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Reference pricing with endogenous generic entry

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Abstract

In this paper we study the effect of reference pricing on pharmaceutical prices and expenditures when generic entry is endogenously determined. We develop a Salop-type model where a brand-name producer competes with generic producers in terms of prices. In the market there are two types of consumers: (i) brand biased consumers who choose between brand-name and generic drugs, and (ii) brand neutral consumers who choose between the different generic drugs. We find that, for a given number of firms, reference pricing leads to lower prices of all products and higher brand-name market shares compared with a reimbursement scheme based on simple coinsurance. Thus, in a free entry equilibrium, the number of generics is lower under reference pricing than under coinsurance, implying that the net effects of reference pricing on prices and expenditures are ambiguous. Allowing for price cap regulation, we show that the negative effect on generic entry can be reversed, and that reference pricing is more likely to result in cost savings than under free pricing. Our results shed light on the mixed empirical evidence on the effects of reference pricing on generic entry.

Keywords: Pharmaceuticals; Reimbursement schemes; Generic entry

JEL Classification: I11; I18; L13; L51

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1 Introduction

The design of reimbursement schemes for prescription drugs is a key issue for policy makers around the world. Most countries have introduced cost sharing on the demand side in order to increase demand elasticity and contain (the growth in) pharmaceutical expenditures. In Europe copayment schemes with coinsurance, where the consumer pays a fixed percentage of the medical cost, have become popular among policy makers.¹ In the US there has been a similar trend. The extension of Medicare to cover prescription drugs (Part D) in 2006 spurred an increase in the use of coinsurance schemes.² The advantage of coinsurance (relative to deductibles or fixed copays) is that it directly links the copayment to the price of the drug, which is likely to make demand more responsive to price differences.

To further increase demand elasticity and contain pharmaceutical expenditures, policy makers in many countries have introduced reference pricing (sometimes called internal referencing). Under reference pricing the payer defines a maximum price that will be reimbursed for a group of drugs with similar therapeutic effects, implying that consumers demanding higher priced drugs have to pay, in addition to the regular copayment, the difference between the actual price and the reference price. Thus, by limiting insurance coverage for high-priced drugs, reference pricing is likely to stimulate demand elasticity and encourage price competition. In this paper we study the competitive effects of these reimbursement schemes, and ask whether reference pricing is more likely to contain pharmaceutical expenditures than coinsurance with a fixed percentage reimbursement.

Several studies have shown that reference pricing stimulates competition between brand-name and generic drugs, and triggers price reductions by brand-name firms to prevent loss of market shares to generic producers.³ However, only a few studies have considered the impact of reference pricing on generic entry, and the results from these studies are mixed.⁴ Clearly,

¹See, for instance, Carone, Schwierz and Xavier (2012) for an overview and a discussion of the recent development of cost-containment policies in the EU.

²The Medicare Modernization Act in 2003 established a standard drug benefit that all Medicare Part D plans must offer, which basically is a coinsurance scheme (with a deductible). For exact details, see www.medicare.gov/part-d.

³This was first shown in the seminal paper of Pavcnik (2002). Later papers, such as Bergman and Rudholm (2003), Brekke et al. (2009, 2011) and Kaiser et al. (2014), report similar findings.

⁴A few studies report a negative effect of reference pricing on generic entry (Ekelund, 2001, Moreno-Torres et al., 2009), whereas others find no effect (Rudholm, 2001) or a positive effect (Brekke et al., 2015)

if the brand-name producers are more aggressive in their price setting under reference pricing, the expected profits to generic producers may be lower than under coinsurance. In this case reference pricing may reduce generic competition and thus, in theory, be counterproductive in reducing pharmaceutical prices and expenditures.

To study the effects of reference pricing on generic entry, we develop a novel Salop-type model where a brand-name producer competes with several generic producers in terms of prices. In the market there are two types of consumers; *brand biased* and *brand neutral*. Brand biased consumers have a preference for the brand-name drug and only buy a generic alternative if it is sufficiently cheaper. Brand neutral consumers, on the other hand, always prefer a generic drug if it is cheaper than the brand-name drug. Thus, as long as the price of the brand-name drug is higher than the price of generic drugs, these consumers only choose between different generic alternatives.

We derive the equilibrium for different reimbursement schemes, i.e., coinsurance and reference pricing, both exogenous (the reference price does not depend on current prices) and endogenous (the reference price depends on current prices). We report three key findings. First, for a given number of firms, reference pricing leads to lower prices of both brand-name and generic drugs and a higher brand-name market share than a reimbursement scheme based on coinsurance. Thus, the brand-name producers responds aggressively to reference pricing and cut prices more than the generic producers. The reason for the weaker price response from the generic producers is due to two counteracting forces. For a given brand-name price, reference pricing shifts demand towards generic drugs and thus provides an incentive for generic producers to *increase* prices. However, the price reduction by the brand-name producer gives an incentive for generic producers to also *reduce* prices, which is due to the fact that prices are strategic complements. Our result shows that the second effect dominates, but that in equilibrium the brand-name producer cuts prices relatively more than the generic producers, and thus obtain a higher market share under reference pricing, for a given number of firms.

Second, reference pricing reduces the number of generic drugs that enters the market compared with coinsurance. This result holds for both endogenous and exogenous reference pricing. The aggressive price setting by the brand-name producer under reference pricing implies lower expected profits for the generic producers than under coinsurance. Thus, in the free entry

equilibrium, the net effects of reference pricing on prices and expenditures are in general ambiguous. We illustrate with a numerical example that reference pricing can be counterproductive in reducing prices and expenditures.

Third, allowing for price cap regulation, which is binding for the higher priced brand-name drug, we show that the negative effect of reference pricing on generic entry can be reversed. Indeed, if the price cap is sufficiently strict, introducing reference pricing may actually increase the number of generic drugs on the market. The reason is that binding price cap regulation reduces the brand-name price difference between reimbursement schemes with and without reference pricing. Generic producers may therefore obtain higher market shares under reference pricing. Thus, reference pricing is more likely to stimulate generic entry and facilitate cost savings when prices are regulated than in the free pricing equilibrium.

Our paper contributes to the existing literature along several dimensions. First, our model builds on the seminal work by Frank and Salkever (1992) who proposed a model with two consumer segments – a price insensitive and a price sensitive segment – in order to explain the generic competition paradox, i.e., brand-name producers respond to generic entry by increasing their prices. Their model provides a very appealing explanation for the generic competition paradox, namely market segmentation: the brand-name producer serves only the price insensitive consumers, leaving the price sensitive consumers to the generic producers. To arrive at this result, the model involved three key assumptions; (i) the demand from the price insensitive consumers depends only on the price of the brand-name drug, (ii) the game is Stackelberg where the brand-name producer commits to a price; (iii) generic producers compete in quantities *à la Cournot* with a market-clearing price of generic drugs. Later studies by Kong and Seldon (2004) and Regan (2008) generalise the model by Frank and Salkever (1992) by allowing demand from price insensitive consumers to depend on both the brand-name and the generic drug prices, but they maintain the other two assumptions.

The contribution of our paper is to build on the market segmentation model by Frank and Salkever (1992), but propose a model that relax all the three above-mentioned assumptions. More precisely, we allow for (i) the demand from brand biased (or price insensitive) consumers to depend on prices of generic drugs; (ii) brand-name and generic producers to simultaneously set prices; and (iii) generic producers to set prices rather than quantities. Thus, we avoid the

criticism of Stackelberg games, where the first-mover (brand-name producer) has an incentive to re-optimize (its price) after entry (of generic producers). We also avoid the criticism of a market-clearing price related to Cournot competition, which has limited empirical support in the pharmaceutical market.

