Reference Pricing with Endogenous Generic Entry*

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Abstract

Reference pricing intends to reduce pharmaceutical expenditures by increasing demand elasticity and stimulating generic competition. We develop a novel model where a brand-name producer competes in prices with several generics producers in a market with brand-biased and brand-neutral consumers. Comparing with coinsurance, we show that reference pricing, contrary to policy makers' intentions, discourages generic entry, as it induces the brand-name producer to price more aggressively. Thus, the net effect of reference pricing on drug prices is ambiguous, implying that reference pricing can be counterproductive in reducing expenditures. However, under price regulation, we show that reference pricing may stimulate generic entry, since a binding price cap weakens the aggressive price response by the brand-name producer. This may explain mixed empirical results on the competitive effects of reference pricing. Finally, we show that reference pricing may be welfare improving when accounting for brand preferences despite its adverse effects on entry and prices.

Keywords: Pharmaceuticals; Reimbursement schemes; Generic entry

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1 Introduction

The design of reimbursement schemes for prescription drugs is a key issue for policy makers around the world. To contain the growth in pharmaceutical expenditures, almost every health insurance scheme includes cost sharing on the demand side. One of the most popular cost sharing instruments recently is *reference pricing*, which is now adopted by most European countries for reimbursement of drug expenditures, especially for therapeutically equivalent (branded and generic) drug versions.[1] Outside Europe, countries such as Canada and New Zealand have introduced some form of reference pricing.[2] In the US, reference pricing is a well-established practice through the Maximum Allowable Cost (MAC) programmes used by Medicaid and some managed-care programmes for multisource compounds.[3]

Under reference pricing, the payer limits the insurance coverage by defining a maximum price that will be reimbursed for a category of drugs with therapeutically similar effects.[4] Consumers demanding a (branded) drug version priced higher than the reference price will not receive reimbursement for the additional costs and have to pay the difference between the actual price of the (branded) drug and the reference price out-of-pocket.[5] The intention of reference pricing is not primarily to shift costs from the payer to the consumers, but rather to reduce total (both payer and consumer) expenditures by making demand more price elastic and promoting competition between (branded and generic) drug producers. In this paper, we will show that these conjectures are not necessarily true. In fact, we find that reference pricing can be anti-competitive when accounting for the entry decision by generics producers and counter-productive in reducing pharmaceutical expenditures.[6]

To study the competitive effects of reference pricing, we develop a novel Salop-type model

[1] See, for instance, Carone et al. (2012) for a review of pharmaceutical regulation and cost containment policies in the European Union. A few countries, such as Germany and the Netherlands, also apply reference pricing to therapeutically related drug categories, potentially including drugs with different substances.

[2] See Lee et al. (2012).

[3] See, for instance, Danzon and Ketcham (2004) or a recent study by Kelton et al. (2014).

[4] Supplementary health insurance is not very common in Europe (except for in France, the Netherlands, and Belgium), and will usually not cover out-of-pocket expenses related to prescription drugs (see OECD, 2015).

[5] The reference pricing schemes may vary across countries according to the formula for fixing the reference price and the wideness of the therapeutic categories that are included. See, for instance, Danzon and Ketcham (2004) and Carone et al. (2012).

[6] Generics producers can enter the market after the patent has expired. The entry procedures are much less restrictive than for the original brand-name drug. In the US, there is an abrreviated new drug application process (ANDA) in place that expedites generic entry. In Europe, a similar procedure is implemented by the European Medicine Agency and the national authorities in most countries.

where a brand-name producer competes in prices with several generics producers. 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 the copayment (out-of-pocket payment) is sufficiently lower.[7] 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. Based on this modeling approach, we derive the equilibrium under reference pricing – both exogenous (the reference price does not depend on current prices) and endogenous (the reference price depends on current prices) – and compare with the equilibrium under coinsurance, where the consumer pays a fixed percentage of the medical cost.[8]

We report four key findings. First, for a given number of firms, reference pricing triggers price competition. The brand-name producer responds aggressively to reference pricing by cutting prices more than the generic producers, resulting in higher brand-name market shares. This result holds irrespective of whether the reference price is exogenous or endogenous. The strong price response by the brand-name producer is due to the increased demand elasticity induced by reference pricing. The weaker price response by the generics 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 generics producers to *increase* prices. However, the price reduction by the brand-name producer gives an incentive for generics producers to also *reduce* prices, which is due to the fact that prices are strategic complements.

