Endogenous versus exogenous generic reference pricing for pharmaceuticals

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ABSTRACT

In this paper we carry out a vertical differentiation duopoly model applied to pharmaceutical markets to analyze how endogenous and exogenous generic reference pricing influence competition between generic and branded drugs producers. Unlike the literature, we characterize for the exogenous case the equilibrium prices for all feasible relevant reference prices. Competition is enhanced after the introduction of a reference pricing system. We also compare both reference pricing systems on welfare grounds, assuming two different objective functions for health authorities: i) standard social welfare and ii) gross consumer surplus net of total pharmaceutical expenditures. We show that regardless of the objective function, health authorities will never choose endogenous reference pricing. When health authorities are paternalistic, the exogenous reference price that maximizes standard social welfare is such that the price of the generic drug is the reference price while the price of the branded drug is higher than the reference price. When health authorities are not paternalistic, the optimal exogenous reference price is such that the price of the branded drug is the reference price while the price of the generic drug is lower than the reference price.

Keywords: Endogenous reference price, exogenous reference price, off-patent drug, generic drug, pharmaceutical expenditures

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1. Introduction

Health authorities, concerned with the sustainability of growing public pharmaceutical expenditures, have traditionally regulated pharmaceutical markets. Reference prices have been extensively used to reverse the increasing trend in pharmaceutical expenditures, together with other regulatory instruments. Under a reference pricing system, drugs are grouped into clusters and a reference price is set for each cluster. Generic reference pricing is the term used when the cluster includes only drugs with the same principle active (generic and off-patent drugs), as in Spain. When the cluster includes therapeutically equivalent drugs (drugs under patent protection also belong to the cluster), the term used is therapeutic reference pricing, as it is the case in Germany. In this paper, we are going to analyze how reference prices are fixed and their effect in competition between producers of generic and off-patent drugs.

Reference pricing seeks to enhance competition to reduce drug prices. As a result, public pharmaceutical expenditure is either contained or lowered. On the other hand and indirectly, reference pricing pursues also to increase generic drug sales. Reference pricing fixes an upper bound for public reimbursement to pharmaceutical firms. When a pharmaceutical firm sets its price above the reference price, the consumer pays the difference between the price and the public reimbursement.

Reference prices can be exogenously (they are not specifically linked to drug prices) or endogenously (they do depend on the prices of the drugs) determined. Strictly speaking, although the literature uses the term "exogenous" to refer to reference prices fixed without any dependency on drug prices, it should be understood that they are not exogenous in the strict meaning of the term. By exogenous reference pricing we mean that health authorities do not follow any explicit rule to fix them or even an explicit mechanism to periodically modify them. As Brekke *et al.* (2015a) pointed out, exogenous policies take place when "the reference price is not frequently updated or where updates are not based on predefined rules". On the other hand, when health authorities fix the reference price endogenously they follow explicit rules and make the reference price depend on the drug prices of the cluster. In this latter case, firms´ strategic behaviors determine the reference price.

Until now, most research (both theoretical and empirical) has focused on endogenous reference pricing, and less attention has been paid to analyze exogenous reference prices. Interestingly, some studies (e.g. Brekke *et al.* (2011)) have analyzed both reference price mechanisms, although to the best of our knowledge, the question of which system is better from a social welfare perspective has not been addressed yet. Moreover, the impact of exogenous reference pricing on firms´ prices has only been analyzed for a specific range of feasible values for the reference price (the generic firm setting its price below the reference price, while the price of the off-patent drug is above the reference price). In this paper, as Brekke *et al.* (2011), we use a standard vertical differentiation model to characterize firms' optimal pricing behaviors for any feasible exogenous reference price. Additionally, for the sake of the comparison, we also characterize the optimal firms' prices when the reference price is set endogenously. Unlike the literature, we determine both the exogenous and endogenous optimal reference prices and we compare both systems on welfare grounds to identify the optimal one. In order to do so, we consider two different objective functions for health authorities: i) social welfare defined as the sum of consumer surplus and firms' profits net of pharmaceutical public expenditures, and ii) gross consumer surplus net of total pharmaceutical expenditures.

We find that the optimal exogenous reference price is such that the generic firm chooses a price equal to the reference price while the price of the off-patent firm is higher than the reference price. We also find that, regardless of how social welfare is measured, health authorities will always prefer to set the reference price exogenously. This result holds when health authorities value both drug equally (i.e. in this context, they are paternalistic). When health authorities are not paternalistic, the optimal exogenous reference price is such that the price of the branded drug coincides with the reference price while the price of the generic drug is lower. For the standard measure of social welfare, we show that exogenous reference pricing leads to higher social welfare.

The paper is structured as follows. Section 2 presents the related literature. Section 3 describes the model and section 4 characterizes the equilibrium prices when there is no reference pricing (no regulation). Section 5 focuses on exogenous reference pricing, and analyzes its impact on drug prices. In section 6 we carry out the analysis when the

reference price is endogenously determined. In section 7 we compare both reference pricing systems on social welfare grounds to determine the best regulatory policy. Finally some conclusions and insights are provided.

2. Related literature

In this section we summarize the most relevant theoretical literature related to reference pricing. Until now, there have been many papers dealing with reference prices, most of them addressing the empirical consequences on drug prices derived from their implementation in specific countries (Danzon *et al*. 2004; Brekke *et al.* 2009; Dylst *et al.* 2011; Ghislandi et al. 2013). However, theoretical research on reference prices is more limited. Modelling approaches vary, and generally most authors has focused on how firms react to this policy when setting their prices, and on the consequences on public expenditures.

Galizzi *et al.* (2011) reviewed the existing literature, both theoretical and empirical, on this topic, emphasizing the elements that characterized the different theoretical approaches (i.e. clusters, benchmarking for reference prices, therapeutic *vs.* generic reference pricing, etc.) and highlighted that all papers focused on the impact of reference prices on quantities and drug prices, showing that drug prices under generic reference pricing were generally lower than otherwise.

In their seminal paper, Brekke *et al.* (2007) analyzed both generic and therapeutic reference pricing using a vertical and horizontal differentiation model. They characterized the prices of the firms and obtained the expected results of higher competition and lower prices. However, most research has focused largely on generic reference pricing. Some authors have analyzed exogenous generic reference pricing in vertical differentiation models, generally considering only an intermediate range for the reference price between the generic and the off-patent price; their main result was that new equilibrium prices were lower that under no regulation (see, for example, Brekke *et al.* 2011). Mestre-Ferrándiz (2003) used a horizontal differentiation model with exogenous reference prices to show that the impact on drug prices depended on the specific reference price. For a relatively high reference price, the price of the off-patent drug was above the price without intervention, while the price of the generic drug was lower. Competition was enhanced when the reference price was set within a given interval. However, generic sales decreased when compared to sales under no regulation.

Alternatively, other authors (Merino-Castelló 2003; Brekke *et al.* 2011) have analyzed endogenous reference pricing with vertical differentiation models, yielding also the result that both prices were lower after the introduction of the policy. As a result of this approach, the price of the off-patent drugs diminishes more than the price of the generic drug as compared to the exogenous case.

Differently from the aforementioned static approaches, Miraldo (2009) developed a dynamic horizontal and vertical differentiation model where the reference price was based on the prices fixed by the firms in a previous period. Interestingly, she found that drug prices were higher after the introduction of a reference price policy. Ghislandi (2011) carried out a dynamic model to study the impact of reference pricing in the collusive behavior of generic firms, and concluded that the optimal reference price should be designed as an average of the prices of the generic drugs.