However, our study is not the first to assume that generic producers set prices. There exists several studies that allow for price competition between brand-name and generic producers.⁵ However, these studies assume only one generic producer in the market. Thus, the contribution of our paper in regard to this literature is to allow for several generic producers. There is one recent paper by Ghislandi (2011) that allows for more than one generic producer in the market. By considering an infinitely repeated two-stage game, where at stage 1 the firms set prices that determine the reference price and at stage 2 the firms set prices taking the reference price as given, he shows that an optimal reference pricing scheme should only depend on generic prices in order to avoid collusion among generic producers. However, in Ghislandi (2011) there is either perfect competition (à la Bertrand) or collusion among the generic producers, and he is not concerned with the impact of reference pricing on generic entry. Thus, our paper differs significantly both in terms of research question and modeling framework.

Finally, our paper contributes to the empirical literature on the effect of reference pricing on generic competition. Several papers have analysed the impact of reference pricing and tend to find that it stimulates generic competition and leads to lower prices and expenditures.⁶ An exception is Danzon and Chao (2000), who argue that reference pricing might be counterproductive in curbing pharmaceutical expenditures.⁷ Moreover, Ekelund (2001) analyse the Swedish pharmaceutical market and find (weak) evidence of a negative effect of reference pricing on generic entry, whereas Rudholm (2001) find no effect of reference pricing on generic entry in Sweden. A study by Moreno-Torres et al. (2009) on the Spanish market find that reference pricing has a negative effect on generic entry, whereas a recent study by Brekke et al. (2015) on the Norwegian market find that reference pricing has a positive effect on generic entry. Our paper suggests that the mixed empirical findings can be explained by the presence and strictness

⁵See, for instance, Brekke et al. (2007, 2011) and Miraldo (2009).

⁶See, for instance, Aronsson et al. (2001), Pavcnik (2002), Brekke et al. (2009, 2011) and Kaiser et al. (2014).

⁷Danzon and Ketcham (2004) provide empirical evidence that RP leads to a price convergence towards the reference price, implying that brand-name drug prices drop whereas generics prices increase.

of price cap regulation.

The rest of the paper is organised as follows. In Section 2 we present our basic model. In Section 3 we derive the equilibrium for a coinsurance (or fixed percentage) reimbursement scheme. In Section 4 we derive the equilibrium for (endogenous and exogenous) reference pricing, and compare this with the equilibrium under coinsurance. In Section 5 we introduce price cap regulation. Section 6 concludes the paper. The proofs of all Lemmas and Propositions are relegated to the Appendix.

2 Model

Consider a pharmaceutical market with a brand-name drug that has lost patent protection and faces competition from generic producers (indexed by $i = 1, \dots, n$). Each generic producer can enter the market by incurring a fixed cost f . Suppose the market is represented by a Salop circle with circumference 1 and a uniform distribution of consumers with total mass equal to 1, and that the n generic producers that enter the market are symmetrically located on the circle.⁸

We assume that there are two different types of consumers in the market. At each point on the circle, a share λ of the consumers are *brand biased*, whereas the remaining share $1 - \lambda$ are *brand neutral*. *Brand biased* consumers have a preference for the brand-name drug and will only buy a generic alternative if it is sufficiently much cheaper. We model this by assuming that there are mismatch costs associated with buying a generic drug instead of the brand-name drug. The utility of an arbitrary *brand biased* consumer located at $x \in [0, 1]$ on the circle is given by

$$u^{bb}(x) = \begin{cases} v - c_b & \text{if consuming the brand-name drug} \\ v - c_g^i - t|x - z_g^i| & \text{if consuming generic drug } i \end{cases}, \quad (1)$$

with $i = 1, \dots, n$. The parameter v denotes the gross utility (reservation price) of medical treatment, c_b and c_g^i are the copayments of the brand-name drug and the generic drug i , respectively, and $t|x - z_g^i|$ is the mismatch (switching) cost of consuming a generic drug i located at z_g^i . Thus, in the segment of *brand biased* consumers, the degree of brand bias varies across consumers and

⁸This assumption is reasonable given that consumers are uniformly distributed and there is price competition among firms (see Economides, 1989), and captures the fact that generic drugs can be perceived as horizontally differentiated by consumers (e.g., due to different product name, package, presentation form, etc.).

is reflected by the consumer locations on the circle.

The remaining consumers are assumed to be *brand neutral* and will always prefer a generic drug if it is cheaper than the brand-name drug. Thus, as long as the price of the brand-name drug is higher than the price of generic drugs, these consumers will only choose between different generic alternatives, which we assume are considered imperfect substitutes in a strictly horizontal sense. The utility of an arbitrary *brand neutral* consumer located at x who consumes generic drug i , located at z_g^i , is given by

$$u^{bn}(x) = v - c_g^i - t |x - z_g^i|. \quad (2)$$

Notice that the parameter t has different interpretations for *brand biased* and *brand neutral* consumers. For the former, it reflects the degree of vertical differentiation between brand-name and generic drugs, whereas for the latter it reflects the degree of horizontal differentiation between different generic drugs.⁹

Technically, the difference between *brand biased* and *brand neutral* consumers lies in their perceptions about the location of the brand-name drug. Whereas *brand biased* consumers perceive the brand-name drug to be located at every single point on the circle, *brand neutral* consumers perceive the brand-name drug to be co-located with the generic drugs (implying that a *brand neutral* consumer would buy the brand-name drug only if the copayment is lower than the copayment for this consumer's most preferred generic drug).

Applying this model to price competition in off-patent drug markets, we will look for equilibria where the market is fully covered (implying that total demand is perfectly price inelastic) and where both the brand-name and the generic producers have positive sales. In such equilibria, a fraction of the *brand biased* consumers will buy the brand-name drug (with the remaining ones buying the most preferred generic drug) whereas all *brand neutral* consumers will buy generic drugs. Notice that, in the *brand biased* demand segment, each generic producer competes directly with the brand-name producer and only indirectly with the other generic producers (i.e., a price change by generics producer i will trigger a price response by the brand-name producer,

⁹A common parameter t is chosen in order to save notation. Our main results hold qualitatively also in the case where the degree of vertical and horizontal differentiation are represented by parameters t_b and t_g , respectively, and where $t_b \neq t_g$.

which in turn triggers price responses by the remaining generics producers $j \neq i$). However, in the *brand neutral* segment, there is direct competition between different generic producers.

In the *brand neutral* demand segment, demand allocations are determined by the locations of the consumers who are indifferent between the neighbouring generic drugs i and $i + 1$. These consumers are located a distance $(1/2n) + ((c_g^{i+1} - c_g^i) / 2\tau)$ from the location of generic drug i . With the assumption of full market coverage, demand allocations in the *brand biased* segment are determined by the location of the consumers who are indifferent between the brand-name drug and their most preferred generic drug i . These consumer are located a distance $(c_b - c_g^i) / t$ from the location of the generic drug i .¹⁰ Taking into consideration that in each demand segment there are two locations of indifferent consumers, one on each side of generic drug i , the total demand for this drug is given by

$$D_g^i = \frac{2\lambda}{t} (c_b - c_g^i) + (1 - \lambda) \left(\frac{1}{n} + \frac{c_g^{i+1} + c_g^{i-1} - 2c_g^i}{2\tau} \right). \quad (3)$$

The demand for the brand-name drug is given by total demand minus the sum of demands for generic products:

$$D_b = \lambda \left(1 - \frac{2n}{t} \left(c_b - \frac{1}{n} \sum_{i=1}^n c_g^i \right) \right). \quad (4)$$

Observe that positive demand for the generic firm i in the *brand biased* segment requires that the copayment for the generic drug is strictly lower than the copayment of the brand-name drug, otherwise all *brand biased* consumers prefer to buy the brand-name drug. However, the difference in copayments cannot be too large, i.e., $(c_b - c_g^i) < t/2n$, otherwise no consumer is willing to buy the brand-name drug. This condition will always be satisfied in the equilibria we are considering.

