayment:* $P_F^* < P_H^*$.

Therefore, we focus on the situation where the foreign country F is the reference country for the home country H when the latter adopts an ER policy.

5. External referencing in the weak-threats scenario

In this section we consider the effects of an ER policy by H based on the price of country F. Our aim is to explain how H's ER affects the bargaining outcome in country F and to investigate whether it is in the interest of H to implement this policy. To do this, first, we must specify what happens in the case of failed negotiations in F. As we are under the weak-threat scenario, we assume that if negotiations in country F fail, H ceases to reimburse the drug but still allows the firm to sell the drug at a full price chosen by the firm. Similarly, we assume that, if the firm decides not to respect the ER policy and sells the drug in country H at a price higher than the price cap, H ceases to reimburse the drug but still allows the firm to sell the drug at any price chosen by the firm.

The following table summarizes the types of ER that we analyze, anticipating the tough threat case developed in the end of the paper. It shows, for each type of threats and possible contingencies, the price paid by patients and the price received by the firm.

Table 1: The types of ER by agency H

(patients' price, firm's price)	*ER with weak threats*	*ER with tough threats*
Negotiations in F succeed; Firm accepts ER	(C_F, P_F) in F (C_H, P_F) in H	
Negotiations in F succeed; Firm rejects ER	(C_F, P_F) in F (P_H, P_H) in H	(C_F, P_F) in F No sales in H
Negotiations in F fail	ER not proposed, product delisted in both countries : (P_F, P_F) in F (P_H, P_H) in H	No sales in either country

If the negotiations in country F fail, the firm sells the drug with no subsidy in both countries. The disagreement payoffs of F's agency and the firm become, respectively, CS^M and $(1+K)\pi^M$. By backward induction, assume that *P* has been set in country F after successful negotiations. Then ER in H implies that the price offer made by the agency in H to the firm is *P*. This offer is accepted by the firm if and only if

$$P\ D(Min\{P, C_H\}) \geq \Pi^M .$$

Otherwise, the firm prefers to reject ER even at the cost of selling an unsubsidized drug in H. This restriction leads to the following lemma.

Lemma 4. *To be acceptable to the firm in H, P must be strictly larger than C_H.*

Once $P > C_H$, we know that $D(Min\{P, C_H\}) = D(C_H) = D_H$. Let us therefore define $P^{MIN} = \Pi^M / D_H$ as the minimum acceptable price by the firm. The next lemma further characterizes this price.

Lemma 5. $C_H < P^{MIN} < P^M$.

As a consequence of Lemma 5, three separate intervals for P must be considered when F negotiates with the agency, since the formulae for negotiation payoffs are different in each interval. Namely,

(i) $P < C_F < P^{MIN}$, where P is rejected by the firm in country H so consumers in H pay P^M while consumers in F pay P; [10]

(ii) $C_F \leq P \leq P^{MIN}$, where P is still rejected by the firm so consumers in H pay P^M while consumers in F pay C_F;

(iii) $C_H < P^{MIN} \leq P$, where P is accepted by the firm in country H and consumers in F pay C_F while consumers in H pay C_H.

We now provide sufficient conditions ensuring that the Nash bargaining solution (hereafter NBS) in F yields $P \geq P^{MIN}$. We do this in two lemmas.

Lemma 6. *The NBS solution in F cannot yield $P < C_F$.*

Lemma 7. *There exists a function $\tilde{\beta} = \tilde{\beta}(C_F, C_H)$ such that, for all $\beta < \tilde{\beta}(C_F, C_H)$, if we restrict P to be in $[C_F, P^{MIN}]$ then the NBS yields $P = P^{MIN}$. The function $\tilde{\beta}(C_F, C_H)$ is smaller than 1 and is decreasing in C_H.*

Let us explain the condition $\beta < \tilde{\beta}(C_F, C_H)$. This condition guarantees that the Nash bargaining function reaches a maximum at P^{MIN} if we restrict attention to $P \leq P^{MIN}$. This allows us to also restrict attention to $P \geq P^{MIN}$ when solving the Nash bargaining

[10] We must consider $P < C_F$ because part (iii) of Lemma 2 was derived under independent price negotiations, so the lemma does not directly apply once B engages in ER.

problem, which greatly simplifies the analysis. If β was instead very large, then agency F's negotiation power would be so high that the negotiated price in A might fall below P^{MIN} and in this case the firm would reject ER. Notice that $\beta < \widetilde{\beta}(C_F, C_H)$ imposes some restrictions on the combination of parameters (β, C_F, C_H), and that it is independent on *K*.[11] Finally, notice that by Lemma 4, we know that the resulting price P is strictly above C_H.