Other static approaches have analyzed the impact of reference pricing on generic entry (Brekke *et al.* 2015b). They endogenized generic entry under a reference pricing system using a Salop model of product differentiation. They showed that generic entry was limited, and consequently the market share of branded drugs increased. Therefore, the final effect on prices and public expenditures resulted to be ambiguous. Brekke *et al*. (2015a), in a companion paper on generic entry, showed that the impact of reference prices on the market share of generic drugs was also ambiguous as higher generic firms´ profits were offset by tougher price competition.

Finally, Gonçalves *et al* (2015) analyzed reference prices in a theoretical framework (vertical and horizontal differentiation model) when the off-patent firm may also introduce a pseudo-generic drug and found that the presence of the pseudo-generics increase the effects of the reference price policy compared to a reimbursement system based on a fixed percentage (copayment).

3. The model

We consider a standard vertical differentiation duopoly model where one firm produces an off-patent branded drug (drug b) while the other firm produces a generic drug (drug g). There is a mass of consumers (patients) of size one. Each consumer buys, at most, one unit and enjoys net utility U_i when drug $i = b, g$ is consumed:

$$U_i = \begin{cases} v\theta - p_i^c \ if \ i = g \\ \theta - p_i^c \ if \ i = b \end{cases}$$

where $v < 1$ denotes the perceived quality of the generic drug, θ stands for the marginal valuation for quality and it is distributed uniformly in the interval [0,1], and p_i^c is the price the consumer pays if she buys drug i, $i = b, g$. If the consumer does not buy any product, her utility is zero. Consumers, at equal prices, prefer the off-patent drug, but marginal valuation differs across consumers. Although both drugs have the same active principle, consumers perceive them as different, and derive higher utility from consuming the off-patent drug (consumers are brand-oriented) at equal prices. [1]

The firms set simultaneously the prices p_i, $i = b, g$ to maximize their profits. For simplicity, we assume that the marginal costs are zero.

Under a copayment system, the price consumers pay $p_i^c$is αp_i, $i = b, g$, where $\alpha \in (0,1]$ is the co-payment rate. When health authorities use a generic reference pricing system (the cluster to which the reference price affects includes both drugs) to influence firms' pricing behavior, the price the consumer pays for drug $i, i = b, g$, is

$$p_i^c = \begin{cases} \alpha p_i & if \ p_i \leq r \\ \alpha r + p_i - r & if \ p_i > r \end{cases}$$

where r denotes the reference price. If the price of the drug is below the reference price, health authorities reimburse the full price to the firm (strictly speaking, public reimbursement equals the difference between the price and the copayment made by the consumer). If the price of the drug is above the reference price, health authorities only reimburse the reference price, and the consumer pays the difference between the price and the reference price. Thus, we consider public health insurance systems where payments to the firms are shared between patients and health authorities.

We briefly consider the no-regulation situation before analyzing the behavior of the firms when a reference price system is in place. Later, we focus first on exogenous reference pricing (the reference price is not related to the prices of the drugs by a specific formulation), and then, we carry out the analysis for the endogenous reference pricing (the reference price is a function of both drug prices).

4. No regulation

Under no regulation, the firms set the prices p_i simultaneously to maximize profits $\pi_i = p_i q_i(p_i, p_j, \alpha)$, where $q_i(p_i, p_j, \alpha)$ denotes the demand of firm i, $i = b, g; i \neq j$. The equilibrium prices and quantities are:

$$p_b^*(\alpha) = \frac{2(1-v)}{\alpha(4-v)} \qquad p_g^*(\alpha) = \frac{v(1-v)}{\alpha(4-v)} \qquad (1.a)$$

$$q_b^* = \frac{2}{4-v} \qquad q_g^* = \frac{1}{4-v} \qquad (1.b)$$

[1] In real world, drugs are prescribed by physicians. In the framework of the model, physicians would observe θ, and prescribe the drug that gives the highest net utility to the consumer.

As Brekke *et al.* (2011) and Gonçalves *et al.* (2015) previously pointed out, the off-patent drug is more expensive than the generic drug. The larger the co-payment rate, the lower the prices. It is easy to see that sales of the off-patent drug are higher that generic drug sales. Notice that sales do not depend on the co-payment rate. (See Appendix 1 for the derivation of the demands and the equilibrium prices)

5. Exogenous reference pricing

Let us now suppose health authorities set a reference price $r > 0$ that does not depend on drug prices in a functional form. Other authors (Brekke *et al.* (2011) and Mestre-Ferrandiz (2003)) have modelled exogenous reference prices by considering that $r \in (p_g, p_b)$. As a result, the equilibrium price of the generic firm is below the reference price while the equilibrium price of the off-patent firm is above the reference price. We do not restrict the reference price to be in such interval, and allow the reference price to take any positive value. Notice that if $r \geq \frac{2(1-v)}{\alpha(4-v)}$, the price of the off-patent firm under no regulation, reference pricing has no effect on drug prices. Consequently, we will carry out the analysis for $\in (0, \frac{2(1-v)}{\alpha(4-v)})$, the range of feasible values for the reference price for which this regulatory mechanism really has an impact on drug prices.

5.1 Demands

Consumers with marginal valuation $\theta \geq \hat{\theta}$ buy the off-patent drug and consumers with $\theta \in [\underline{\theta}, \hat{\theta})$ buy the generic drug:

$$v\hat{\theta} - p_g^c = \hat{\theta} - p_b^c \Longrightarrow \hat{\theta} = \frac{p_b^c - p_g^c}{1-v}$$

$$v\underline{\theta} - p_g^c = 0 \Longrightarrow \underline{\theta} = \frac{p_g^c}{v}$$

The consumer with marginal valuation $\hat{\theta}$ is indifferent between both drugs, while the consumer with marginal valuation $\underline{\theta}$ is indifferent between buying the generic drug and no consumption. If both prices are above the reference price ($p_b > p_g > r$), the consumer pays a price $p_i^c = p_i - r(1-\alpha)$ for drug i, $i = b, g$, and the demands are given by:

$$q_b(p_b, p_g, r) = 1 - \hat{\theta} = 1 - \frac{p_b - p_g}{1-v} = \frac{1 - v - p_b + p_g}{1-v}$$

$$q_g(p_b, p_g, r) = \hat{\theta} - \underline{\theta} = \frac{p_b - p_g}{1-v} - \frac{p_g - r(1-\alpha)}{v} = \frac{[vp_b - p_g + r(1-\alpha)(1-v)]}{v(1-v)}$$

When $p_b > r \geq p_g$, the effective price the consumer pays for the off-patent drug is $p_b^c = p_b - r(1-\alpha)$ and $p_g^c = \alpha p_g$ for the generic drug. The demands are:

$$q_b(p_b, p_g, r) = 1 - \hat{\theta} = 1 - \frac{p_b - r(1-\alpha) - \alpha p_g}{1-v} = \frac{1 - v - [p_b - r(1-\alpha)] + \alpha p_g}{1-v}$$

$$q_g(p_b, p_g, r) = \hat{\theta} - \underline{\theta} = \frac{p_b - r(1-\alpha) - \alpha p_g}{1-v} - \frac{\alpha p_g}{v} = \frac{[vp_b - vr(1-\alpha) - \alpha p_g)}{v(1-v)}$$

Finally, when $p_g < p_b \leq r$, the effective price of drug i is $p_i^c = \alpha p_i$, $i = b, g$, and the demands are:

$$q_b(p_b, p_g, r) = 1 - \hat{\theta} = 1 - \frac{\alpha(p_b - p_g)}{1 - v} = \frac{1 - v - \alpha p_b + \alpha p_g}{1 - v}$$

$$q_g(p_b, p_g, r) = \hat{\theta} - \underline{\theta} = \frac{\alpha(p_b - p_g)}{1 - v} - \frac{\alpha p_g}{v} = \frac{\alpha(v p_b - p_g)}{v(1 - v)}$$

In summary, for $r \in (0, \frac{2(1-v)}{\alpha(4-v)})$, the demands for both drugs are given by:

$$q_g(p_b, p_g, r) = \begin{cases} \frac{[v p_b - p_g + r(1-\alpha)(1-v)]}{v(1-v)} & if \quad p_b > p_g > r \\ \frac{[v p_b - v r(1-\alpha) - \alpha p_g]}{v(1-v)} & if \quad p_g \leq r < p_b \\ \frac{\alpha(v p_b - p_g)}{v(1-v)} & if \quad p_g < p_b \leq r \end{cases}$$

$$q_b(p_b, p_g, r) = \begin{cases} \frac{1 - v - p_b + p_g}{1 - v} & if \quad p_b > p_g > r \\ \frac{1 - v - [p_b - r(1-\alpha)] + \alpha p_g}{1 - v} & if \quad p_b > r \geq p_g \\ \frac{1 - v - \alpha p_b + \alpha p_g}{1 - v} & if \quad r \geq p_b > p_g \end{cases}$$

Notice that the price of the off-patent drug must be larger than the price of the generic drug as the off-patent drug is perceived to be of higher value.