Second, reference pricing limits generic entry. Despite the extra copayments on brand-name drugs, we show that, in a free entry equilibrium, the number of generic entrants are (weakly) lower than with pure coinsurance. The reason is the aggressive price response by the brand-name producer induced by reference pricing, which reduces the expected profits for the generic producers from entering the market. This result also holds for both endogenous and exogenous reference pricing. Thus, the net effect of reference pricing on drug prices and expenditures

[7] Copayments refer to the out-of-pocket payments made by a consumer when demanding a given drug. It should not be confused with co-pay, which in the US refers to a fixed payment (deductible) that is usually just a part of the total out-of-pocket payments.

[8] Coinsurance is highly common for reimbursement of drug costs and thus a natural benchmark. In Europe almost every country uses coinsurance; see Carone et al. (2012). In the US, The 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.

are in general ambiguous when accounting for the entry decision by generics producers. Using numerical simulations, we illustrate that reference pricing can reduce generic entry, lead to higher prices, and result in increased pharmaceutical expenditures (mainly for the consumers).

Third, other forms of price regulation may reverse the adverse effects of reference pricing on generic entry. We consider the case where drugs are subject to price caps, which are a very common regulatory tool in Europe and often coexist with reference pricing.[9] Assuming a price cap that is binding for the brand-name drug under pure coinsurance, we show that reference pricing may increase the number of generic entrants if the price cap is sufficiently strict. The reason is that price cap regulation weakens the price response by the brand-name producer, implying that generics producers may obtain higher market shares under reference pricing. In this case, reference pricing can actually stimulate generic entry and result in lower prices and cost-savings (mainly for the third party payer). Thus, perhaps somewhat counter-intuitively, reference pricing tends to perform better in the presence of price regulation than under unconstrained pricing.

Finally, reference pricing can increase both total welfare and consumer welfare despite the adverse effects on generic entry and prices. There are two effects that contribute to these results. First, there is excessive generic entry under pure coinsurance, a market failure that is partly corrected by reference pricing. Second, reference pricing may reduce the copayment difference between brand-name and generic drugs, inducing a larger share of brand-biased consumers to purchase the brand-name drug and leading to lower mismatch costs in this consumer segment.

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 generics producers.[10] To arrive at this

[9] Carone et al. reports that, in 2012, 24 EU members applied price caps (also called "external reference pricing" since caps depend on prices abroad), and 20 applied reference pricing.

[10] Frank and Salkever (1992) and Grabowski and Vernon (1992) also confirm the generic paradox empirically. However, Wiggins and Maness (2004) find that the brand producers tend to reduce their price due to generic entry.

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) generics 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.[11]

The contribution of our paper is to build on the market segmentation model by Frank and Salkever (1992), but propose a model that relaxes 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 generics producers to simultaneously set prices; and (iii) generics producers to set prices rather than quantities. By modelling competition as a simultaneous game (rather than a Stackelberg one), we avoid the strong assumption that firms can commit to prices. We also avoid the assumption of a Cournot competition, which has limited empirical support in the pharmaceutical market.

Our study is not the first to assume that generics producers set prices. There exists several studies that allow for price competition between brand-name and generics producers.[12] However, these studies assume that only one generic producer is present in the market. Thus, the contribution of our paper in regard to this literature is to allow for several generics 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 generics producers. However, in Ghislandi (2011) there is either perfect competition (à la Bertrand) or collusion among the generics producers, and he is not concerned with the impact of reference pricing on generic entry. Thus, our paper differs significantly from his both in terms of research question and modeling framework.

Another related paper is Bardey et al. (2013), who study the optimal reimbursement schemes

[11] A similar set-up is considered by Wiggins and Maness (2004).
[12] See, for instance, Brekke et al. (2007, 2011) and Miraldo (2009).

for drugs in a set-up with pharmaceutical innovation, allowing for a reference price based on minimal and maximal market prices. They show that the optimal reference pricing is more lenient than the one that would be optimal in the static case without entry and innovation. Our analysis complements theirs by focusing on generic entry (rather than entry of patented drugs) and by showing that reference pricing may be dominated by pure coinsurance even if drug diversity is not an issue, and the payer exclusively minimises total expenditures. Furthermore, we consider the case where the maximum reimbursement is computed using different (and less extreme) formulae.