The Nash bargaining solution in country F is therefore the solution to the following program:

$$\underset{\{P \geq P^{MIN}\}}{Maximize}$$

$$\beta \ln\{CS_F - (P - C_F)D_F - CS^M\} + (1-\beta)\ln\{P(D_F + KD_F) - (1+K)\pi^M\}. \qquad (5)$$

By solving (5) we obtain the following lemma.

Lemma 8. *If* $\beta < \widetilde{\beta}(C_F, C_H)$, *the negotiated price in country F is:*

$$P^{WC} = (1-\beta)C_F + (1-\beta)\frac{CS_F - CS^M}{D_F} + \beta\frac{(1+K)\pi^M}{D_F + KD_H}, \qquad (6)$$

which is strictly greater than P^{MIN} *and is increasing in* C_F, C_H *and K.*

Lemma 8 allows us to write the following equality:

$$(1-\beta)\frac{D_F + KD_H}{D_F}\{CS_F - (P^{WC} - C_F)D_F - CS^M\}$$

$$= \beta\{P^{WC}(D_F + KD_H) - (1+K)\pi^M)\} \qquad (7)$$

Equation 7 illustrates that the total surplus generated by the negotiation above the disagreement point is split between country F and the firm in the ratio:

[11] We provide a numerical example at the end of this section.

β to $(1-\beta)\dfrac{D_F + KD_H}{D_F} > (1-\beta)$.

This shows that the implicit negotiation power of the firm is higher when country H engages in ER as compared to independent negotiations.

It is also interesting to analyze how changes in *K* affect the outcome of the negotiation in F on the face of ER. A raise in *K* affects the bargaining between F and the firm in two ways. First, the pie to be shared between both parties is larger. Hence there is an outwards shift in the frontier of the problem. Second, the firm has a stronger disagreement payoff whilst F's disagreement payoff remains the same. The next proposition tells us the outcome of these two effects.

Proposition 9. *Suppose that Assumption 1 holds and that* $\beta < \widetilde{\beta}(C_F, C_H)$. *Then:*

(i) $P^{WC} - P_F^* > 0$ *and this difference increases in K.*

(ii) $P^{WC} - P_H^* < 0$. *This difference decreases in K and converges to an asymptote as K tends to infinity. This asymptote decreases in the difference* $C_H - C_F$. *Therefore, the difference between* P^{WC} *and* P_H^* *decreases monotonically as* C_F *tends to* C_H.

Proposition 9 is illustrated in Figure 1. It implies that H prefers to commit to an ER policy rather than to engage in independent price negotiations with the firm. It also implies that this preference diminishes as the size of country H increases and as copayments become more homogeneous, but it is always positive. However, as a direct result of the adoption of ER in country H, the price negotiated in country F raises. This is explained by the change in the differences between failure and success payoffs of F and the firm. Moreover, as *K* increases the negotiated price in country F raises, but never to be so high that H loses out by choosing the ER policy rather than independently negotiating with the firm. Public expenses as well as the firm's profit in country H are lower. The opposite holds in country F.

[FIGURE 1 AROUND HERE]

Notice that consumers in either country are not affected by the ER policy since they pay a fixed copayment. The next proposition states that the total profits of the firm decrease because of the adoption of such an ER policy.

Proposition 10. *Under Assumptions 1 and* $\beta < \widetilde{\beta}(C_F, C_H)$*, the total profits of the firm are lower when country H engages in ER, that is,*

$$P^{WC}(D_F + KD_H) < P_F^* D_F + P_H^* KD_H \,.$$

Consequently, the sum of public expenses in both countries also decreases, implying that the decrease in H's expenses compensates for the extra expenses in country F. This means that if country H wanted to fully compensate F for her "free riding", she could do so and still achieve higher welfare than under independent negotiations.