5.2 The determination of the equilibrium prices

Given the reference price r, the firms choose simultaneously the prices p_i to maximize their profits $\pi_i = p_i q_i(p_i, p_j, r)$, $i = b, g; i \neq j$. The equilibrium prices $(p_b^*(r), p_g^*(r))$ satisfy $p_i^*(r) = p_i(p_j^*, r)$, $\forall i = b, g;\ i \neq j$, where $p_i(p_j, r)$ denotes the reaction function of firm i, $i = b, g$. The next propositions characterize both reaction functions.

Proposition 1

The reaction function of the generic firm is:

$$p_g(p_b, r) = \begin{cases} \frac{v p_b}{2} & if \quad p_b \leq r \\ \frac{v[p_b - r(1-\alpha)]}{2\alpha} & if \quad p_b \in \left(r, \frac{r(2\alpha + (1-\alpha)v)}{v}\right] \\ r & if \quad p_b \in \left(\frac{r(2\alpha + (1-\alpha)v)}{v}, \frac{r[2 - (1-\alpha)(1-v)]}{v}\right] \\ \frac{v p_b + r(1-\alpha)(1-v)}{2} & if \quad p_b > \frac{r[2 - (1-\alpha)(1-v]}{v} \end{cases}$$

Proof (See Appendix)

When $p_b \leq r$, the generic firm also chooses a price below the reference price. When the price of the off-patent drug is higher than the reference price, the best strategy of the generic firm depends on the size of the difference between the price of the off-patent drug and the reference price. When such difference is not too big, the generic firm chooses

a price lower than the reference price (or equal to r). When the price of the off-patent firm is too big, the best strategy for the generic-firm is to choose also a price above the reference price.

Proposition 2

Let $r < 1 - v$. The reaction function of the off-patent firm is:

$$p_b(p_g, r) = \begin{cases} \dfrac{1 - v + \alpha p_g}{2\alpha} & if \quad p_g \leq \max\left\{0, \dfrac{2\alpha r - 1 + v}{\alpha}\right\} \\ r & if \quad p_g \in (\max\left\{0, \dfrac{2\alpha r - 1 + v}{\alpha}\right\}, \max\left\{0, \dfrac{r(1+\alpha) - 1 + v}{\alpha}\right\}] \\ \dfrac{1 - v + \alpha p_g + r(1-\alpha)}{2} & if \quad p_g \in (\max\left\{0, \dfrac{r(1+\alpha) - 1 + v)}{\alpha}\right\}, r] \\ \dfrac{1 - v + p_g}{2} & if \quad p_g > r \end{cases}$$

Proof (See Appendix)

Corollary 1

When $r \geq 1 - v$, the reaction function of the off-patent firm is:

$$p_b(p_g, r) = \begin{cases} \dfrac{1 - v + \alpha p_g}{2\alpha} & if \quad p_g \leq \max\left\{0, \dfrac{2\alpha r - 1 + v}{\alpha}\right\} \\ r & if \quad p_g \in (\max\left\{0, \dfrac{2\alpha r - 1 + v}{\alpha}\right\}, \mathrm{r}) \end{cases}$$

Notice that, in this case, the feasible prices for the generic drug producer are lower than the reference price. Otherwise, as the reaction function of the off-patent drug producer is $\frac{1-v+p_g}{2}$ and p_b must be larger than p_g, it follows that $1 - v > p_g \geq r \geq 1 - v$ must be satisfied, but this is a contradiction.

Once both reaction functions have been derived, we characterize the equilibrium prices.

Proposition 3

Let $r_1 = \frac{v(1-v)}{2+v+2\alpha(1-v)}$. If $r < r_1$, both equilibrium prices are higher than the reference price. The equilibrium prices are $p_b^*(r) = \frac{(1-v)[2+r(1-\alpha)]}{4-v}$ and $p_g^*(r) = \frac{(1-v)[v+2r(1-\alpha)]}{4-v}$.

Proof

We need to show that $p_i^*(r) = p_i(p_j^*(r), r), i = b, g, i \neq j$ for $r < r_1$. From the reaction functions, we have:

$$\frac{(1-v)[v+2r(1-\alpha)]}{4-v} = p_g\left(\frac{(1-v)[2+r(1-\alpha)]}{4-v}, r\right)$$

$$\frac{(1-v)[2+r(1-\alpha)]}{4-v} = p_b\left(\frac{(1-v)[v+2r(1-\alpha)]}{4-v}, r\right)$$

as long as the following conditions are satisfied:

$$\frac{(1-v)[2+r(1-\alpha)]}{4-v} > \frac{r[2-(1-\alpha)(1-v)]}{v} \Rightarrow (1-v)v > r[2+v+2\alpha(1-v)]$$

$$\frac{(1-v)[v+2r(1-\alpha)]}{4-v} > r \Rightarrow (1-v)v > r[2+v+2\alpha(1-v)]$$

Thus, r must be lower than r_1. In order to prove that both prices are higher than the reference price, it suffices to show that $p_g^*(r) > r$:

$$p_g^*(r) > r \Leftrightarrow (1-v)v > r[4-v-2(1-v)(1-\alpha)] \Leftrightarrow \frac{v(1-v)}{2+v+2\alpha(1-v)} = r_1 > r \qquad \text{(Q. E. D)}$$

When the reference price is too low, both firms optimally choose prices above the reference price. Although the generic firm can increase sales by cutting its price to the level of the reference price, its profits would decrease as the reference price is too small. The equilibrium quantities are $q_b^*(r) = \frac{[2+r(1-\alpha)]}{4-v}$ and $q_g^*(r) = \frac{[v+2r(1-\alpha)]}{v(4-v)}$. It is easily checked that, according to the literature, reference pricing enhances competition, and increases sales of both drugs.

From (1.a):

$$p_b^*(\alpha) - p_b^*(r) = \frac{(1-v)(1-\alpha)(2-r\alpha)}{\alpha(4-v)} > 0$$

$$p_g^*(\alpha) - p_g^*(r) = \frac{(1-v)(1-\alpha)(v-2r\alpha)}{\alpha(4-v)} > 0$$

given the range for the reference price. With regard to the quantities, we have from (1.b):

$$q_b^*(\alpha) - q_b^*(r) = \frac{-r(1-\alpha)}{4-v} < 0$$

$$q_g^*(\alpha) - q_g^*(r) = \frac{-2r(1-\alpha)}{v(4-v)} < 0$$

Proposition 4

Let $r_2 = \frac{v(1-v)}{v+2\alpha(2-v)}$. If $r \in [r_1, r_2)$, the price of the generic firm is the reference price while the price of the off-patent firm is higher than the reference price: $p_b^*(r) = \frac{1-v+r}{2}$ and $p_g^*(r) = r$.