All producers (including the brand-name producer) are assumed to have constant and identical marginal costs of production, which we set to zero without loss of generality. The profit

¹⁰Technically, for this to be the location of the indifferent *brand biased* consumers, we also need $(c_b - c_g^i) / t$ to be smaller than $(1/2n) + ((c_g^{i+1} - c_g^i) / 2\tau)$, ensuring that i is the most preferred generic drug of the indifferent consumer. Since we focus on symmetric equilibria, where the most preferred generic drug is the closest one, this condition trivially holds under the assumption of positive sales.

functions of the brand-name producer and generic producer i are then given by

$$\pi_b = p_b D_b, \quad (5)$$

$$\pi_g^i = p_g^i D_g^i - f, \quad (6)$$

where p_b and p_g^i are the prices of the brand-name drug and the generic drug i , respectively.

We consider a two-stage game, where at Stage 1 the patent protection of the brand-name drug expires and n generic producers (simultaneously) decide whether to enter (symmetrically) the market depending on the expected profits relative to the fixed cost. At Stage 2 there is price competition between all firms in the market. The outcome of this price competition depends on the regulatory policies in place. We will consider, and compare, two different reimbursement schemes: coinsurance and reference pricing.¹¹

3 Coinsurance

Suppose that the copayment is a fixed percentage of the price of the demanded product. If we let $\alpha \in (0, 1)$ be the coinsurance rate, the copayments for the brand-name drug and the generic drug i are $c_b = \alpha p_b$ and $c_g^i = \alpha p_g^i$, respectively. With this copayment rule, the profit maximisation problems of the brand-name producer and the generic producer i , at the second stage of the game, are given by, respectively,

$$\max_{p_b} \pi_b = p_b \lambda \left(1 - \frac{2n\alpha}{t} \left(p_b - \frac{1}{n} \sum_{i=1}^n p_g^i \right) \right), \quad (7)$$

$$\max_{p_g^i} \pi_g^i = p_g^i \left(\frac{2\lambda\alpha}{t} (p_b - p_g^i) + (1 - \lambda) \left(\frac{1}{n} + \frac{\alpha}{2t} (p_g^{i+1} + p_g^{i-1} - 2p_g^i) \right) \right). \quad (8)$$

The first-order conditions of the profit-maximisation problems defined above are given by

$$\frac{\partial \pi_b}{\partial p_b} = \lambda \left(1 - \frac{2\alpha n}{t} \left(2p_b - \frac{1}{n} \sum_{i=1}^n p_g^i \right) \right) = 0, \quad (9)$$

¹¹Following the standard practice in the literature, we use the term *coinsurance* to designate a reimbursement scheme based on fixed percentage reimbursement.

$$\frac{\partial \pi_g^i}{\partial p_g^i} = \frac{2\lambda\alpha}{t} (p_b - 2p_g^i) + (1 - \lambda) \left(\frac{1}{n} + \frac{\alpha}{2t} (p_g^{i+1} + p_g^{i-1}) - \frac{2\alpha}{t} p_g^i \right) = 0, \quad i = 1, \dots, n. \quad (10)$$

Applying symmetry ($p_g^i = p_g$ for all $i = 1, \dots, n$), the candidate equilibrium prices are given by

$$p_b^*(n) = \frac{(3 + \lambda)t}{4n\alpha(1 + 2\lambda)} \quad (11)$$

$$p_g^*(n) = \frac{(2 - \lambda)t}{2n\alpha(1 + 2\lambda)} \quad (12)$$

As expected, a higher number of generic firms will lead to lower prices of all drugs in the market.

The following Lemma defines the condition for the existence of this equilibrium:¹²

Lemma 1 *Under coinsurance, the unique Nash equilibrium in the price game, for a given number of firms, is given by (11)-(12), if $\lambda > 0.84216$.*

Notice that equilibrium existence requires that the share of *brand biased* consumers is sufficiently large. Otherwise, there will be an incentive for the brand-name producer to deviate unilaterally from its candidate equilibrium strategy by setting the price equal to (or slightly below) the generics price and capture all demand from both segments.

Assuming that the condition stated in Lemma 1 is satisfied, the demand (and market share) of the brand-name drug is given by

$$D_b(p_b^*(n), p_g^*(n)) = \frac{\lambda(3 + \lambda)}{2(1 + 2\lambda)}. \quad (13)$$

A noteworthy feature of the equilibrium under coinsurance is that the brand-name market share does not depend on the number of generic competitors. In this equilibrium, generic entry will reduce brand-name and generic drug prices (and therefore copayments) proportionally, leaving the brand-name market share unchanged.

The equilibrium profits of the two types of drug suppliers are given by

$$\pi_b(p_b^*(n), p_g^*(n)) = \frac{\lambda(3 + \lambda)^2 t}{8\alpha n(1 + 2\lambda)^2}, \quad (14)$$

¹²All proofs are in Appendix.

$$\pi_g(p_b^*(n), p_g^*(n)) = \frac{(1+\lambda)(2-\lambda)^2 t}{4\alpha n^2(1+2\lambda)^2} - f. \quad (15)$$

In a free-entry equilibrium (i.e., the subgame perfect Nash equilibrium of the full game), the equilibrium number of generic producers, n^* , is the highest integer number that satisfies the following weak inequality,

$$\frac{(1+\lambda)(2-\lambda)^2 t}{4\alpha(n^*)^2(1+2\lambda)^2} - f \geq 0. \quad (16)$$

4 Reference pricing

Suppose now that the reimbursement scheme is based on reference pricing. Let the reference price set by the regulator, which defines the maximum reimbursement, be given by r . Assuming that r lies somewhere between the prices of brand-name and generic drugs, which is the most frequently observed case, this reimbursement scheme implies that the patient copayments for the brand-name drug and for generic drug i , respectively, are given by

$$c_b = \alpha r + p_b - r \quad (17)$$

and

$$c_g^i = \alpha p_g^i. \quad (18)$$

Applying the terminology of Brekke et al. (2011), we will distinguish between two different cases: (i) *exogenous reference pricing*, where r does not depend on actual drug prices, and (ii) *endogenous reference pricing*, where r is endogenously determined as a function of the prices chosen by the drug suppliers. Although most countries that use reference pricing practice some form of endogenous RP, the case of exogenous reference pricing is arguably the best approximation to reimbursement schemes where the reference price is not frequently updated or where updates are not based on predefined rules.

4.1 Exogenous reference pricing

Applying the copayment rules given by (17)-(18), the profit maximisation problems of the brand-name producer and the generic producer i , at the second stage of the game, are given by,

respectively,

$$\max_{p_b} \pi_b = p_b \lambda \left(1 - \frac{2n}{t} \left(\alpha r + p_b - r - \frac{\alpha}{n} \sum_{i=1}^n p_g^i \right) \right), \quad (19)$$

$$\max_{p_g^i} \pi_g^i = p_g^i \left(\frac{2\lambda}{t} (\alpha r + p_b - r - \alpha p_g^i) + (1 - \lambda) \left(\frac{1}{n} + \frac{\alpha (p_g^{i+1} + p_g^{i-1} - 2p_g^i)}{2t} \right) \right). \quad (20)$$

We will here look for a Nash equilibrium in the price game that implies an interior solution, with $p_g^i < r < p_b$. Assuming an interior solution, the first-order conditions of the profit-maximisation problems defined above are given by

$$\frac{\partial \pi_b}{\partial p_b} = \lambda \left(1 - \frac{2n}{t} \left(2p_b - (1 - \alpha) r - \frac{\alpha}{n} \sum_{i=1}^n p_g^i \right) \right) = 0, \quad (21)$$

$$\frac{\partial \pi_g^i}{\partial p_g^i} = \frac{2\lambda}{t} (p_b - (1 - \alpha) r - 2\alpha p_g^i) + (1 - \lambda) \left(\frac{1}{n} + \frac{\alpha}{2t} (p_g^{i+1} + p_g^{i-1}) - \frac{2\alpha}{t} p_g^i \right) = 0, \quad i = 1, \dots, n. \quad (22)$$

Applying symmetry ($p_g^i = p_g$ for all $i = 1, \dots, n$) and simultaneously solving (21)-(22), the equilibrium candidate prices are

$$p_b^*(r, n) = \frac{(3 + \lambda) t + 2(1 + \lambda)(1 - \alpha) nr}{4n(1 + 2\lambda)}, \quad (23)$$

$$p_g^*(r, n) = \frac{(2 - \lambda) t - 2\lambda(1 - \alpha) nr}{2\alpha n(1 + 2\lambda)}. \quad (24)$$