Numerical example

We now present a numerical example to illustrate that the condition $\beta < \widetilde{\beta}(C_F, C_H)$ is not too restrictive and that it leaves enough room for ER to apply under a large set of parameter configurations. Let $D(P) = 10 - P$, so that $P^M = 5$. In Figure 2 we plot $\widetilde{\beta}(C_F, C_H)$ for different values of C_F: $\{0, 1, 2, 3, 4\} < P^M = 5$. For each value of C_F, any point (C_H, β) lying below the corresponding curve is admissible.

[FIGURE 2 AROUND HERE]

6. Extension to tough-threats

As explained in the introduction, our main motivation is to provide insights into the European markets, where price negotiations have no bearing on the drug authorization decision (i.e. only weak threats are feasible). However, it is interesting to see that our main results remain even when agencies in charge of price negotiation can also threaten with a ban on the drug. In this section we assume that agencies in countries F and H are able to make such tough threats.

That is, with independent negotiations if the negotiation in a country fails, this country's agency does not authorize the drug for sale. Similarly, if H implements an

ER policy, then if negotiations in country F fail, again H does not authorize the drug for sale. Notice that tough threats change the disagreement payoff of both the Nash bargaining problem under independent negotiations and the Nash bargaining problem in F when H engages in ER.

Unfortunately, solving the model with tough threats at the same level of generality as the model with weak threats is quite complex. To illustrate this note that with tough threats and independent negotiations the disagreement point is no longer (CS^M, π^M), but (0,0). This means that it is difficult to rule out situations where price is so low that it falls below the copayment. Hence the analysis needs to deal with the non-differentiability of the patients' payment function. In contrast, in the weak threats scenario one can use the fact that profits must be above π^M to avoid this non-differentiability.

In order to derive some explicit results, we restrict attention to the linear demand case. More precisely, for $\alpha, \psi > 0$, let demand be given by

$$D(Z) = (\alpha - Z)/\psi.$$

We also assume that $C_F = 0$. This obviously guarantees that the price resulting from any negotiation taking place in country F is above the copayment in that country. This drastically reduces the number of cases and comparisons that one must address. Of course, we still assume that $0 = C_F < C_H < P^M = \alpha/2$, in order to have an interesting problem.

These assumptions allow us to derive a sufficient condition ensuring that:

i) The price resulting from the Nash bargaining problem with ER by H is above C_H.

ii) The price resulting from the Nash bargaining problem when H conducts independent price negotiations with the firm is also above C_H.

iii) Agency H is able to decrease prices using ER. Thus, the main result that we obtained under weak threats is maintained.

iv) In contrast to the weak threats scenario, under tough threats country F is unaffected by ER. In other words, the negotiated price in F is the same irrespective of whether H engages in ER or not.

v) As a direct result of (iii) and (iv), overall firm's profits decrease with ER.

Let us formalize these results.

Proposition 11 *There exists a function* $\overline{\beta} = \overline{\beta}(K, C_H)$ *such that, for all* $\beta < \overline{\beta}(K, C_H)$, we have that

$$P_F^{IPN} = P^{ER} = \alpha \frac{(1-\beta)}{2} < (\alpha + C_H)\frac{(1-\beta)}{2} = P_H^{IPN}.$$

The function $\overline{\beta}(K, C_H)$ *is decreasing in K and* C_H. *Total firm's profits are lower under ER.*

The intuition for Proposition 11 is similar to the one in the previous section. If health authorities' bargaining power was high, prices would tend to be low, which as explained above, would require dealing with the fact that the consumer copayment function is non-differentiable at C_H.[12]

A feature of ER under tough threats is that the negotiated price becomes independent of *K*. Intuitively, when the threat point is a sales ban in both countries, the size of the home country ceases –trivially– to influence the threat point.

Finally, and as we did in section 5, we provide a numerical example that shows that the assumption $\beta < \overline{\beta}(K, C_H)$ is not too restrictive. In Figure 3, we depict $\overline{\beta}(K, C_H)$ as a function of H's country size *K* for C_H = 1, 2, 3, 4 and $\alpha = 10$ (so that $C_H < P^M$ = 5).