Proof

From the reaction functions:

$$p_g^*(r) = r = p_g\left(\frac{1-v+r}{2}, r\right)$$

$$p_b^*(r) = \frac{1-v+r}{2} = p_b(r, r)$$

as long as:

$$\frac{1-v+r}{2} \in \left(\frac{r(2\alpha+(1-\alpha)v)}{v}, \frac{r[2-(1-\alpha)(1-v)]}{v}\right]$$

Thus, we need:

$$v(1-v) > r[4\alpha + 2(1-\alpha)v - v] \Rightarrow v(1-v) > r[v + 2\alpha(2-v)] \Rightarrow r_2 > r$$

$$v(1-v) \leq r[4 - 2(1-\alpha)(1-v) - v] \Rightarrow v(1-v) \leq r[2 + v + 2\alpha(1-v)] \Rightarrow r_1 \leq r$$

Therefore, $r \in [r_1, r_2)$. Notice that $p_b^* > r$ for this range of values for the reference price:

$$p_b^* > r \Leftrightarrow 1 - v > r$$

what it is true for all $r \in [r_1, r_2)$. (Q. E. D.)

In this case, the reference price is not high enough for the off-patent firm to set its price at or below the reference price, and prefers the consumer to pay the price difference. However, the reference price is sufficiently high to compensate the generic firm for a price cut instead of pricing above the reference price. The equilibrium quantities are $q_b^*(r) = \frac{1-v+r}{2(1-v)}$ and $q_g^*(r) = \frac{v(1-v+r)-2r[\alpha+v(1-\alpha)]}{2v(1-v)}$. Notice that sales of the off-patent drug grow with the reference price, while the higher the reference price the lower the sales of the generic drug. Sales of the off-patent drug do not depend on the co-payment rate, and generic sales decrease with α. As before, reference pricing enhances competition, and prices are lower than the prices under no regulation.

Proposition 5

Let $r_3 = \frac{2(1-v)}{2+\alpha(2-v)}$. *If* $r \in [r_2, r_3)$, *the equilibrium prices are:* $p_b^*(r) = \frac{2(1-v)+r(1-\alpha)[2-v]}{4-v}$ *and* $p_g^*(r) = \frac{v[(1-v)-r(1-\alpha)]}{\alpha[4-v]}$.

Proof

From the reaction functions, it is easy to check that for each firm, the equilibrium price is a best response to the price of the other producer:

$$p_g^*(r) = p_g\left(\frac{2(1-v)+r(1-\alpha)[2-v]}{4-v}, r\right)$$

$$p_b^*(r) = p_b\left(\frac{v[(1-v)-r(1-\alpha)]}{\alpha[4-v]}, r\right)$$

as long as

$$p_g^*(r) \in (\max\left\{0, \frac{r(1+\alpha)-1+v)}{\alpha}\right\}, r]$$

$$p_b^*(r) \in (r, \frac{r[2\alpha+v(1-\alpha)]}{v}]$$

If $\max\left\{0, \frac{r(1+\alpha)-1+v)}{\alpha}\right\} = 0$, we need $p_g^*(r) \in (0, r]$. Clearly, $p_g^* > 0$ for the range of values for the reference price and $p_g^*(r) \leq r$ if $r \geq r_2$. Regarding the price of the off-patent firm, we need:

$$\frac{2(1-v)+r(1-\alpha)[2-v]}{4-v} > r \Leftrightarrow 2(1-v) > r[2+\alpha(2-v]$$

$$\frac{2(1-v)+r(1-\alpha)[2-v]}{4-v} \leq \frac{r[2\alpha+v(1-\alpha)]}{v} \Leftrightarrow v(1-v) \leq r[v+2\alpha(2-v)]$$

It follows that $r \in [r_2, r_3)$. If $\max\left\{0, \frac{r(1+\alpha)-1+v)}{\alpha}\right\} = \frac{r(1+\alpha)-1+v)}{\alpha}$, we need $p_g^*(r) \in (\frac{r(1+\alpha)-1+v)}{\alpha}, r]$:

$$p_g^*(r) > \frac{r(1+\alpha)-1+v)}{\alpha} \Leftrightarrow r_3 > r$$

Therefore, $r \in [r_2, r_3)$. (Q. E. D.)

The price of the off-patent firm is above the reference price while the price of the generic firm is below. Within the range $[r_2, r_3)$, the reference price is not still high enough to make the off-patent firm choose a price below the

reference price. The generic firm, however, chooses strategically a price strictly below the reference price. The price of the off-patent drug grows with the reference price, while the price of the generic drug decreases with r. However, the effective price paid by the consumer decreases with the reference price. The generic producer reduces its price in order not to lose market share to the brand producer. As before, reference pricing reduces the price of both drugs:

$$p_b^*(\alpha) - p_b^*(r) = \frac{(1-\alpha)[2(1-v) - r\alpha(2-v)]}{\alpha(4-v)} > 0$$

$$p_g^*(\alpha) - p_g^*(r) = \frac{vr(1-\alpha)}{\alpha(4-v)} > 0$$

The equilibrium quantities are $q_b^*(r) = \frac{2(1-v)+r(1-\alpha)(2-v)}{(1-v)(4-v)}$ and $q_g^*(r) = \frac{1-v-r(1-\alpha)}{(1-v)(4-v)}$. Within this range, reference pricing increases total sales. However, generic drug sales are lower. Copayment affects sales. If the copayment rate increases, generic drug sales grow while off-patent drug sales go down. The higher α, the lower total sales.

Proposition 6

If $r \in [r_3, \frac{2(1-v)}{\alpha(4-v)})$, the price of the off-patent firm is the reference price while the price of the generic firm is lower than the reference price: $p_b^*(r) = r$ and $p_g^*(r) = \frac{vr}{2}$.

Proof

From the reaction functions, we have:

$$\frac{vr}{2} = p_g(r, r)$$

$$r = p_b\left(\frac{vr}{2}, r\right)$$

as long as:

$$\max\left\{0, \frac{r(1+\alpha)-1+v}{\alpha}\right\} \geq p_g^*(r) > \max\left\{0, \frac{2\alpha r - 1 + v}{\alpha}\right\}$$

For $r \in [r_3, \frac{2(1-v)}{\alpha(4-v)})$, it follows that $\max\left\{0, \frac{r(1+\alpha)-1+v}{\alpha}\right\} = \frac{r(1+\alpha)-1+v}{\alpha}$. Thus, we need:

$$\frac{r(1+\alpha)-1+v}{\alpha} \geq \frac{vr}{2} \Leftrightarrow r \geq r_3$$

If $\max\left\{0, \frac{2\alpha r-1+v}{\alpha}\right\} = \frac{2\alpha r-1+v}{\alpha}$, we need:

$$\frac{vr}{2} > \frac{2\alpha r - 1 + v}{\alpha} \Leftrightarrow \frac{2(1-v)}{\alpha(4-v)} > r$$

Thus, $r \in [r_3, \frac{2(1-v)}{\alpha(4-v)})$. If $\max\left\{0, \frac{2\alpha r-1+v}{\alpha}\right\} = 0$, we need $p_g^*(r) \in (0, \frac{r(1+\alpha)-1+v}{\alpha}]$. Thus, $r \geq r_3$. Notice that $\max\left\{0, \frac{2\alpha r-1+v}{\alpha}\right\} = \frac{2\alpha r-1+v}{\alpha}$ for $r = \frac{2(1-v)}{\alpha(4-v)}$. Thus, for $r \in [r_3, \frac{2(1-v)}{\alpha(4-v)})$, the equilibrium is $p_b^*(r) = r$ and $p_g^*(r) = \frac{vr}{2}$. (Q. E. D.)