Finally, our paper contributes to the interpretation of the results from 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 (see, for instance, Aronsson et.al, 2001, Pavcnik, 2002, Brekke et al., 2009, 2011, and Kaiser et al., 2014). An exception is Danzon and Chao (2000), who argue that reference pricing might be counterproductive in curbing pharmaceutical expenditures.[13] 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 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 pure coinsurance (or fixed percentage) reimbursement scheme. In Section 4 we derive the equilibrium with (endogenous and exogenous) reference pricing, and compare this with the equilibrium under pure coinsurance. In Section 5 we introduce price cap regulation. In Section 6 we conduct a welfare analysis. Section 7 concludes the paper. The proofs of all Lemmas and Propositions are relegated to the Appendix.

[13] Danzon and Ketcham (2004) provide empirical evidence that reference pricing leads to a price convergence towards the reference price, implying that brand-name drug prices drop whereas generic prices increase.

2 Model

Consider a pharmaceutical market with a brand-name drug that has lost patent protection and faces competition from generics producers, indexed by $i = 1, ..., n$. Each generic drug producer can enter the market by incurring a fixed (sunk) cost f.[14] 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 generics producers that enter the market are symmetrically located on the circle.[15]

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 the copayments (out-of-pocket payments) are sufficiently lower.[16] The reason for a brand preference may be that consumers perceive the brand-name drug to be of higher quality or less risky than generic drug versions due to, for instance, marketing effort by the brand-name producer during the patent period or past consumption of the brand-name drug.[17] 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

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

with $i = 1, ..., n$. The parameter v denotes the gross utility (reservation price) of medical treatment, c_b and c_g^i are the copayments (out-of-pocket payments) of the brand-name drug and the generic drug i, respectively, and $t_b \left| x - z_g^i \right|$ is the mismatch (switching) cost of consuming

[14] The fixed costs capture all relevant sunk costs associated with market entry of the generics producers, including the costs of setting up a new production line, obtain approval and marketing licence, etc.

[15] This 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.).

[16] We use the term *copayments* for the out-of-pocket payments made by the patients when demanding a given drug. Thus, copayments should not be confused with the term co-pay used in, for instance, the US Medicare program, which is a deductible.

[17] Brand loyalty is a standard assumption in the literature on competition between brand-name and generic drug producers; see, e.g., Frank and Salkever (1992, 1997), Grabowski and Vernon (1992), Brekke et al. (2007, 2011).

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 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

$$u^{bn}(x) = v - c_g^i - t_g \left| x - z_g^i \right|. \tag{2}$$

Notice the different interpretations of the parameters t_b and t_g. Whereas t_b reflects the degree of vertical differentiation between brand-name and generic drugs for *brand-biased* consumers, t_g reflects the degree of horizontal differentiation between different generic drugs for *brand-neutral* consumers.[18] We assume throughout the paper that $t_g \leq t_b$, i.e., the mismatch cost for *brand-biased* consumers is (weakly) higher than for the *brand-neutral* consumers. It is arguably a reasonable assumption that the vertical differentiation among brand-name and generic drug versions is (weakly) stronger than the horizontal differentiation between different generic drug versions.

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 generics 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. Note that, in the *brand-biased* demand segment, each generic drug producer competes directly with the brand-name producer and only indirectly with the other generic drug producers (i.e., a price change by generic drug producer i will trigger a price response by the brand-name producer, which in turn triggers price responses by the remaining generic drug producers $j \neq i$).

[18] 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.

However, in the *brand-neutral* segment, there is direct competition between different generics producers.

In the *brand-neutral* demand segment, demand allocations are determined by the locations of the consumers who are indifferent between the neighboring generic drugs i and $i+1$. These consumers are located a distance $(1/2n) + \left(\left(c_g^{i+1} - c_g^i\right)/2t_g\right)$ 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 consumers are located a distance $\left(c_b - c_g^i\right)/t_b$ from the location of the generic drug i.[19] 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

$$D_g^i = \frac{2\lambda}{t_b}\left(c_b - c_g^i\right) + (1-\lambda)\left(\frac{1}{n} + \frac{c_g^{i+1} + c_g^{i-1} - 2c_g^i}{2t_g}\right). \tag{3}$$

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

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

Observe that the demand for the generics producer i in the brand-biased segment is positive only if 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, some consumers are willing to buy the brand-name drug as long as $\left(c_b - c_g^i\right) < t_b/2n$, i.e. the difference in copayments is not too large. This condition will always be satisfied in the equilibria we consider.