[12] We must preclude prices from falling below C_H in both the Nash bargaining program in H under IPN and in the Nash bargaining program in F when H engages in ER. This requires two upper bounds on $\overline{\beta}$, one for each program. The more restrictive bound arises with ER. The reason for this is that, under ER, agency H free rides on the better bargaining position of F.

[FIGURE 3 AROUND HERE]

7. Conclusions

Using a model where two countries differ only in their population size and subsidization policies, our most general result is that a country has an incentive to engage in ER if its copayment levels are high as compared to the other country's. This preference dwindles as the relative size of the country engaging in ER increases. We have analyzed the effects of an ER policy by H on the negotiation in F, showing that ER increases the surplus to be shared between F and the firm. The idea is that the profits obtained by the firm in the home country, H, become part of the pie.

For the case of ER with weak threats, we can provide a clear empirical prediction that hinges on the relative size of the home country. Perhaps surprisingly, it turns out that the relative size of the home country is irrelevant as to *the sign* of the advantage of ER over independent negotiations, which is always positive. Only the size of the advantage is affected. In other words, should ER have some external and fixed cost that we have not taken into account,[13] then ER would only be implemented if the size of the home country is not too large. In a nut shell, only small countries should be observed to engage in ER and/or ER should be based on prices in large countries (or a large group of countries). Our analysis yields an analogous prediction if one substitutes "large country" by "small copayment country" and *vice versa*.

With tough threats the firm suffers a harsher punishment in the case that negotiations fail. We show that if all countries are able to make tough threats the main result with weak threats turns out to be robust: ER benefits the home country and harms the firm. However, in contrast to the scenario with weak threats, the benefits derived from an ER policy cease to depend on relative country size. Moreover, the negative externality that ER inflicts on the foreign country disappears.

[13] For instance, some political cost.

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Appendix

Proof of Lemma 1

Since $CS'(P) = -D(P)$, differentiating W yields $PD'(P)$. Differentiating once again yields $D'(P) + PD''(P)$, which is negative. By setting the first derivative to zero, we obtain $P = 0$.

Proof of Lemma 2

Part (i)

We first prove that $P < C_i$ is not feasible in the Nash Bargaining Problem in any country i = F, H:

Notice that $PD(P) < \Pi^M \equiv P^M D(P^M)$, since $P < C_i < P^M$ and P^M maximizes $PD(P)$. Hence, $PD(P)$ is below the disagreement payoff for the firm for any $P < C_i$. Therefore, we can restrict attention to $P \geq C_i$ so that $Z_i = Min\{C_i, P\} = C_i$ can be substituted into (1), which yields

$$\underset{p_i}{Maximize}$$

$$NB_{1i} = \ln[K_i] + \beta \ln[CS(C_i) - (P_i - C_i)D_i - CS^M] + (1-\beta)\ln[P_i D_i - \pi^M] \tag{A1}$$

The first order condition associated to (A1) can be written as:

$$\left.\frac{\partial NB_{1i}}{\partial P_i}\right|_{P_i^*} = -\beta \frac{D_i}{CS_i - (P_i^* - C_i)D_i - CS^M} + (1-\beta)\frac{D_i}{P_i^* D_i - \pi^M} = 0\,.$$

Rearranging this expression, equation (2) in Lemma 2 is obtained. This is the solution to (A1) since (A1) is concave in P:

$$\frac{\partial^2 NB_{1i}}{\partial P_i^2} = -\beta\left[\frac{D_i}{CS_i - (P_i - C_i)D_i - CS^M}\right]^2 - (1-\beta)\left[\frac{D_i}{P_i D_i - \pi^M}\right]^2 < 0\,.$$

Part (ii)

To check that P_i^* is increasing in C_i, rewrite the first-order condition associated to (A1) as:

$$(1-\beta)\left(CS_i - (P_i^* - C_i)D_i - CS^M\right) - \beta\left(P_i^* D_i - \pi^M\right) = 0 .$$

Applying the implicit function theorem to this expression, we obtain:

$$\frac{\partial P_i^*}{\partial C_i} = -\frac{(1-\beta)\left[CS_i' + D_i - (P_i^* - C_i)D_i'\right] - \beta P_i^* D_i'}{-(1-\beta)D_i - \beta D_i} = -\frac{D_i'}{D_i}\left[P_i^* - (1-\beta)C_i\right].$$

This is positive, since equation (2) implies $P_i^* > (1-\beta)C_i$.