For this range, the generic firm chooses a price below the reference price. However, for the off-patent-firm, the reference price is so high that pricing above the reference price would reduce market share and profits. Thus, it chooses the reference price. It is easily checked, as before, that reference pricing enhances competition. The

equilibrium quantities are $q_b^*(r) = \frac{2(1-v)-\alpha r(2-v)}{2(1-v)}$ and $q_g^*(r) = \frac{\alpha r}{2(1-v)}$. Notice that off-patent sales decrease with α while generic sales increase with α.

As the reference price affects public reimbursement and the net price paid by consumers, the equilibrium prices change depending on the reference price chosen by the health authorities. Intuitively, when the reference price is fixed at a relatively small level (Proposition 3), both firms set their prices above r. As the reference price increases, the generic firm matches the reference price while the off-patent firm keeps its price above the reference price (Proposition 4). This behavior is optimal as long as the reference price is not too high. For intermediate values of r, the generic firm sets its price below the reference price, while the off-patent firm charges a price above r (Proposition 5). Finally, when the reference price is sufficiently high, the price of the off-patent drug is the reference price while the generic firm charges a price below the reference price (Proposition 6). As aforementioned, if the reference price is above $\frac{2(1-v)}{\alpha(4-v)}$, both firms set their prices below the reference price, and there is no effect on drug prices (the prices are similar to those under no regulation).

6. Endogenous reference pricing

With endogenous reference pricing, the reference price depends on drug prices. In the literature, the endogenous reference price has been defined as either $r_e = \min(p_{b,} p_g)$ or $r_e = \beta p_b + (1-\beta)p_g$, with $\beta \in [0,1]$. In most countries, the reference price equals the price of the less expensive drug (Brekke *et al.* (2007)). Here, we consider the latter definition.

Let the reference price be defined as $r_e = \beta p_b + (1-\beta)p_g$, with $\beta \in [0,1]$. Notice that $p_g < r_e$ and $p_b > r_e$. Consumers pay αp_g for the generic drug and $p_b - r_e(1-\alpha) = [1-(1-\alpha)\beta]p_b - (1-\alpha)(1-\beta)p_g$ for the off-patent drug. Following Brekke *et al.* (2011), the equilibrium prices are:

$$p_b^e(\beta) = \frac{2(1-v)[\alpha(1-v) + v(1-(1-\alpha)\beta)]}{[1-(1-\alpha)\beta][4\alpha(1-v) + 3v(1-(1-\alpha)\beta)]}$$

$$p_g^e(\beta) = \frac{v(1-v)}{4\alpha(1-v) + 3v(1-(1-\alpha)\beta)} \qquad (2.a)$$

We can analyze the response of both equilibrium prices to changes in the reference price.

$$\frac{\partial p_b^e(\beta)}{\partial \beta} = \frac{6(1-v)(1-\alpha)v[\alpha(1-v) + v(1-(1-\alpha)\beta)]}{(1-(1-\alpha)\beta)[4\alpha(1-v) + 3v(1-(1-\alpha)\beta)]^2} > 0$$

$$\frac{\partial p_g^e(\beta)}{\partial \beta} = \frac{3v^2(1-v)(1-\alpha)}{[4\alpha(1-v) + 3v(1-(1-\alpha)\beta)]^2} > 0$$

Both prices grow with β. The equilibrium quantities are given by:

$$q_b^e(\beta) = \frac{2[\alpha(1-v) + v(1-(1-\alpha)\beta)]}{4\alpha(1-v) + 3v(1-(1-\alpha)\beta)} \qquad q_g^e(\beta) = \frac{[\alpha(1-v) + v(1-(1-\alpha)\beta)]}{4\alpha(1-v) + 3v(1-(1-\alpha)\beta)} \quad (2.b)$$

The higher β, the lower the equilibrium quantities.

$$\frac{\partial q_g^e(\beta)}{\partial \beta} = \frac{-\alpha v(1-v)(1-\alpha)}{[4\alpha(1-v) + 3v(1-(1-\alpha)\beta)]^2} < 0$$

In equilibrium:

$$\hat{\theta}^e(\beta) = \frac{2\alpha(1-v) + v(1-(1-\alpha)\beta)}{4\alpha(1-v) + 3v(1-(1-\alpha)\beta)} \qquad (3.a)$$

$$\underline{\theta}^e(\beta) = \frac{\alpha(1-v)}{4\alpha(1-v) + 3v(1-(1-\alpha)\beta)} \qquad (3.b)$$

Notice that both $\hat{\theta}^e(\beta)$ and $\underline{\theta}^e(\beta)$ grow with β:

$$\frac{\partial \hat{\theta}^e(\beta)}{\partial \beta} = \frac{2\alpha v(1-v)(1-\alpha)}{[4\alpha(1-v) + 3v(1-(1-\alpha)\beta)]^2} > 0$$

$$\frac{\partial\, \underline{\theta}^e(\beta)}{\partial \beta} = \frac{3\alpha v(1-v)(1-\alpha)}{[4\alpha(1-v) + 3v(1-(1-\alpha)\beta)]^2} > 0$$

7. Endogenous *versus exogenous reference pricing*

In this section, we compare both reference pricing mechanisms from a social welfare perspective. We will consider two different measures of social welfare: 1) social welfare defined as consumer surplus plus firms' profits net of public pharmaceutical expenditures (standard social welfare), and 2) a measure of social welfare where firms' profits are not included (social welfare without profits). When calculating gross consumer surplus, we will assume that, from the perspective of health authorities, both drugs have the same therapeutic effects (same active principle), and, therefore, gross utility obtained from consuming any drug is given by θ, where θ is distributed uniformly in the interval $[0,1]$. In other words, we assume that health authorities are paternalistic.

7.1 Standard social welfare

Let us initially assume that health authorities seek to maximize standard social welfare. As total pharmaceutical expenditures are equal to firms' profits, it turns out that standard social welfare is given by the gross consumer surplus. In order to choose the reference pricing mechanism, we need to see which mechanism maximizes market coverage.

Under endogenous reference pricing, social welfare $W_1^e(\beta)$ is given by:

$$W_1^e(\beta) = \int_{\underline{\theta}^e(\beta)}^{1} sf(s)ds$$

The lower $\underline{\theta}^e$, the higher social welfare. From (3.b), as $\underline{\theta}^e$ grows with β, it follows that social welfare is maximized for $\beta = 0$. Therefore, the optimal endogenous reference price r_e^* is the price of the generic drug:

$$r_e^* = p_g^e(0) = \frac{v(1-v)}{4\alpha(1-v) + 3v}$$

The higher the copayment rate, the lower the optimal endogenous reference price. Market coverage is $1 - \underline{\theta}^e(0)$. From (3.b), we have:

$$\underline{\theta}^e(0) = \frac{\alpha(1-v)}{4\alpha(1-v) + 3v} \qquad (4)$$

Under exogenous reference pricing, social welfare $W_1^r(r)$ is given by:

$$W_1^r(r) = \int_{\underline{\theta}^r(r)}^{1} sf(s)ds$$

where $\underline{\theta}^r(r)$ is defined as $\frac{p_g^c}{v}$. The value of $\underline{\theta}^r(r)$ depends on the equilibrium effective price of the generic drug, which changes with r. For $r < r_1$, the effective price of the generic drug is $p_g^*(r) - r(1-\alpha)$, where $p_g^*(r)$ is given in Proposition 3. For $r \geq r_1$, the effective price of the generic drug is $\alpha p_g^*(r)$, where $p_g^*(r)$ is given in Propositions 4-6. By taking into account the equilibrium effective prices of the generic drug (Propositions 3-6), we have:

$$\underline{\theta}^r(r) = \begin{cases} \dfrac{v(1-v) - r(1-\alpha)(2+v)}{v(4-v)} & if \quad r < r_1 \\ \dfrac{\alpha r}{v} & if \quad r \in [r_1, r_2) \\ \dfrac{1-v-r(1-\alpha)}{4-v} & if \quad r \in [r_2, r_3) \\ \dfrac{\alpha r}{2} & if \quad r \in [r_3, \dfrac{2(1-v)}{\alpha(4-v)}) \end{cases}$$