As for the case of drug reimbursement based on coinsurance, drug prices are monotonically decreasing in the number of generic firms. It is worth noticing, though, that changes in the reference price, r , have opposite effects on brand-name and generic drug prices. As long as the reference price lies between generic and brand-name prices, a reduction in the reference price makes the brand-name drug relatively more expensive for consumers, which, all else equal, shifts demand from brand-name to generic drugs. The optimal response from a generic (brand-name) producer is therefore to increase (reduce) its price. The exact conditions for these prices to constitute a Nash equilibrium in the price game are given by the following Lemma:

Lemma 2 *Under exogenous reference pricing, the unique Nash equilibrium in the price game, for a given number of firms, is an interior solution given by (23)-(24), if the following conditions*

are satisfied: (i) $\underline{r} < r < \bar{r}$, where $\underline{r} := \frac{(2-\lambda)t}{2((1+\lambda)\alpha+\lambda)n}$ and $\bar{r} := \frac{(3+\lambda)t}{2((1+\lambda)\alpha+1+3\lambda)n}$; (ii) $\lambda > \max\left(\frac{2-\alpha}{2+\alpha}, \tilde{\lambda}\right)$, where $\tilde{\lambda}$ is strictly less than one.

Assuming that these conditions are satisfied, the brand-name market share and the profits of both types of drug producers are, in equilibrium, given by

$$D_b(p_b^*(r, n), p_g^*(r, n)) = \frac{\lambda((3+\lambda)t + 2(1+\lambda)(1-\alpha)nr)}{2(1+2\lambda)t} \quad (25)$$

and

$$\pi_b(p_b^*(r, n), p_g^*(r, n)) = \frac{\lambda((3+\lambda)t + 2(1+\lambda)(1-\alpha)nr)^2}{8t(1+2\lambda)^2n}, \quad (26)$$

$$\pi_g(p_b^*(r, n), p_g^*(r, n)) = \frac{(1+\lambda)((2-\lambda)t - 2\lambda(1-\alpha)nr)^2}{4(1+2\lambda)^2\alpha tn^2} - f. \quad (27)$$

Notice that changes in the reference price affect equilibrium profits in a way that corresponds to the equilibrium price responses. For a given number of firms, a lower reference price benefits generic producers at the expense of the brand-name producer. Since $\pi_g(p_b^*(r, n), p_g^*(r, n))$ is monotonically decreasing in n , the number of generic producers in a free-entry equilibrium, n^* , is given by the highest integer number that satisfies the following weak inequality,

$$\frac{(1+\lambda)((2-\lambda)t - 2\lambda(1-\alpha)n^*r)^2}{4(1+2\lambda)^2\alpha t(n^*)^2} - f \geq 0, \quad (28)$$

and that simultaneously satisfies the conditions in Lemma 2.

4.2 Endogenous reference pricing

Under endogenous reference pricing systems, the reference price is calculated as a function of one or more drug prices in the market. A formulation that is sufficiently general to capture several realistic possibilities is

$$r = (1-\beta)p_b + \frac{\beta}{n} \sum_{i=1}^n p_g^i, \quad (29)$$

where the reference price is a linear combination of the brand-name drug price and the average price of all generic drugs. A higher value of $\beta \in (0, 1)$ implies that cheaper drugs are given larger weights when calculating the reference price. In a symmetric equilibrium, $\beta = 1$ implies that

the reference price is equal to the lowest price in the market.

Applying the copayment rules given by (17)-(18), and where r is given by (29), the profit maximisation problems of the brand-name producer and the generic producer i , at the second stage of the game, are given by, respectively,

$$\max_{p_b} \pi_b = p_b \lambda \left(1 - \frac{2n\theta}{t} \left(p_b - \frac{1}{n} \sum_{i=1}^n p_g^i \right) \right), \quad (30)$$

$$\max_{p_g^i} \pi_g^i = p_g^i \left(\lambda \left(\frac{2}{t} \left(\theta p_b - \frac{(1-\alpha)\beta}{n} \sum_{i=1}^n p_g^i - \alpha p_g^i \right) \right) + (1-\lambda) \left(\frac{1}{n} + \frac{\alpha(p_g^{i+1} + p_g^{i-1} - 2p_g^i)}{2t} \right) \right), \quad (31)$$

where $\theta := \alpha + (1-\alpha)\beta \in (0,1)$. The first-order conditions of these profit maximisation problems are

$$\frac{\partial \pi_b}{\partial p_b} = \lambda \left(1 - \frac{2n\theta}{t} \left(2p_b - \frac{1}{n} \sum_{i=1}^n p_g^i \right) \right) = 0 \quad (32)$$

$$\frac{\partial \pi_g^i}{\partial p_g^i} = \frac{2\lambda}{t} \left(\theta p_b - \frac{(1-\alpha)\beta}{n} \left(2p_g^i + \sum_{j \neq i} p_g^j \right) - 2\alpha p_g^i \right) + (1-\lambda) \left(\frac{1}{n} + \frac{\alpha(p_g^{i+1} + p_g^{i-1} - 4p_g^i)}{2t} \right) = 0 \quad (33)$$

Notice here how the endogeneity of the reference price gives the suppliers of generic drugs incentives to price strategically in order to influence the reference price. By reducing its price, a generics producer will enforce a reduction in the reference price, which makes the brand-name drug more expensive and therefore shifts demand towards generic drugs. This effect, which is captured by the second term in the first parenthesis in (33), is stronger when β is higher or when n is lower (which implies a larger weight on each single generic drug price in the reference price formula). Reference pricing also gives the brand-name producer incentives to reduce its price (second term in (32)), because demand becomes more elastic for prices above r .

Applying symmetry ($p_g^i = p_g$ for all $i = 1, \dots, n$) and simultaneously solving (33)-(32), the equilibrium candidate prices are

$$p_b^*(\beta, n) = \frac{(n\alpha(3+\lambda) + 2\beta(1-\alpha)(n+\lambda))t}{4n\theta(n\alpha(1+2\lambda) + \beta\lambda(1-\alpha)(n+2))}, \quad (34)$$

$$p_g^*(\beta, n) = \frac{(2-\lambda)t}{2(n\alpha(1+2\lambda) + \beta\lambda(1-\alpha)(n+2))}. \quad (35)$$

As for the case of coinsurance or exogenous RP, it is straightforward to confirm that all drug prices are decreasing in n . They are also monotonically decreasing in β . The more weight the prices of generic drugs carry in the reference price formula, the lower are the prices set by all drug suppliers in the market. The condition for these prices to constitute a Nash equilibrium in the price game is given by the following Lemma:

Lemma 3 *Under endogenous reference pricing, the unique Nash equilibrium in the price game, for a given number of firms, is given by (34)-(35), if $\lambda > \bar{\lambda}$, where $\bar{\lambda}$ is strictly less than one.*

Given that this condition is satisfied, the equilibrium brand-name market share is given by

$$D_b(p_b^*(\beta, n), p_g^*(\beta, n)) = \frac{\lambda n\alpha(3 + \lambda) + 2\beta(1 - \alpha)(n + \lambda)}{2n\alpha(1 + 2\lambda) + \beta\lambda(1 - \alpha)(n + 2)}. \quad (36)$$

It is easily confirmed that the brand-name market share is increasing in n . The reason for this perhaps surprising result is related to the fact that changes in n have partly counteracting effects on the pricing incentives of brand-name and generic producers. An increase in n makes the demand for all drug types more elastic, which – all else equal – leads to lower prices. This is the dominant effect for both brand-name and generic drugs. However, an increase in n also has a counteracting effect on the pricing incentives of generics producers. A higher number of generic drugs implies that the price of each of these drugs has a smaller weight in the reference price formula, which reduces the incentive for each generic producer to strategically reduce its price in order to induce a lower reference price. Thus, increased generic competition leads to a larger price reduction for brand-name than for generic producers, to the extent that the equilibrium brand-name market share increases.