Part (iii)

To prove that P_i^* is decreasing in β, take the derivative of P_i^* with respect to β. Using (2), this yields:

$$\frac{\partial P_i^*}{\partial \beta} = -C_i - \frac{CS_i - CS^M}{D_i} + \frac{\Pi^M}{D_i}.$$

This is negative if and only if $\Pi^M + CS^M < C_i D_i + CS_i$. This is equivalent to $W(P^M) < W(C_i)$, which holds by Lemma 1 and $C_i < P^M$.

Part (iv)

We now prove that $P_i^* > C_i$, $\forall i = F, H$. By definition, $\pi^M > P \cdot D(P)$, $\forall P \neq P^M$. Therefore, $C_i < P^M \Rightarrow \frac{\pi^M}{D_i} > C_i$. Moreover, $C_i < P^M \Rightarrow CS_i > CS^M$. Therefore, $P_i^* > C_i$, $\forall i = F, H$.

Proof of Corollary 3

By part (ii) of Lemma 2 and $C_F < C_H$.

Proof of Lemma 4

Suppose $P \leq C_H$. Then $Min\{C_H, P\} = P$ and $PD(Min\{C_H, P\}) = PD(P)$. However, since P^M maximizes $PD(P)$ and $C_H < P^M$, we have that

$$PD(Min\{C_H, P\}) = PD(P) < P^M D^M \equiv \Pi^M,$$

a contradiction.

Proof of Lemma 5.

On the one hand, since $C_H < P^M$, we have that $D_H > D^M$ and we can write

$$P^M > P^M \frac{D^M}{D_H} \equiv \frac{\Pi^M}{D_H} \equiv P^{MIN}.$$

On the other hand, since P^M maximizes $PD(P)$, we have that $P^M D^M > C_H D_H$. This implies that $P^{MIN} \equiv \frac{\Pi^M}{D_H} > C_H$.

Proof of Lemma 6.

By Lemma 4, a price $P < C_F$ would be rejected by the firm in H. Therefore, if by contradiction this price solves the NBS in F, it would solve

$$Max \quad \beta \ln\{CS(P) - CS^M\} + (1-\beta)\ln\{PD(P) + K\pi^M - (1+K)\pi^M\}.$$

This is equivalent to maximize

$$Max \quad \beta \ln\{CS(P) - CS^M\} + (1-\beta)\ln\{PD(P) - \pi^M\}.$$

Notice that $PD(P) < \Pi^M \equiv P^M D^M$, since $P < C_F < P^M$ and P^M maximizes $PD(P)$, so $PD(P)$ is below the disagreement payoff of the firm for any $P < C_F$, contradiction.

Proof of Lemma 7

A first step is to show that $\frac{\Pi^M}{D_F} < C_F + \frac{CS_F - CS^M}{D_F}$. To see this, rewrite the expression to get $\Pi^M + CS^M < C_F D_F + CS_F$. This inequality holds, as shown in the proof of Lemma 2 (part (ii)). The second step is to find *P* that solves

$$Max\ \beta \ln\{CS_F - (P - C_F)D_F - CS^M\} + (1-\beta)\ln\{PD_F + K\pi^M - (1+K)\pi^M\}.$$

This is equivalent to $Max\ \beta \ln\{CS_F - (P - C_F)D_F - CS^M\} + (1-\beta)\ln\{PD_F - \pi^M\}$, which is the Nash bargaining problem in F under independent price negotiations, NB_{IF}. We know that the solution is given by P_F^*, given in Lemma 2. In the proof of this lemma we showed that the objective function in the Nash bargaining problem under independent price negotiations is concave in *P*. Therefore, it suffices to show that there exists some parameter configuration under which $P_F^* > P^{MIN}$, so that the Nash bargaining program defined here reaches a maximum at P^{MIN} when restricting the negotiated price to $C_F < P \leq P^{MIN}$. Comparing P_F^* with P^{MIN}, we find that the inequality $P_F^* > P^{MIN}$ holds when

$$\beta < \frac{C_F + \frac{CS_F - CS^M}{D_F} - \frac{\Pi^M}{D_H}}{C_F + \frac{CS_F - CS^M}{D_F} - \frac{\Pi^M}{D_F}} \equiv \tilde{\beta}(C_F, C_H).$$

Notice that $\tilde{\beta}(C_F, C_H) = 1$ when $C_F = C_H$, and $\tilde{\beta}(C_F, C_H)$ is decreasing in C_H. Therefore, $\tilde{\beta}(C_F, C_H) < 1$ when $C_F < C_H$.