It follows that the exogenous reference price that maximizes social welfare is $r_1 = \frac{v(1-v)}{2+v+2\alpha(1-v)}$. It can be shown that this reference price maximizes market coverage[2]:

$$\min_r \underline{\theta}^r(r) \Rightarrow r^* = r_1 = \frac{v(1-v)}{2+v+2\alpha(1-v)}$$

$$\Downarrow$$

$$\underline{\theta}^r(r^*) = \frac{\alpha(1-v)}{2+v+2\alpha(1-v)} \qquad (5)$$

The higher the copayment rate, the lower the optimal exogenous reference price. Most models on exogenous reference pricing focus only on intermediate values for the reference price, for which one of the firms (the producer of the generic drug) charges a price below the reference price while the firm that produces the off-patent drug chooses a price above the reference price. When health authorities seek to maximize social welfare, the optimal exogenous reference price is such that the generic firm chooses the reference price while the off-patent firm sets its price above the reference price.

When we compare the levels of social welfare for each reference pricing mechanism, it follows that $W_1^r(r^*) > W_1^e(0)$ if and only if $\underline{\theta}^r(r^*) < \underline{\theta}^e(0)$. From (4) and (5):

$$\underline{\theta}^e(0) - \underline{\theta}^r(r^*) = \frac{\alpha(1-v)}{4\alpha(1-v)+3v} - \frac{\alpha(1-v)}{2+v+2\alpha(1-v)} = \frac{\alpha(1-v)[2+v+2\alpha(1-v)-4\alpha(1-v)-3v]}{(4\alpha(1-v)+3v)[2+v+2\alpha(1-v)]}$$
$$= \frac{2\alpha(1-v)^2(1-\alpha)}{(4\alpha(1-v)+3v)[2+v+2\alpha(1-v)]} > 0$$

Proposition 7

If health authorities pursue to maximize social welfare defined as the sum of consumer and producer surplus net of public pharmaceutical expenditures, they choose exogenous reference pricing.

7.2 Social welfare without profits

Let us now assume, as some authors (Brekke *et al* 2007), that health authorities seek to maximize social welfare defined as gross consumer surplus net of total (private and public) pharmaceutical expenditures. As total pharmaceutical expenditures equal firms' profits, this definition of social welfare does not take into account firms' profits. It makes sense when the country does not have a strong pharmaceutical industry. In this case, social welfare under endogenous reference pricing is:

[2] The proof is available upon request.

$$W_2^e(\beta) = \int_{\underline{\theta}^e(\beta)}^{1} sf(s)ds - \sum_{i=b,g} \Pi_i^e(\beta)$$

where $\Pi_i^e(\beta)$denotes the profits of the drug i producer when the reference price is endogenously set.

As before, gross consumer surplus is maximized for $\beta = 0$. Regarding aggregated profits, notice that a higher weight attached to the generic drug in the definition of the reference price (a lower β) leads to a reduction in both drug prices. Competition is enhanced, and profits for both producers are lower (See Proposition 3 in Brekke *et al.* (2011)). Thus, when the measure of social welfare does not include profits, the optimal endogenous reference price is given by the price of the generic drug evaluated at $\beta = 0$.

Similarly, social welfare under exogenous reference pricing is:

$$W_2^r(r) = \int_{\underline{\theta}^r(r)}^{1} sf(s)ds - \sum_{i=b,g} \Pi_i^r(r)$$

where $\Pi_i^r(r)$ denotes the profits of the drug i producer when the reference price is exogenously set. Given this definition of social welfare, it is analytically difficult to characterize the optimal exogenous reference price although we can show that exogenous reference pricing leads to a higher level of social welfare as compared to the level achieved with endogenous reference pricing.

Proposition 8

Drug prices for the exogenous reference price r^* are lower than drug prices for the optimal endogenous reference price: $p_i^*(r^*) < p_i^e(0)$, $i = b, g$.

Proof

(See Appendix 2)

From Proposition 8, it follows that aggregated profits are lower when health authorities fix exogenously the reference price. As gross consumer surplus is also higher for r^*, it turns out that social welfare is higher with exogenous reference pricing. Thus, regardless of the measure of social welfare, we conclude that the reference price chosen by the health authorities will be exogenously determined.

So far, we have assumed that health authorities are paternalistic as they consider that both drugs have the same quality. When health authorities are concerned with standard social welfare, the size of market coverage becomes relevant. Thus, the optimal exogenous reference price is the price that leads to the largest market coverage. When health authorities are not paternalistic, meaning that they respect consumers' preferences for drugs, firms' market shares become relevant, and it is not clear *a priori* which reference pricing mechanism is better. As an illustration, we are going to carry out the analysis when health authorities pursue to maximize standard social welfare.

Under endogenous reference pricing, social welfare $W_1^e(\beta)$ is now given by:

$$W_1^e(\beta) = \int_{\underline{\theta}^e(\beta)}^{\hat{\theta}^e(\beta)} vsf(s)ds + \int_{\hat{\theta}^e(\beta)}^{1} sf(s)ds = {}^1\!/_2\,[1 - (1-v)\hat{\theta}^e(\beta)^2 - v\underline{\theta}^e(\beta)^2]$$

As $\hat{\theta}^e(\beta)$ and $\underline{\theta}^e(\beta)$ grow with β, it follows that $W_1^e(\beta)$ is maximized for $\beta = 0$, as in the paternalistic case. By taking into account the expressions for $\hat{\theta}^e(\beta)$ and $\underline{\theta}^e(\beta)$ from (3.a) and (3.b), we have:

$$W_1^e(0) = {}^1\!/_2\left[1 - \frac{(1-v)[(2\alpha(1-v)+v)^2 + v(1-v)\alpha^2]}{[4\alpha(1-v)+3v]^2}\right] \qquad (6)$$

Under exogenous reference pricing, social welfare $W_1^r(r)$ is defined as:

$$W_1^r(r) = \int_{\underline{\theta}^r(r)}^{\hat{\theta}^r(r)} vsf(s)ds + \int_{\hat{\theta}^r(r)}^{1} sf(s)ds = {}^1\!/_2\,[1 - (1-v)\hat{\theta}^r(r)^2 - v\underline{\theta}^r(r)^2]$$

Recall that $\hat{\theta}^r(r)$ is defined as $\frac{p_b^c - p_g^c}{1-v}$. Plugging the effective prices for both drugs into this expression yields:

$$\hat{\theta}^r(r) = \begin{cases} \dfrac{2 - v - r(1-\alpha)}{4-v} & if \quad r < r_1 \\ \dfrac{1 - v - r}{2(1-v)} & if \quad r \in [r_1, r_2) \\ \dfrac{(2-v)[1 - v - r(1-\alpha)]}{(1-v)(4-v)} & if \quad r \in [r_2, r_3) \\ \dfrac{\alpha r(2-v)}{2(1-v)} & if \quad r \in [r_3, \dfrac{2(1-v)}{\alpha(4-v)}) \end{cases}$$