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

[19] Technically, for this to be the location of the indifferent *brand-biased* consumers, we also need $\left(c_b - c_g^i\right)/t_b$ to be smaller than $(1/2n) + \left(\left(c_g^{i+1} - c_g^i\right)/2t_g\right)$, 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 generics producer i are then given by

$$\pi_b = p_b D_b, \tag{5}$$

$$\pi_g^i = p_g^i D_g^i - f, \tag{6}$$

where p_b and p_g^i are the prices of the brand-name drug and the generic drug i, respectively, and f is the (sunk) entry cost of generics producer.

We consider a two-stage game, where at Stage 1 the patent protection of the brand-name drug expires and n generics producers (simultaneously) decide whether to enter (symmetrically) the market depending on the expected profits relative to the fixed entry cost. At Stage 2 there is (Bertrand) price competition between all (brand-name and generics) firms in the market.[20] The outcome of this price competition depends on the regulatory policies in place. We will consider, and compare, two different reimbursement schemes: pure coinsurance (or fixed percentage reimbursement) and reference pricing. These are the two most commonly used reimbursement schemes in European countries (see, e.g., Carone et al., 2012).[21]

3 Pure 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 generics producer i, at the second stage of the game, are given by, respectively,

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

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

[20] As explained in the Introduction, a Stackelberg pricing game (with the brand-name producer as a first mover) is not plausible due to the standard time inconsistency problem. The brand-name producer has an incentive to reoptimise its price once the generics producers enter the market, resulting in a Bertrand price equilibrium.

[21] In European countries, it is uncommon for consumers to purchase supplementary private insurance covering out-of-pocket expenditures. See OECD (2014).

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

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

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

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

$$p_b^* (n) = \frac{\left((1-\lambda) t_b + 2 (1+\lambda) t_g \right) t_b}{4n\alpha \left((1-\lambda) t_b + 3\lambda t_g \right)} \tag{11}$$

$$p_g^* (n) = \frac{(2-\lambda) t_g t_b}{2n\alpha \left((1-\lambda) t_b + 3\lambda t_g \right)} \tag{12}$$

As expected, a higher number of generics producers will lead to lower prices of all drugs in the market. The following Lemma defines the condition for the existence of this equilibrium:

Lemma 1 *Under pure coinsurance, there is a unique Nash equilibrium in the price game, for a given number of firms, if either λ is sufficiently high or t_g is sufficiently low relative to t_b. The equilibrium is given by (11)-(12).*

Equilibrium existence requires that the brand-name producer has no incentive to deviate unilaterally from its candidate equilibrium strategy by setting the price equal to (or slightly below) the generics price and thereby capture all demand from both segments. Such a deviation is not profitable if either the brand-biased segment is sufficiently large or if the degree of vertical differentiation between brand-name and generic drugs is sufficiently large relative to the degree of horizontal differentiation between generics drugs. A similar condition is required for equilibrium existence in all reimbursement scenarios subsequently considered in this paper.[22]

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

$$D_b \left(p_b^* (n), p_g^* (n) \right) = \frac{\lambda \left((1-\lambda) t_b + 2 (1+\lambda) t_g \right)}{2 \left((1-\lambda) t_b + 3\lambda t_g \right)}. \tag{13}$$

[22] Notice also that

$$p_b^* (n) - p_g^* (n) = \frac{\left((1-\lambda) t_b + 2t_g (2\lambda - 1) \right) t_b}{4n\alpha \left((1-\lambda) t_b + 3\lambda t_g \right)},$$

which is positive under the general conditions for equilibrium existence provided in Lemma 1.

A noteworthy feature of the equilibrium under pure 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

$$\pi_b\left(p_b^*(n), p_g^*(n)\right) = \frac{\lambda t_b\left((1-\lambda)t_b + 2(1+\lambda)t_g\right)^2}{8n\alpha\left((1-\lambda)t_b + 3\lambda t_g\right)^2}, \tag{14}$$

$$\pi_g\left(p_b^*(n), p_g^*(n)\right) = \frac{(2-\lambda)^2 t_b t_g\left((1-\lambda)t_b + 2\lambda t_g\right)}{4n^2\alpha\left((1-\lambda)t_b + 3\lambda t_g\right)^2} - f. \tag{15}$$