The equilibrium profits of both type of drug suppliers are given by

$$\pi_b(p_b^*(\beta, n), p_g^*(\beta, n)) = \frac{\lambda t(n\alpha(3 + \lambda) + 2\beta(1 - \alpha)(n + \lambda))^2}{8n\theta(n\alpha(1 + 2\lambda) + \beta\lambda(1 - \alpha)(n + 2))^2}, \quad (37)$$

$$\pi_g(p_b^*(\beta, n), p_g^*(\beta, n)) = \frac{t(n\alpha(1 + \lambda) + 2\beta\lambda(1 - \alpha))(2 - \lambda)^2}{4n(n\alpha(1 + 2\lambda) + \beta\lambda(1 - \alpha)(n + 2))^2} - f. \quad (38)$$

Since $\pi_g(p_b^*(\beta, n), p_g^*(\beta, n))$ is monotonically decreasing in n , the number of generic producers in a free-entry equilibrium, n^* , is given by the highest integer number that satisfies the

following weak inequality,

$$\frac{t(n^*\alpha(1+\lambda) + 2\beta\lambda(1-\alpha))(2-\lambda)^2}{4n^*(n^*\alpha(1+2\lambda) + \beta\lambda(1-\alpha)(n^*+2))^2} - f \geq 0, \quad (39)$$

and that simultaneously satisfies the condition in Lemma 3.

4.3 Coinsurance versus reference pricing

Let us now compare the two reimbursement systems considered – coinsurance and (exogenous or endogenous) reference pricing – and see how the choice of reimbursement scheme affects equilibrium drug prices and profits for a given number of firms, and how it consequently affects generic entry.

Proposition 1 *Suppose that the conditions given by Lemmas 1-3 are all satisfied. Then, for a given number of firms, the price equilibrium under reference pricing is characterised by lower prices for all drugs and a higher brand-name market share, compared with the price equilibrium under coinsurance. These results hold regardless of whether the reference price is exogenous or endogenous.*

The intuition for the price reducing effect of reference pricing is fairly straightforward. Since reference pricing makes demand for the brand-name drug more price elastic (for prices above the reference price), the brand-name producer will respond by lowering its price. Although reference pricing makes generic drugs relatively cheaper (all else equal), and therefore gives the generic producers an isolated incentive to raise prices, the strategic complementarity of price setting ensures that generic prices also drop.¹³ If the reference price is endogenous, the generic producers also have an extra incentive to reduce prices, since such price reductions will reduce the reference price and therefore make the brand-name drug more expensive for consumers.¹⁴

In many ways, though, the key result in Proposition 1 is not that reference pricing leads to lower prices, which is intuitive and expected, but that the reduction in brand-name prices is

¹³For the case of exogenous reference pricing, notice the difference between switching from coinsurance to reference pricing and changing the reference price within the latter system. Whereas generic prices are lower under reference pricing than under coinsurance for any $r \in (\underline{r}, \bar{r})$, a reduction in r under an exogenous reference pricing system leads to an increase in generic drug prices, as discussed in Section 4.1.

¹⁴Notice that the results in Proposition 1 hold for all values of λ that ensure equilibrium existence. Thus, our results do not depend crucially on the presence of a brand neutral consumer segment.

proportionally larger than the reduction in generic prices, implying that the market share of the brand-name drug increases. When reference pricing (whether endogenous or exogenous) leads to a reduction in both price and demand for generic producers, the implications for generic entry follow directly:

Corollary 1 *Suppose that the conditions given by Lemmas 1-3 are all satisfied. Then, in a free entry equilibrium, the number of generic drugs is (weakly) higher under coinsurance than under (exogenous or endogenous) reference pricing.*

In some sense, this result might be seen as counterintuitive, since reference pricing is a reimbursement scheme designed to give generic producers a competitive advantage vis-à-vis brand-name producers. Indeed, for given drug prices, a switch from coinsurance to reference pricing will shift demand towards generic drugs and therefore benefit generic producers. However, as Proposition 1 shows, such a switch will also trigger price responses such that the generic producers end up with lower profits. Thus, a switch from coinsurance to reference pricing will lead to fewer generic drugs in a free entry equilibrium.

4.4 Can reference pricing be counterproductive?

When taking into account the effect on generic entry, the intended cost-containing effect of reference pricing is no longer obvious. On the one hand, reference pricing leads to lower prices for all existing drugs in the market. On the other hand, the above analysis also shows that reference pricing can drive out generic competition (measured by the number of generic drugs), which – all else equal – leads to higher prices. If the latter effect dominates the former, reference pricing will actually be counterproductive, in the sense that reference pricing will increase total drug expenditures.

In our model it is not analytically feasible to give a precise characterisation of the required conditions for reference pricing to be counterproductive or not. However, we have constructed a numerical example (in Table 1) in order to show that a cost increasing effect of reference pricing

is at least a theoretical possibility.

Table 1: Endogenous reference pricing and generic entry

	Coinsurance	Endogenous reference pricing
	$\alpha = 0.4$	$\alpha = 0.4, \beta = 0.5$
n^*	5	3
p_b	0.348	0.355
p_g	0.196	0.234
D_b	0.627	0.671
p_{av}	0.292	0.315
Parameter values: $\lambda = 0.9, t = 2, f = 0.0146$		

In this example, endogenous reference pricing leads to higher prices for all drugs (compared to coinsurance) in the free entry equilibrium. Moreover, under reference pricing a larger share of consumers choose the most expensive drug. Consequently, the equilibrium under reference pricing is characterised by a higher average drug price and therefore higher total drug expenditures. The reason is that only three generic firms find it profitable to enter the market under reference pricing, whereas five generic firms can profitably survive under coinsurance.

5 Price cap regulation

In the above analysis we have assumed that only the reimbursement scheme is subject to regulation (coinsurance versus endogenous or exogenous reference pricing), whereas the drug producers can freely set prices. However, in many countries drug pricing is subject to price cap regulation, which is also often combined with reference pricing. The presence of price cap regulation can potentially change the effect of reference pricing on generic entry, as we will explore in this section where we assume that the drug producers are not allowed to set prices in excess of \bar{p} . We also assume that this price cap binds for the brand-name producer in the Nash equilibrium under coinsurance.¹⁵

¹⁵If the price cap does not bind under coinsurance, it will not bind under reference pricing either, which implies that price cap regulation is irrelevant for any decisions taken by the firms, including the decision of generic producers to enter or exit the market.

With a binding price cap, the Nash equilibrium in the price game (under coinsurance) is then a corner solution with the following prices:

$$p_b = \bar{p}, \quad (40)$$

$$p_g^*(\bar{p}, n) = \frac{(1 - \lambda)t + 2n\alpha\lambda\bar{p}}{n\alpha(1 + 3\lambda)}, \quad (41)$$

where the candidate equilibrium price p_g is found by inserting $p_b = \bar{p}$ into (10), applying symmetry, and solving for p_g . The following Lemma states the condition for equilibrium existence:

Lemma 4 *Under coinsurance, the unique Nash equilibrium in the price game for a given number of firms is a corner solution, given by (40)-(41), if the following conditions are satisfied: (i) $\frac{(1-\lambda)t}{\alpha n(1+\lambda)} < \bar{p} < \frac{(3+\lambda)t}{4n\alpha(1+2\lambda)}$; (ii) $\lambda > \max\left(\frac{1}{3}, \hat{\lambda}\right)$, where $\hat{\lambda}$ is strictly less than one.*

Notice that the lower bound on \bar{p} is necessary to ensure that all firms are active in equilibrium (which requires that the the generic producers price their drugs below the regulated price cap).