Proof of Lemma 8

The first-order condition associated to the Nash bargaining program (5) can be written as:

$$\left.\frac{\partial NB_2}{\partial P}\right|_{P^{**}} = -\beta \frac{D_F}{CS_F - (P^{WC} - C_F)D_F - CS^M}$$

$$+ (1-\beta)\frac{D_F + KD_H}{P^{WC}(D_F + KD_H) - (1+K)\pi^M} = 0\,.$$

Rearranging this expression, equation (6) in Lemma 8 is obtained. This is the solution to (5) since the objective function in (5) is concave in P:

$$\frac{\partial^2 NB_2}{\partial P^2} = -\beta\left[\frac{D_F}{CS_F - (P - C_F)D_F - CS^M}\right]^2 - (1-\beta)\left[\frac{D_F + KD_H}{P(D_F + KD_H) - (1+K)\pi^M}\right]^2 < 0.$$

Since we already proved that the Nash bargaining function is concave for $P \geq P^{MIN}$, to show that P^{WC} is a global maximum it suffices to prove that (i) $P^{WC} > P^{MIN}$ and (ii) that the Nash bargaining function is continuous at $P = P^{MIN}$. Let us prove (i). From the proof of Lemma 7, we know that $P_F^* > P^{MIN}$ when $\beta < \widetilde{\beta}(C_F, C_H)$. Let us now prove that $P^{WC} > P_F^*$. Indeed, using Lemma 2 (for i = F) and Lemma 8, we can write

$$P^{WC} = P_F^* + \beta K\pi^M\left[\frac{D_F - D_H}{D_F(D_F + KD_H)}\right] > P_F^*\,.$$

Let us now prove (ii). This is by inspection by substituting $P = P^{MIN}$ in NB_1 and NB_2.

Differentiating P^{WC} with respect to C_F we obtain:

$$\frac{\partial P^{WC}}{\partial C_F} = (1-\beta)\left[1 + \frac{CS_F' D_F - D_F'(CS_F - CS^M)}{(D_F)^2}\right] - \beta D_F' \frac{(1+K)\pi^M}{(D_F + KD_H)^2}.$$

Using the fact that $CS_F' = -D_F$ we can simplify the expression to:

$$\frac{\partial P^{WC}}{\partial C_F} = -D_F'\left[(1-\beta)\frac{CS_F - CS^M}{(D_F)^2} + \beta\frac{(1+K)\pi^M}{(D_F + KD_H)^2}\right] > 0,$$

and

$$\frac{\partial P^{WC}}{\partial C_H} = -KD'_H \beta \frac{(1+K)\pi^M}{(D_F + KD_H)^2} > 0 .$$

Finally note that:

$$\frac{\partial P^{WC}}{\partial K} = \frac{\beta \pi^M (D_F - D_H)}{(D_F + KD_H)^2} > 0 .$$

Proof of Proposition 9

Part (i)

In the proof of Lemma 8 we proved that $P^{WC} > P_F^*$. Notice that

$$\frac{\partial (P^{WC} - P_F^*)}{\partial K} = \beta \pi^M \left[\frac{D_F - D_H}{D_F (D_F + KD_H)} \right] > 0 \quad .$$

Part (ii)

As K tends to infinity, P^{WC} tends to:

$$P_{\lim}^{WC} = (1-\beta) C_F + (1-\beta) \frac{CS_F - CS^M}{D_F} + \beta \frac{\pi^M}{D_H} .$$

To compare $P_{\lim}^{WC}$ with P_H^* as defined in Lemma 2, it is enough to notice that the auxiliary function $f(Z)$ is increasing in Z, where:

$$f(Z) = Z + \frac{CS(Z) - CS^M}{D(Z)} .$$

Using $CS'(Z) = -D(Z)$ and assuming that $Z < P^M$, we have that:

$$f'(Z) = -\frac{D'(Z)\left[CS(Z) - CS^M\right]}{\left[D(Z)\right]^2} > 0.$$

This implies $P_{\lim}^{WC} < P_H^*$, since $C_F < C_H$. Given that P^{WC} is increasing in K (see Lemma 8), $P^{WC} - P_H^* < 0, \ \forall K$.