By taking into account the expressions for $\underline{\theta}^r(r)$ and $\hat{\theta}^r(r)$, we can write social welfare as:

$$W_1^r(r) = \begin{cases} {}^1\!/_2\,[1 - \dfrac{v(1-v)[2 - v - r(1-\alpha)]^2 + [v81 - v) - r(1-\alpha)(2+v)]^2}{v(4-v)^2}] & if \quad r < r_1 \\ {}^1\!/_2\,[1 - \dfrac{v(1-v-r)^2 + 4(1-v)\alpha^2 r^2}{4v(1-v)}] & if \quad r \in [r_1, r_2) \\ {}^1\!/_2\,[1 - \dfrac{(4-3v)[1-v-r(1-\alpha)]^2}{(1-v)(4-v)^2}] & if \quad r \in [r_2, r_3) \\ {}^1\!/_2\,[1 - \dfrac{(4-3v)\alpha^2 r^2}{4(1-v)}] & if \quad r \in [r_3, \dfrac{2(1-v)}{\alpha(4-v)}) \end{cases}$$

Social welfare grows with r for $r < r_3$ and decreases for $r \geq r_3$. Thus, social welfare is maximized for $r = r_3 = \frac{2(1-v)}{2+\alpha(2-v)}$. For this reference price, the price of the off-patent firm is the reference price, while the price of the generic firm is lower. This result contrasts with the equilibrium drug prices when health authorities are paternalistic. In that case, for the optimal exogenous reference price, the price of the generic drug was the reference price while the price of the off-patent drug was higher than the reference price. From Proposition 6, drug prices are:

$$p_b^* = \frac{2(1-v)}{2 + \alpha(2-v)} \qquad p_g^* = \frac{v(1-v)}{2 + \alpha(2-v)}$$

Drug prices are higher when health authorities are not paternalistic. It can be shown that sales of the off-patent drug are higher while sales of the generic-drug are lower. Intuitively, as consumers value the off-patent drug more than the generic drug, health authorities choose a reference price for which sales of the most valued drug increase.

Plugging the optimal exogenous price into the social welfare function yields:

$$W_1^r(r_3) = {}^1\!/_2\left[1 - \frac{(1-v)(4-3v)\alpha^2}{[2 + \alpha(2-v)]^2}\right] \qquad (7)$$

We can compare the levels of social welfare yielded by both reference pricing mechanisms. From (6) and (7):

$$W_1^r(r_3) - W_1^e(0) = \frac{1-v}{2}\left[\alpha^2(4-3v)\left(\frac{1}{[4\alpha(1-v)+3v]^2} - \frac{1}{[2+\alpha(2-v)]^2}\right) + \frac{v[v+4\alpha(1-v)-\alpha^2(4-3v)]}{[4\alpha(1-v)+3v]^2}\right]$$

Notice that $[2+\alpha(2-v)]^2 > [4\alpha(1-v)+3v]^2$ and $v+4\alpha(1-v)-\alpha^2(4-3v) \geq 0$ for all α and v. Therefore, $W_1^r(r_3) > W_1^e(0)$.

Proposition 9

Let health authorities be non- paternalistic. Then, standard social welfare is maximized when the reference price is exogenously fixed.

8. Conclusions

Public health systems frequently apply reference prices to contain pharmaceutical expenditures. With reference prices, health authorities set an upper bound for public reimbursement. Health authorities can make the reference price either depend on drug prices or be independent of such prices. The introduction of reference prices fosters competition and, as a result, drug prices are expected to be lower.

When the reference price is fixed exogenously, we have found that both drug producers chose prices above the reference price if the reference price is relatively low; as the reference price increases, the producer of the branded drug maintains its pricing strategy above the reference price while the generic drug manufacturer chooses a price below or equal to the reference price. We need a sufficiently high reference price for both producers to select prices below that threshold. In general, we also obtained that sales of both drugs grow with the reference price when health authorities fix it at low levels. However, for intermediate values of the reference price, generic sales decrease with the reference price, while the off-patent drug sales grow. Finally, for high values of the reference price, we find the opposite behavior of sales.

Should health authorities seek to maximize standard social welfare, our results point out to exogenous reference pricing as being the best regulatory mechanism. We have also obtained the same result when health authorities seek to maximize social welfare defined as the difference between gross consumer surplus and total pharmaceutical expenditures. These results have been derived under the assumption that health authorities adopt a paternalistic position about the quality of both drugs (i.e. they consider both drugs are of equal quality).

Interestingly, when health authorities follow a non-paternalistic approach the results also hold for the standard social welfare measure. Hence, the results seem to be robust to different specifications of social welfare as well as behavioral patterns of health authorities (paternalistic *vs* non-paternalistic approach).

We have found that the optimal exogenous reference price depends on the copayment rate. The higher the copayment rate, the lower the reference price. Copayment rates do not affect the selection of the best reference pricing policy.

To the best of our knowledge, exogenous reference pricing, as defined in this paper, (i.e. prices that are not set according to a specific functional form that automatically generate them) are not explicitly applied by health care systems and, consequently, we cannot offer specific examples of this policy. Perhaps, the more common utilization of endogenous reference pricing is due to the fact that it requires less information *ex ante*, and then health authorities do not need to fix a price directly. Also, we may think that fixing a price without any 'reference' (i.e. exogenous reference pricing), in a purely arbitrary way, would be difficult to be accepted by firms. Furthermore, competition seems to be more fiercely promoted through an exogenous reference pricing mechanism. As a consequence, firms´ profits would be reduced and again we may suspect that drug companies would be reluctant to accept such a mechanism. Nevertheless, our results point out that health authorities should pay more attention to this alternative way of setting the reference price.

In real world, usually more than just one generic firm compete in the drug market. However, our model as those of the other aforementioned studies, only considers one company. Intuitively, in the presence of more generic firms we would expect that generic prices would tend towards zero and the branded drug firm would charge a lower price than otherwise. Anyways, this question is open to further research.

Health authorities frequently use also copayments as a way to contain (or to reduce) public pharmaceutical expenditures. Copayments tend to reduce drug utilization and hence market coverage is compromised. Reference prices are used to foster competition, reduce prices and increase gross consumer surplus; therefore, a public policy in this area should carefully combine both instruments as their effects work in opposite directions in terms of social welfare. Copayments tend to negatively affect patients in terms of welfare whilst reference prices seek to reduce firms´ profits. If health authorities decide to use both instruments, they should cautiously consider who bears the burden of the pharmaceutical policy.

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Appendix 1: No regulation

Under no regulation, the price consumer pays when she buys drug i is αp_i, $i = b, g$. Physicians prescribe the off-patent drug to consumers with $\theta \geq \hat{\theta}$ and prescribe the generic drug to consumers with $\theta \in [\underline{\theta}, \hat{\theta})$:

$$v\hat{\theta} - \alpha p_g = \hat{\theta} - \alpha p_b \Longrightarrow \hat{\theta} = \frac{\alpha(p_b - p_g)}{1 - v}$$

$$v\underline{\theta} - \alpha p_g = 0 \Longrightarrow \underline{\theta} = \frac{\alpha p_g}{v}$$

Consumer $\hat{\theta}$ is indifferent between both drugs, while consumer $\underline{\theta}$ is indifferent between the generic drug and no consumption. The demands $q_i(p_i, p_j, \alpha)$, $i = b, g$; $i \neq j$, are consequently:

$$q_b(p_b, p_g, \alpha) = (1 - \hat{\theta}) = \frac{1 - v - \alpha p_b + \alpha p_g}{1 - v}$$

$$q_g(p_g, p_b, \alpha) = (\hat{\theta} - \underline{\theta}) = \frac{\alpha(v p_b - p_g)}{v(1 - v)}$$

The firms set the prices p_i simultaneously to maximize their profits $\pi_i = p_i q_i(p_i, p_j, \alpha)$, $i = b, g; i \neq j$. It is straightforward to verify that firms' best responses are:

$$p_b(p_g, \alpha) = \frac{1 - v + \alpha p_g}{2\alpha} \qquad p_g(p_b, \alpha) = \frac{v p_b}{2}$$

The equilibrium prices (p_b^*, p_g^*) satisfy $p_i^* = p_i(p_j^*, \alpha)$, $\forall i = b, g$; $i \neq j$. Therefore, the equilibrium prices are $p_b^*(\alpha) = \frac{2(1-v)}{\alpha(4-v)}$ and $p_g^*(\alpha) = \frac{v(1-v)}{\alpha(4-v)}$. The equilibrium quantities are obtained after plugging the equilibrium prices into the expressions for the demands: $q_b^* = \frac{2}{4-v}$ and $q_g^* = \frac{1}{4-v}$.