Assuming that the conditions in Lemma 4 are satisfied, the brand-name market share and the profits of both types of drug producers are, in equilibrium, given by

$$D_b(\bar{p}, p_g^*(\bar{p}, n)) = \frac{\lambda((3 + \lambda)t - 2(1 + \lambda)n\alpha\bar{p})}{(1 + 3\lambda)t} \quad (42)$$

and

$$\pi_b(\bar{p}, p_g^*(\bar{p}, n)) = \frac{\lambda((3 + \lambda)t - 2(1 + \lambda)n\alpha\bar{p})\bar{p}}{(1 + 3\lambda)t}, \quad (43)$$

$$\pi_g(\bar{p}, p_g^*(\bar{p}, n)) = \frac{(1 + \lambda)(t(1 - \lambda) + 2n\alpha\lambda\bar{p})^2}{(1 + 3\lambda)^2 n^2 \alpha t} - f. \quad (44)$$

In contrast to the case of an interior solution, as long as the price cap is binding for the brand-name producer, generic entry will reduce generic drug prices without affecting the brand-name drug price, thus reducing the market share of the brand-name producer. Nevertheless, it is straightforward to verify that $\pi_g(\bar{p}, p_g^*(\bar{p}, n))$ is monotonically decreasing in n . Thus, in a free-entry equilibrium, the equilibrium number of generic producers, n^* , is given by the highest

integer number satisfying the weak inequality

$$\frac{(1 + \lambda) (t(1 - \lambda) + 2n^* \alpha \lambda \bar{p})^2}{(1 + 3\lambda)^2 (n^*)^2 \alpha t} - f \geq 0, \quad (45)$$

while simultaneously satisfying the conditions given in Lemma 4.

Let us now compare this equilibrium with the equilibrium under exogenous reference pricing.¹⁶ If the price cap binds also in the reference pricing equilibrium (i.e., the equilibrium is characterised by $p_g^* < r < p_b^* = \bar{p}$), then reference pricing has no effect on the brand-name price and therefore does not stimulate price competition between brand-name and generic drugs. In this case the only effect of reference pricing is the positive demand effect for generics, since reference pricing makes the brand-name drug more expensive. Consequently, reference pricing will unambiguously stimulate generic entry.

On the other hand, if the price cap does not bind in the reference pricing equilibrium (i.e., the equilibrium is characterised by $p_g^* < r < p_b^* < \bar{p}$), the conditions for such an equilibrium to exist are given by Lemma 2. A comparison between coinsurance and exogenous reference pricing under price cap regulation yields the following results:

Proposition 2 *Suppose that the conditions given by Lemma 2 and Lemma 4 are all satisfied. Then, for a given number of firms, brand-name drug prices are always lower under exogenous reference pricing than under coinsurance, whereas generic drug prices are lower (higher) and brand-name market shares are higher (lower) under exogenous reference pricing if $\bar{p} > (<) \hat{p}$, where $\hat{p} := \frac{(3+\lambda)t-2(1-\alpha)(1+3\lambda)nr}{4(1+2\lambda)n\alpha}$.*

We see that the previous results (given by Proposition 1) holds only if the price cap is sufficiently large ($\bar{p} > \hat{p}$). If the price cap binds to a sufficiently strong degree ($\bar{p} < \hat{p}$), the price difference between brand-name and generic drugs is relatively small under coinsurance, and the brand-name market share is larger than it would have been with a less binding price cap. In this case, the brand-name price reduction in response to a switch from coinsurance to reference pricing is relatively small (zero if the price cap binds in both equilibria) and the generic producers' incentive to increase prices under reference pricing dominates the strategic

¹⁶Similar results would obtain if we instead consider endogenous reference pricing.

complementarity effect, leading to both higher prices and higher market shares for the generic producers. The implications for generic entry follow immediately:

Corollary 2 *Suppose that the conditions given by Lemma 2 and Lemma 4 are all satisfied. Then, in a free entry equilibrium, the number of generic drugs is (weakly) higher under exogenous reference pricing than under coinsurance if $\bar{p} < \hat{p}$.*

As previously stated, there are two counteracting effects of reference pricing on the profits of generic sales, and therefore on the incentives for generic entry. For given prices, reference pricing makes the brand-name drug more expensive for consumers, which shifts demand towards generic drugs. However, this effect is counteracted by the negative price response of the brand-name producer. For reference pricing to stimulate generic entry, the second (price) effect therefore needs to be sufficiently small relative to the first (demand) effect. In our model this happens if price cap regulation is sufficiently strict.

Even in the more general case where reference pricing has both a demand effect and a price competition effect, Proposition 2 suggests that the potential for reference pricing to stimulate generic entry relies crucially on how the introduction of reference pricing affects market shares for the existing drugs in the market:

Corollary 3 *Suppose that the conditions given by Lemma 2 and Lemma 4 are all satisfied. Switching from coinsurance to reference pricing can then lead to generic entry if and only if it increases the market share of the existing generic producers in the market.*

Since, in equilibrium, all drug prices are monotonically decreasing in the number of generic producers, initial price reductions caused by the introduction of reference pricing might be counteracted (reinforced) by exit (entry) of generics producers. It is perhaps instructive to consider a numerical example in order to see the mechanisms at play.

Table 2: RP and generic entry under price cap regulation

	Coinsurance		Reference pricing
	(1) $\bar{p} = 0.3$	(2) $\bar{p} = 0.35$	$r = 0.25$
n^*	2	4	3
p_b	0.3	0.35	0.283
p_g	0.214	0.204	0.207
D_b	0.838	0.690	0.764
p_{av}	0.286	0.305	0.265
Parameter values: $\alpha = 0.4, \lambda = 0.9, t = 2, f = 0.015$			

In Table 2 we consider two different scenarios under coinsurance. In both scenarios the free-entry equilibrium is a corner solution, but in Scenario 2 ($\bar{p} > \hat{p}$) the price cap is less binding than in Scenario 1 ($\bar{p} < \hat{p}$). Notice first that, under coinsurance, stricter price cap regulation drives out generic competition (the equilibrium number of generic firms is two in Scenario 1 and four in Scenario 2). The brand-name market share is consequently much higher in the scenario with the lower price cap, for two different reasons: there is less competition from generic firms and the branded-generic price difference is lower. Thus, in Scenario 1 the introduction of reference pricing leads to only a small drop in the brand-name price. This makes generic entry profitable and the equilibrium number of generic firms increases from two to three. From Proposition 2 and Corollary 2 we know that if reference pricing increases incentives for generic entry, it leads to higher generic drug prices in the absence of new entrants. In the numerical example in Table 2 we see that this effect is more than outweighed by increased competition from the new entrant, implying that reference pricing leads to lower generic prices in the free-entry equilibrium. As expected, the brand-name market share also goes down.

On the other hand, in Scenario 2, where the price cap is less binding in equilibrium under coinsurance, and where there is consequently room for four generic drugs, the introduction of reference pricing leads to a much larger drop in the brand-name drug price, with a corresponding reduction in generic drug prices. This makes the existing market structure unsustainable and the number of generics producers is reduced from four to three in the free-entry equilibrium. Exit of one generic drug reduces the degree of competition in the market and partly counteracts

the initial reduction in prices. However, despite an increase in generic prices, and despite the fact that a larger fraction of consumers buy the more expensive (brand-name) drug after the introduction of reference pricing, the average price in the market (p_{av}) nevertheless drops, mainly because of the relatively large drop in the brand-name price.

6 Conclusion

Since reference pricing is a widespread regulatory mechanism in pharmaceutical markets, determining its effect on prices is crucial. Many studies have addressed this issue – theoretically and empirically. However, to the best of our knowledge, these studies, by taking the number of generics as given, ignore the effect of reference pricing on generic entry. This is a serious limitation of the existing literature, since any effect on entry would reflect indirectly on prices and pharmaceutical expenditures.

This paper is an attempt to provide a theoretical framework to study the impact of reference pricing on entry and, ultimately, its overall effect on drug prices. We develop a Salop-type model that allows us to study generic entry. In a nutshell, we show that reference pricing always discourages entry, and can thus drive up equilibrium drug prices. Such a result is very robust to alternative specifications of the demand function, and to alternative formulas defining the reference price. The main intuition for this result is that brand-name firms respond very aggressively to the introduction of reference pricing, and they always increase their market shares through price reductions.