The fact that $f'(Z) > 0$ also implies that the difference $R = P_H^* - P_{\lim}^{WC}$ decreases as C_F tends to C_H. Therefore, the difference between P^{WC} and P_H^* decreases monotonically as C_F tends to C_H.

Proof of Proposition 10

Define $\Delta(C_F, C_H, K) = P_F^* D_F + P_H^* K D_H - P^{WC}(D_F + K D_H)$. We need to prove that $\Delta(C_F, C_H, K) > 0$. Suppose first that $K = 0$. In this case $P_F^* = P^{WC}$ and therefore $\Delta(C_F, C_H, 0) = \left(P_F^* - P^{WC}\right) D_F = 0$. Hence it suffices to prove that $\frac{\partial \Delta}{\partial K} > 0$. That is, we need:

$$\frac{\partial \Delta}{\partial K} = P_H^* D_H - (D_F + K D_H)\frac{\partial P^{WC}}{\partial K} - P^{WC} D_H = (P_H^* - P^{WC}) D_H - (D_F + K D_H)\frac{\partial P^{WC}}{\partial K} > 0.$$

Substituting P^{WC} from Lemma 8, P_H^* from Lemma 2, and the formula of $\frac{\partial P^{WC}}{\partial K}$ derived in the proof of Lemma 8 we obtain:

$$\frac{\partial \Delta}{\partial K} = \left[f(C_H)`- f(C_F)\right](1-\beta) D_H + \beta \pi^M \left[1 - \frac{(1+K)D_H}{D_F + K D_H} - \frac{(D_F - D_H)}{D_F + K D_H}\right],$$

where $f(Z)$ is as defined in the proof of Proposition 9. It is easy to check that the expression in brackets in the second term of the last expression is zero. The expression in brackets in the first term is positive since $f'(Z) > 0$ as shown in the proof of Proposition 9.

Proof of Proposition 11

The proof of Proposition 11 is available upon request from the authors. It is similar to the proof of Propositions 9 and 10 and of the lemmas preceding those propositions.

We limit ourselves to provide the exact formula of the function $\overline{\beta}(K, C_H)$. To ease presentation, we introduce two auxiliary functions. Let $\Gamma = K(\alpha - 2C_H)^2 + \alpha^2$. By inspection, Γ is increasing in K. Since $C_H < P^M = \alpha/2$, we have that $2C_H < \alpha$. This implies that Γ is increasing in α and decreasing in C_H. Then,

$$\overline{\beta}(K, C_H) = \frac{1 - \dfrac{2\alpha C_H}{\Gamma}}{1 + 2KC_H \dfrac{\alpha - C_H}{\Gamma}}.$$

Notice that $\overline{\beta}(K, C_H) < 1$. One can also check that $\overline{\beta}(K, C_H) > 0$ and that it is decreasing in K and C_H.