Appendix 2

Proof of Proposition 1

Let $p_b \leq r$. In this case, the profits of the generic firm are $p_g(\frac{\alpha(vp_b - p_g)}{v(1-v)})$ as p_g must be lower than r. It is straightforward to see that the price that maximizes the profits is $\frac{vp_b}{2}$.

For $p_b > r$, the generic firm may choose either a price above r or a price $p_g \leq r$. If $p_g > r$, the profits of the generic firm are given by $\frac{p_g[vp_b - p_g + r(1-\alpha)(1-v)]}{v(1-v)}$. Profits are maximized for $\frac{vp_b + r(1-\alpha)(1-v)}{2}$ as long as this price is above r:

$$\frac{vp_b + r(1-\alpha)(1-v)}{2} > r \Rightarrow p_b > \frac{r[2-(1-\alpha)(1-v]}{v}$$

If $p_g \leq r$, the profits of the generic firm are $\frac{p_g[vp_b - vr(1-\alpha) - \alpha p_g]}{v(1-v)}$. Profits reach their maximum level for a price $\frac{v[p_b - r(1-\alpha)]}{2\alpha}$ as long as $vp_b - vr(1-\alpha) - 2\alpha r \leq 0$. Thus, we require $p_b \leq \frac{r(2\alpha + (1-\alpha)v)}{v}$. Otherwise, profits are higher when the price is r. It follows that the best strategy is r for $p_b \in (\frac{r(2\alpha+(1-\alpha)v)}{v}, \frac{r[2-(1-\alpha)(1-v)]}{v}]$. For $p_b > \frac{r[2-(1-\alpha)(1-v)]}{v}$, there are two candidates to best response: r or $\frac{[vp_b - p_g + r(1-\alpha)(1-v)]}{v(1-v)}$, but the profits for the generic firm are higher for the latter. (Q.E.D.)

Proof of Proposition 2

Let $r < 1 - v$. If $p_g > r$, the off-patent firm chooses the price above the reference price to maximize its profits $p_b(\frac{1-v-p_b+p_g}{1-v})$. Thus, $p_b(p_g, r) = \frac{1-v+p_g}{2}$.

Let $p_g = r$. Then, the off-patent firm chooses the price above the reference price to maximize its profits $p_b(\frac{1-v-p_b+r}{1-v})$. Thus, $p_b(p_g, r) = \frac{1-v+r}{2}$

For $p_g < r$, we may have different situations depending on the values of r and α.

Let $2\alpha r > 1 - v$. Notice that α must be bigger than 0.5. The off-patent firm may choose either a price p_b such that $p_g < p_b \leq r$ or a price above r. If $p_g < p_b \leq r$, its profits would be $p_b(\frac{1-v-\alpha p_b+\alpha p_g}{1-v})$ and a candidate to best response is $\frac{1-v+\alpha p_g}{2\alpha}$ if $p_g \leq \frac{2\alpha r-1+v}{\alpha}$ and r if $p_g > \frac{2\alpha r-1+v}{\alpha}$. If $p_b > r$, its profits would be $p_b(\frac{1-v-p_b+\alpha p_g+r(1-\alpha)}{1-v})$, and a candidate to best response would be $\frac{1-v+\alpha p_g+r(1-\alpha)}{2}$ if $p_g > \frac{r(1+\alpha)-1+v}{\alpha}$. As $\frac{2\alpha r-1+v}{\alpha} < \frac{r(1+\alpha)-1+v}{\alpha}$, it follows that the best response is $\frac{1-v+\alpha p_g}{2\alpha}$ if $p_g \leq \frac{2\alpha r-1+v}{\alpha}$. For $p_g \in (\frac{2\alpha r-1+v}{\alpha}, \frac{r(1+\alpha)-1+v}{\alpha}]$, the best response is r. For $p_g \in (\frac{r(1+\alpha)-1+v}{\alpha}, r)$, r and $\frac{1-v+\alpha p_g+r(1-\alpha)}{2}$ are two candidates to best response, but profits are higher when the off-patent firm chooses a price above the reference price (for $p_g = \frac{r(1+\alpha)-1+v)}{\alpha}$, profits are equal for both prices; for $p_g = r$, profits are higher when the price is above the reference price, and both profits grow with p_g).

Let $2\alpha r \leq 1 - v$ and $r(1+\alpha) > 1 - v$. Then, for $p_g < r$, the best response of the off-patent firm cannot be a price below the reference price. Following the above reasoning, the best response of the off- patent firm is r for $p_g \in [0, \frac{r(1+\alpha)-1+v}{\alpha}]$ and $\frac{1-v+\alpha p_g+r(1-\alpha)}{2}$ for $p_g \in (\frac{r(1+\alpha)-1+v)}{\alpha}, r)$.

Finally, let $r(1+\alpha) \leq 1 - v$. In this case, for $p_g < r$, the best response of the off- patent firm is $\frac{1-v+\alpha p_g+r(1-\alpha)}{2}$ for $p_g \in [0, r)$. (Q. E. D)

Proof of Proposition 8

Drugs prices when the exogenous reference price is $r^*$are:

$$p_b^*(r^*) = \frac{1+v+r^*}{2} = \frac{(1-v)[1+v+\alpha(1-v)]}{2+v+2\alpha(1-v)}$$

$$p_g^*(r^*) = r^* = \frac{v(1-v)}{2+v+2\alpha(1-v)}$$

Drug prices for the optimal endogenous reference price are:

$$p_b^e(0) = \frac{2(1-v)[\alpha(1-v)+v]}{4\alpha(1-v)+3v}$$

$$p_g^e(0) = \frac{v(1-v)}{4\alpha(1-v)+3v}$$

The comparison of prices for the off-patent drug yields:

$$p_b^e(0) > p_b^*(r^*) \Leftrightarrow \frac{2[\alpha(1-v)+v]}{4\alpha(1-v)+3v} > \frac{[1+v+\alpha(1-v)]}{2+v+2\alpha(1-v)}$$

$$\Updownarrow$$

$$2v(2+v)+2\alpha(1-v)(2+v)+4\alpha v(1-v) > 4\alpha(1-v)(1+v)+3v(1+v)+3v\alpha(1-v)$$

$$\Updownarrow$$

$$2v(2+v)+2\alpha(1-v)(2+v) > 4\alpha(1-v)+3v(1+v)+3v\alpha(1-v)$$

$$\Updownarrow$$

$$2v(2+v)+2v\alpha(1-v) > 3v(1+v)+3v\alpha(1-v)$$

$$\Updownarrow$$

$$v(1-v) > v\alpha(1-v) \Leftrightarrow 1 > \alpha$$

Thus, the price of the off-patent drug is lower with exogenous reference pricing. The comparison of prices for the generic drug yields:

$$p_g^e(0) > p_g^*(r^*) \Leftrightarrow \frac{1}{4\alpha(1-v)+3v} > \frac{1}{2+v+2\alpha(1-v)}$$

$$\Updownarrow$$

$$2(1-v) > 2\alpha(1-v) \Leftrightarrow 1 > \alpha$$

Thus, the price of the generic drug is lower with exogenous reference pricing. (Q. E. D.)

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