This general result is mitigated if other forms of regulation are present on the market. If prices are also subject to caps, then the effect of reference pricing on generic entry may be positive. Intuitively, if the price of the brand-name firm is constrained by the cap, the introduction of reference pricing leads to a relatively small price response. Thus, whereas either price cap regulation or reference pricing in isolation discourages generic entry, one of these regulatory schemes (reference pricing) can – perhaps paradoxically – serve to counteract the negative effect of the other (price cap regulation) on generic entry.

Our model provides a framework to evaluate the impact of reference pricing in different markets. The overall effect on prices is ambiguous and is ultimately an empirical question. The

main empirical predictions of the model are that, (i) without price caps, generic entry should be discouraged by the introduction of reference pricing and (ii) if price caps are present, the introduction of reference pricing may encourage entry if price caps are sufficiently binding.

Appendix: Proofs

Proof of Lemma 1 Equilibrium existence requires that the brand-name firm has no incentive to deviate by setting $p_b = p_g^*(n)$ and capture the whole market. Since total demand is equal to one, this would give a profit of $\pi_b = p_g^*(n)$. Such a deviation is not profitable if

$$\pi_b(p_b^*(n), p_g^*(n)) - p_g^*(n) = \frac{(\lambda(14\lambda + \lambda^2 - 3) - 8)t}{8n\alpha(1 + 2\lambda)^2} > 0,$$

which holds for $\lambda > 0.84216$. *Q.E.D.*

Proof of Lemma 2 Condition (i): The upper and lower bounds on r are determined by straightforward comparisons of r with $p_b^*(r, n)$ and $p_g^*(r, n)$, applying the equilibrium condition $p_g^*(r, n) < r < p_b^*(r, n)$. Condition (ii): Two lower bounds on λ are needed. The first one ensures that the interval of r established in the first part of the Lemma is non-empty:

$$\bar{r} - \underline{r} = \frac{(1 + 2\lambda)((1 + \lambda)\alpha - 2(1 - \lambda))t}{2n((1 + \alpha)\lambda + \alpha)(1 + 3\lambda + \alpha(1 + \lambda))} > 0 \quad \text{if} \quad \lambda > \frac{2 - \alpha}{2 + \alpha}.$$

The other lower bound on λ is necessary to rule out the possibility of profitable deviations by the brand-name firm. This firm can capture the entire market and obtain a profit $p_g^*(r, n)$ by setting the price $p_b = p_g^*(r, n)$. Such a deviation is not profitable if:

$$\begin{aligned} & \pi_b(p_b^*(r, n), p_g^*(r, n)) - p_g^*(r, n) \\ &= \frac{\left[\begin{aligned} & 4nr\lambda(1 - \alpha) \left(\begin{aligned} & t(2 + 4\lambda(1 + \alpha) + \alpha(3 + \lambda^2)) \\ & + nr\alpha(1 + \lambda)^2(1 - \alpha) \end{aligned} \right) \\ & + t^2 \left(\begin{aligned} & \lambda((3 + \lambda)^2\alpha - 12) \\ & - 8(1 - \lambda)(1 + \lambda) \end{aligned} \right) \end{aligned} \right]}{8nt\alpha(1 + 2\lambda)^2} > 0. \end{aligned}$$

The numerator is monotonically increasing in r . By setting r at the lower bound, $r = \underline{r}$, the condition reduces to

$$\alpha^2\lambda(1 + \lambda)^2 - (1 - \lambda)(8\alpha(1 + \lambda) + 4\lambda) > 0.$$

It is straightforward to verify that the expression on the left-hand side of this inequality is monotonically increasing in λ for $\lambda > \frac{2-\alpha}{2+\alpha}$. Thus, since the expression is strictly positive for $\lambda \rightarrow 1$, the condition must hold for any $\lambda > \tilde{\lambda}$, where $\tilde{\lambda}$ is strictly less than 1. *Q.E.D.*

Proof of Lemma 3 Equilibrium existence requires that it is not profitable for the brand-name producer to deviate by setting $p_b = p_g^*(\beta, n)$, get all demand (which is equal to one) and earn a profit of $p_g^*(\beta, n)$. Such a deviation is not profitable if

$$\pi_b(p_b^*(\beta, n), p_g^*(\beta, n)) - p_g^*(\beta, n) = t \frac{n^2 \alpha^2 (14\lambda^2 + \lambda^3 - 3\lambda - 8) + 4\beta(1-\alpha)\Phi}{8n\theta(n\alpha(1+2\lambda) + \beta\lambda(1-\alpha)(n+2))^2} > 0, \quad (\text{A1})$$

where

$$\begin{aligned} \Phi : &= \beta\lambda^3 - 2n^2\alpha - \alpha\beta\lambda^3 + 4n^2\alpha\lambda^2 + n^2\beta\lambda^2 - 4n\alpha\lambda - 4n\beta\lambda + 5n\alpha\lambda^2 \\ &\quad - 2n^2\alpha\lambda + n\alpha\lambda^3 + 4n\beta\lambda^2 - n^2\beta\lambda - 4n\alpha\beta\lambda^2 + n^2\alpha\beta\lambda - n^2\alpha\beta\lambda^2 + 4n\alpha\beta\lambda. \end{aligned}$$

The sign of (A1) is determined by the sign of the numerator, which we will denote by Ω .

First,

$$\frac{\partial^2 \Omega}{\partial \lambda^2} = 2 \left(\begin{array}{c} n^2 \alpha^2 (14 + 3\lambda) + 4n^2 \beta^2 (1 - \alpha)^2 + 20n\alpha\beta(1 - \alpha) \\ + 4\beta(1 - \alpha)(4n + 3\lambda)(\beta + n\alpha - \alpha\beta) \end{array} \right) > 0,$$

which confirms that Ω is convex in λ . Furthermore,

$$\lim_{\lambda \rightarrow 1} \frac{\partial \Omega}{\partial \lambda} = 4 \left(\begin{array}{c} 7n^2 \alpha^2 + n\beta^2 (1 - \alpha)^2 (n + 4) \\ + 9n\alpha\beta(1 - \alpha) + 3\beta(1 - \alpha)(\beta - \alpha\beta + 2n^2\alpha) \end{array} \right) > 0,$$

$$\lim_{\lambda \rightarrow 1} \Omega = 4(\beta + n\alpha - \alpha\beta)^2 > 0,$$

and

$$\lim_{\lambda \rightarrow 0} \Omega = -8n^2\alpha\theta < 0,$$

which confirms the existence of a threshold value $\bar{\lambda}$, which is strictly below one, such that Ω , and therefore $\pi_b(p_b^*(\beta, n), p_g^*(\beta, n)) - p_g^*(\beta, n)$, is positive (negative) if $\lambda > (<) \bar{\lambda}$. *Q.E.D.*

Proof of Proposition 1 (i) *Exogenous reference pricing versus coinsurance*: Comparing (23)

and (11), the change in the equilibrium brand-name price is

$$p_b^*(r, n) - p_b^*(n) = -\frac{(1-\alpha)((3+\lambda)t - 2\alpha(1+\lambda)nr)}{4n\alpha(2\lambda+1)} < 0 \quad \text{for } r < \bar{r}.$$

Comparing (24) and (12), the change in the equilibrium generic price is

$$p_g^*(r, n) - p_g^*(n) = -\frac{\lambda(1-\alpha)r}{\alpha(2\lambda+1)} < 0.$$

Comparing (25) and (13), the change in the equilibrium brand-name market share is

$$D_b(p_b^*(r, n), p_g^*(r, n)) - D_b(p_b^*(n), p_g^*(n)) = \frac{\lambda(1+\lambda)(1-\alpha)nr}{t(1+2\lambda)} > 0.$$