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

$$\frac{(2-\lambda)^2 t_b t_g\left((1-\lambda)t_b + 2\lambda t_g\right)}{4(n^*)^2\alpha\left((1-\lambda)t_b + 3\lambda t_g\right)^2} - f \geq 0. \tag{16}$$

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 price to be reimbursed, be given by r. We will focus on the case in which r lies somewhere between the prices of brand-name and generic drugs, which is the most frequently observed case in practice.[23] The consumers' copayments for the brand-name drug and for generic drug i, respectively, are then given by

$$c_b = \alpha r + p_b - r \tag{17}$$

and

$$c_g^i = \alpha p_g^i. \tag{18}$$

Applying the terminology of Brekke et al. (2011), we will distinguish between two different

[23] It is not common to set the reference price below the lowest generic drug price. Moreover, if the reference price is higher than the brand-name drug price, we have a *de facto* pure coinsurance scheme, as described in the previous section.

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 reference pricing, 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. There are also a few examples of countries that explicitly use an exogenous reference pricing scheme, such as Belgium and Norway.[24]

4.1 Exogenous reference pricing

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

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

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

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

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

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

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

$$p_b^*(r, n) = \frac{t_b\left((1-\lambda)\, t_b + 2\,(1+\lambda)\, t_g\right) + 2nr\,(1-\alpha)\left((1-\lambda)\, t_b + 2\lambda t_g\right)}{4n\left(t_b\,(1-\lambda) + 3\lambda t_g\right)}, \tag{23}$$

[24] See Carone et al. (2012) for a detailed overview.

$$p_g^*(r,n) = \frac{t_g\left((2-\lambda)t_b - 2(1-\alpha)\lambda nr\right)}{2n\alpha\left((1-\lambda)t_b + 3\lambda t_g\right)}. \tag{24}$$

As for the case of drug reimbursement based on pure coinsurance, drug prices are monotonically decreasing in the number of generic firms. It is worth noting, 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 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, there is a unique Nash equilibrium with an interior solution in the price game, for a given number of firms, if the following conditions are satisfied: (i)* $\underline{r} < r < \overline{r}$*, where* $\underline{r} := \frac{(2-\lambda)t_b t_g}{2n((1-\lambda)\alpha t_b + \lambda(2\alpha+1)t_g)}$ *and* $\overline{r} := \frac{t_b((1-\lambda)t_b + (1+\lambda)2t_g)}{2n((1-\lambda)(1+\alpha)t_b + 2\lambda(2+\alpha)t_g)}$*; (ii)* λ *is sufficiently high or* t_g *is sufficiently low relative to* t_b*. The equilibrium is given by (23)-(24).*

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[25]

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

and

$$\pi_b\left(p_b^*(r,n), p_g^*(r,n)\right) = \frac{\lambda\left(t_b\left((1-\lambda)t_b + 2(1+\lambda)t_g\right) + 2nr(1-\alpha)\left((1-\lambda)t_b + 2\lambda t_g\right)\right)^2}{8nt_b\left((1-\lambda)t_b + 3\lambda t_g\right)^2}, \tag{26}$$

$$\pi_g\left(p_b^*(r,n), p_g^*(r,n)\right) = \frac{\left((1-\lambda)t_b + 2\lambda t_g\right)\left((2-\lambda)t_b - 2(1-\alpha)\lambda nr\right)^2 t_g}{4\alpha n^2 t_b\left((1-\lambda)t_b + 3\lambda t_g\right)^2} - f. \tag{27}$$

Note 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 generics producers at the expense of the brand-name producer. Since $\pi_g\left(p_b^*(r,n), p_g^*(r,n)\right)$ is

[25] Notice also that

$$p_b^*(r,n) - p_g^*(r,n) = \frac{2nr(1-\alpha)\left((1-\lambda)\alpha t_b + 2\lambda(1+\alpha)t_g\right) - t_b\left(2(2-\lambda)t_g - 2\alpha t_g(\lambda+1) - \alpha t_b(1-\lambda)\right)}{4n\alpha\left((1-\lambda)t_b + 3\lambda t_g\right)},$$

which is positive for $r \in (\underline{r}, \overline{r})$.

monotonically decreasing in n, the number of generics producers in a free-entry equilibrium, n^*, is given by the highest integer number that satisfies the following weak inequality,

$$\frac{\left(\left(1-\lambda\right)t_b+2\lambda t_g\right)\left(\left(2-\lambda\right)t_b-2\left(1-\alpha\right)\lambda n^* r\right)^2 t_g}{4\alpha\left(n^*\right)^2 t_b\left(\left(1-\lambda\right)t_b+3\lambda t_g\right)^2}-f\geq 0, \tag{28}$$

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.[26] A formulation that is sufficiently general to capture several realistic possibilities is

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

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. Notice also that $\beta=0$ is equivalent to a pure coinsurance scheme.