FIGURES

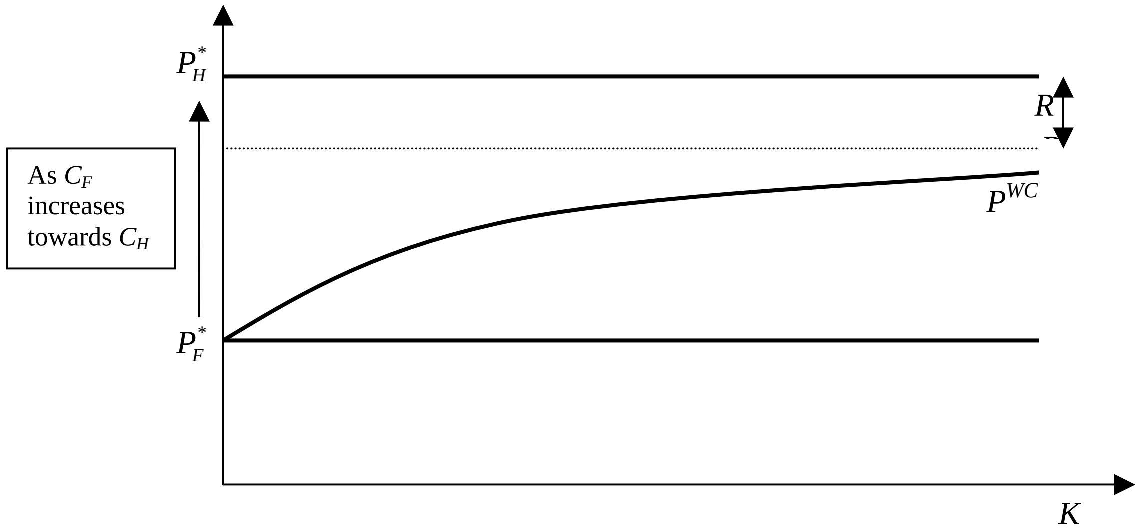

Figure 1. Comparing independent price negotiations (P_i^*) to weak-threats ER (P^{WC}) as country H's size (K) increases relative to country F's. The value of R is derived in the Appendix (proof of Proposition 9). It decreases as C_F increases.

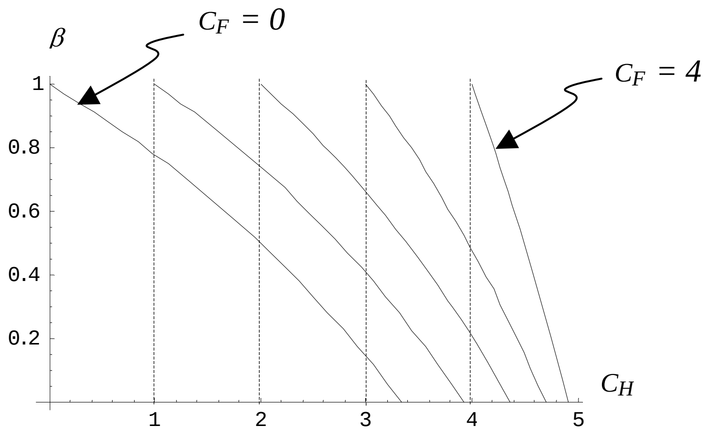

Figure 2. The solid lines show the function $\tilde{\beta}(C_F, C_H)$ for different values of C_H. The admissible parameter configurations lie below the solid lines for each C_H.

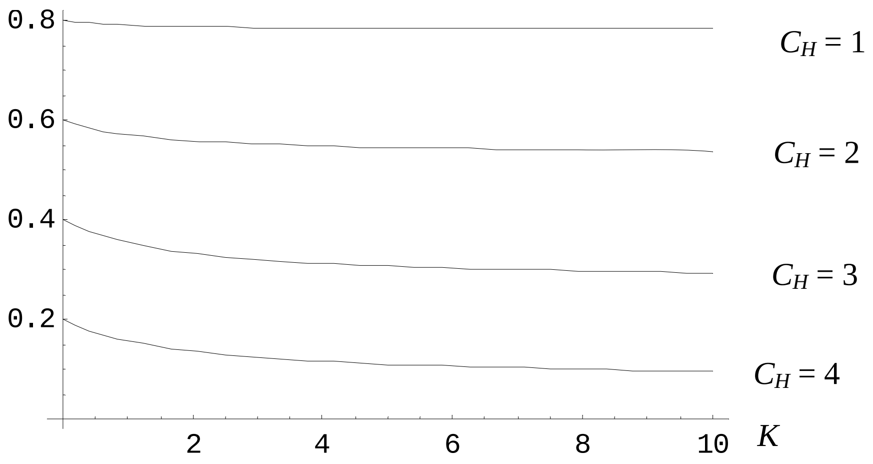

Figure 3. The solid lines show the function $\overline{\beta}(K, C_H)$ for different values of C_H and $\alpha = 10$. The admissible parameter configurations lie below the solid lines for each C_H.