(ii) *Endogenous reference pricing versus coinsurance*: Since all equilibrium variables under endogenous RP are monotonic in β , and since the equilibria under endogenous reference pricing and coinsurance coincide for $\beta = 0$, we can compare the equilibrium outcomes by doing comparative statics on β in the reference pricing equilibrium. From (34), (35) and (36), we have

$$\frac{\partial p_b^*(\beta, n)}{\partial \beta} = -t(1-\alpha) \frac{\left[\begin{array}{c} n\alpha^2(n+4\lambda+6n\lambda-2\lambda^2+3n\lambda^2) \\ +2\beta\lambda(1-\alpha)(n+2)(\beta(1-\alpha)(n+\lambda)+n\alpha(3+\lambda)) \end{array} \right]}{4n\theta^2(n\alpha(1+2\lambda)+\beta\lambda(1-\alpha)(n+2))^2} < 0,$$

$$\frac{\partial p_g^*(\beta, n)}{\partial \beta} = -\frac{t\lambda(1-\alpha)(2-\lambda)(2+n)}{2(n\alpha(1+2\lambda)+\beta\lambda(1-\alpha)(n+2))^2} < 0,$$

$$\frac{\partial D_b(p_b^*(\beta, n), p_g^*(\beta, n))}{\partial \beta} = \frac{n\alpha\lambda(1-\alpha)(2-\lambda)(n(1+\lambda)-2\lambda)}{2(n\alpha(1+2\lambda)+\beta\lambda(1-\alpha)(n+2))^2} > 0.$$

Q.E.D.

Proof of Lemma 4 Part (i): Given the equilibrium prices in the absence of price regulation,

(11)-(12), the upper bound on \bar{p} is trivial. The lower bound on \bar{p} is determined by the condition that the price cap does not bind for the generics producers in equilibrium:

$\bar{p} > p_g^*(\bar{p}, n)$ if $\bar{p} > \frac{(1-\lambda)t}{\alpha n(1+\lambda)}$. Part (ii): Two lower bounds on λ are needed for equilibrium

existence. The first is needed to ensure that the interval of \bar{p} defined in the first part of the Lemma is non-empty:

$$\frac{(3 + \lambda)t}{4n\alpha(1 + 2\lambda)} - \frac{(1 - \lambda)t}{\alpha n(1 + \lambda)} = \frac{(3\lambda - 1)(1 + 3\lambda)t}{4(1 + \lambda)(1 + 2\lambda)\alpha n} > 0 \quad \text{if } \lambda > \frac{1}{3}.$$

In addition, equilibrium existence requires that it is not profitable for the brand-name producer to deviate by setting $p_b = p_g^*(\bar{p}, n)$, capturing the whole market, and obtaining a profit $p_g^*(\bar{p}, n)$. Such a deviation is not profitable if

$$\pi_b(\bar{p}, p_g^*(\bar{p}, n)) - p_g^*(\bar{p}, n) = \frac{\lambda(1 + \lambda)n\alpha\bar{p}(t - 2n\alpha\bar{p}) - (1 - \lambda)t^2}{nt\alpha(1 + 3\lambda)} > 0.$$

This condition holds if the numerator is positive. Using the conditions $\bar{p} < \frac{(3+\lambda)t}{4n\alpha(1+2\lambda)}$ and $\lambda > \frac{1}{3}$, it is straightforward to verify that $t - 2n\alpha\bar{p} > 0$, which implies that the numerator is monotonically increasing in λ . Since the numerator is strictly positive for $\lambda \rightarrow 1$, it follows that the condition holds if $\lambda > \hat{\lambda}$, where $\hat{\lambda}$ is strictly less than 1. *Q.E.D.*

Proof of Proposition 2 The effects of reference pricing on prices and market shares when the price cap binds in both equilibria are trivial. For the case of an interior solution in the reference pricing equilibrium, the change in the equilibrium brand-name price is negative by construction of the equilibrium ($p_b^*(r, n) < \bar{p}$). Comparing (24) and (41), the change in the equilibrium generic price is

$$\begin{aligned} & p_g^*(r, n) - p_g^*(\bar{p}, n) \\ &= \lambda \frac{(3 + \lambda)t - (2(1 + 3\lambda)(1 - \alpha)nr + 4(1 + 2\lambda)\alpha n\bar{p})}{2(1 + 2\lambda)(1 + 3\lambda)\alpha n} \\ &< (>) 0 \quad \text{if } \bar{p} > (<) \hat{p}, \end{aligned}$$

where

$$\hat{p} := \frac{(3 + \lambda)t - 2(1 - \alpha)(1 + 3\lambda)nr}{4(1 + 2\lambda)n\alpha}.$$

Comparing (25) and (42), the change in the equilibrium brand-name market share is

$$\begin{aligned}
& D_b(p_b^*(r, n), p_g^*(r, n)) - D_b(\bar{p}, p_g^*(\bar{p}, n)) \\
&= -\frac{\lambda(1+\lambda)(t(3+\lambda) - 2(1+3\lambda)(1-\alpha)nr - 4(1+2\lambda)n\alpha\bar{p})}{2t(1+2\lambda)(1+3\lambda)} \\
&< (>) 0 \quad \text{if } \bar{p} < (>) \hat{p}.
\end{aligned}$$

In order to make the comparison between the two equilibria meaningful, we also need to ensure that the intersection of the parameter sets that define equilibrium existence is non-empty. Since a non-binding price cap in the reference pricing equilibrium requires

$$\bar{p} > \frac{(3+\lambda)t + 2(1+\lambda)(1-\alpha)nr}{4n(1+2\lambda)},$$

we need to ensure that the parameter set defined by

$$\max\left(\frac{(1-\lambda)t}{\alpha n(1+\lambda)}, \frac{(3+\lambda)t + 2(1+\lambda)(1-\alpha)nr}{4n(1+2\lambda)}\right) < \bar{p} < \frac{(3+\lambda)t}{4n\alpha(1+2\lambda)} \quad (\text{A2})$$

is non-empty. From Lemma 2 we know that $\frac{(3+\lambda)t}{4n\alpha(1+2\lambda)} > \frac{(1-\lambda)t}{\alpha n(1+\lambda)}$ if $\lambda > \frac{1}{3}$. It remains to show that

$$\begin{aligned}
& \frac{(3+\lambda)t}{4n\alpha(1+2\lambda)} - \frac{(3+\lambda)t + 2(1+\lambda)(1-\alpha)nr}{4n(1+2\lambda)} \\
&= \frac{(1-\alpha)(t(3+\lambda) - 2\alpha(1+\lambda)nr)}{4(1+2\lambda)\alpha n} > 0.
\end{aligned}$$

Since $t(3+\lambda) - 2\alpha(1+\lambda)nr = \frac{(3+\lambda)(1+3\lambda)t}{1+3\lambda+\alpha(1+\lambda)} > 0$ for $r = \bar{r}$, this condition holds for all $r \in (\underline{r}, \bar{r})$. Finally, we need to ensure that the threshold value \hat{p} defined by the Proposition belongs to the set defined by (A2). This is easily confirmed, since

$$\frac{(3+\lambda)t}{4n\alpha(1+2\lambda)} - \hat{p} = \frac{(1-\alpha)(1+3\lambda)r}{2\alpha(1+2\lambda)} > 0,$$

$$\begin{aligned}
\hat{p} - \frac{(1-\lambda)t}{\alpha n(1+\lambda)} &= \frac{(1+3\lambda)(t(3\lambda-1) - 2nr(1+\lambda)(1-\alpha))}{4n\alpha(1+\lambda)(1+2\lambda)} > 0 \\
\text{for } \lambda &> \frac{2-\alpha}{2+\alpha} \quad \text{and } r \in (\underline{r}, \bar{r}),
\end{aligned}$$

$$\begin{aligned} & \widehat{p} - \frac{(3 + \lambda)t + 2(1 + \lambda)(1 - \alpha)nr}{4n(1 + 2\lambda)} \\ &= \frac{(1 - \alpha)((3 + \lambda)t - 2nr(\alpha(1 + \lambda) + 1 + 3\lambda))}{4n\alpha(2\lambda + 1)} > 0 \end{aligned}$$

for $r \in (\underline{r}, \bar{r})$.

Q.E.D.

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