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 generics producer i, at the second stage of the game, are given by, respectively,

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

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

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

[26] Some countries base the reference price only on the lowest generic drug price in a reference group, while others set the reference price at the average or median price. See, for instance, Carone et al. (2012) for an overview of the different reference pricing schemes in Europe.

problems are

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

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

Note 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 $i = 1, ..., n$) and simultaneously solving (33)-(32), the equilibrium candidate prices are

$$p_b^* (\beta, n) = \frac{\left(n\alpha \left((1-\lambda) t_b + 2(1+\lambda) t_g \right) + 2\beta t_g (1-\alpha)(n+\lambda) \right) t_b}{4n\theta \left(n\alpha \left((1-\lambda) t_b + 3\lambda t_g \right) + \lambda \beta t_g (1-\alpha)(n+2) \right)}, \tag{34}$$

$$p_g^* (\beta, n) = \frac{(2-\lambda) t_b t_g}{2 \left(n\alpha \left((1-\lambda) t_b + 3\lambda t_g \right) + \lambda \beta t_g (1-\alpha)(n+2) \right)}. \tag{35}$$

As for the case of pure coinsurance or exogenous reference pricing, 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, there is a unique Nash equilibrium in the price game, for a given number of firms, if either λ is sufficiently high or t_g is sufficiently low relative to t_b. The equilibrium is given by (34)-(35).*

Given that this condition is satisfied, the equilibrium brand-name market share is given by[27]

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

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 generics 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 generics producers, to the extent that the equilibrium brand-name market share increases.

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

$$\pi_b\left(p_b^*(\beta,n),p_g^*(\beta,n)\right)=\frac{\lambda t_b\left(n\alpha\left(\left(1-\lambda\right)t_b+2\left(1+\lambda\right)t_g\right)+2\beta t_g\left(1-\alpha\right)\left(n+\lambda\right)\right)^2}{8n\theta\left(n\alpha\left(\left(1-\lambda\right)t_b+3\lambda t_g\right)+\beta\lambda t_g\left(1-\alpha\right)\left(n+2\right)\right)^2}, \tag{37}$$

$$\pi_g\left(p_b^*(\beta,n),p_g^*(\beta,n)\right)=\frac{t_b t_g\left(2-\lambda\right)^2\left(n\alpha\left(\left(1-\lambda\right)t_b+2\lambda t_g\right)+2\left(1-\alpha\right)\beta\lambda t_g\right)}{4n\left(n\alpha\left(\left(1-\lambda\right)t_b+3\lambda t_g\right)+\beta\lambda t_g\left(1-\alpha\right)\left(n+2\right)\right)^2}-f. \tag{38}$$

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

$$\frac{t_b t_g\left(2-\lambda\right)^2\left(n^*\alpha\left(\left(1-\lambda\right)t_b+2\lambda t_g\right)+2\left(1-\alpha\right)\beta\lambda t_g\right)}{4n^*\left(n^*\alpha\left(\left(1-\lambda\right)t_b+3\lambda t_g\right)+\beta\lambda t_g\left(1-\alpha\right)\left(n^*+2\right)\right)^2}-f\geq 0, \tag{39}$$

and that simultaneously satisfies the condition in Lemma 3.

[27]Notice also that

$$p_b^*(\beta,n)-p_g^*(\beta,n)=\frac{\left(n\alpha\left(\left(1-\lambda\right)t_b+2\left(2\lambda-1\right)t_g\right)+2\beta t_g\left(1-\alpha\right)\left(\lambda+\left(\lambda-1\right)n\right)\right)t_b}{4n\theta\left(n\alpha\left(\left(1-\lambda\right)t_b+3\lambda t_g\right)+\beta\lambda\left(1-\alpha\right)\left(n+2\right)t_g\right)},$$

which is positive under the general conditions for equilibrium existence given by Lemma 3.

4.3 Pure coinsurance versus reference pricing

Let us now compare the two reimbursement systems considered – pure 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 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 pure 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 generics producers an isolated incentive to raise prices, the strategic complementarity of price setting ensures that generic prices also drop.[28] As shown by Proposition 1, this second effect dominates for the entire set of parameter values that ensure equilibrium existence. Furthermore, 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.[29]

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 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 generics producers, the implications for generic entry follow directly:

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

[29] Note that the results in Proposition 1 hold also for the special case of $\lambda = 1$. Thus, our results do not depend crucially on the presence of a brand-neutral consumer segment.

Corollary 1 *Suppose that the conditions given by Lemmas 1-3 are satisfied. Then, in a free entry equilibrium, the number of generic drugs is (weakly) higher under pure 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 generics producers a competitive advantage vis-à-vis brand-name producers. Indeed, for given drug prices, a switch from pure coinsurance to reference pricing will shift demand towards generic drugs and therefore benefit generics producers. However, as Proposition 1 shows, such a switch will also trigger price responses such that the generics producers end up with lower profits. Thus, a switch from pure coinsurance to reference pricing will lead to fewer generic drugs in a free entry equilibrium.

4.4 Can reference pricing lead to higher prices?

When taking into account the effect on generic entry, the intended cost-containing effect of reference pricing is no longer obvious. In our model it is not analytically feasible to give a precise characterisation of the required conditions for reference pricing to lead to higher prices or not. However, we have constructed a set of numerical examples which illustrate both possibilities and therefore allow us to gain some further insights into the effects of reference pricing.

Tables 1 and 2 show the effects of going from a reimbursement system with pure coinsurance to a reimbursement system based on reference pricing. We consider two different cases regarding demand: Table 1 illustrates Case 1, where consumers are almost exclusively brand biased, whereas Table 2 shows Case 2, with a larger brand-neutral demand segment, but where the degree of vertical differentiation between brand-name and generic drugs is larger than the degree of horizontal differentiation between generic drugs. In each of the two cases, we vary the parameters α and β to show how the exact design of the reimbursement system affects the comparison between pure coinsurance and reference pricing, and we also consider both types of reference pricing: endogenous and exogenous.[30]

[Table 1 here]

[Table 2 here]

[30] In all numerical examples, the parameters are chosen such that the conditions for equilibrium existence are satisfied.

Consider first the effects of introducing *endogenous* reference pricing. In all parameter configurations considered, the introduction of endogenous reference pricing leads to fewer generic drugs in the free entry equilibrium (the only exception is for $\alpha = 0.4$ in Case 2, where reference pricing has no effect on entry). This negative entry effect contributes to an increase in average drug prices ($p_{av} := D_b p_b + (1 - D_b) p_g$), and therefore higher total drug expenditures, for three different parameter configurations: ($\alpha = 0.4; \beta = 0.5$) and ($\alpha = 0.6; \beta = 0.5$) in Case 1, and ($\alpha = 0.6; \beta = 0.5$) in Case 2. In all of these three cases, the increase in the average drug price is caused by a combination of two effects: (i) all drug prices increase (because of less generic competition), and (ii) a large share of consumers choose the most expensive drug.

Endogenous reference pricing

Even with the limited amount of different parameter configurations on display, a relatively clear pattern can still be detected. *Endogenous reference pricing will not lead to higher drug prices if the coinsurance rate α is sufficiently low or if the weight β on the cheapest drugs in the reference price formula is sufficiently large.* This has a fairly intuitive explanation. A low coinsurance rate implies that drug demand is very inelastic (over all relevant price intervals) in a pure coinsurance system, which in turn implies that equilibrium drug prices are relatively high. The introduction of reference pricing will therefore have a large effect on the price elasticity of demand (for prices above the reference price). The direct price-reducing effect of reference pricing will therefore outweigh the effect of less generic competition, leading to an overall reduction in drug prices. This also appears to be the case if β is given a sufficiently large value in the reference price formula. A higher value of β implies that each generic producer can more effectively reduce the reference price by reducing the price of its drug. This stimulates price competition and increases the direct price-reducing effect of reference pricing.

It is worth noticing, though, that in all examples where endogenous reference pricing leads to a higher average drug price, the increase in expenditures is entirely borne by the consumers, who face an increase in average drug copayments (c_{av}) as a combined result of a higher copayment for the brand-name drug (because of reference pricing) and higher drug prices (because of less generic competition).[31] For the third-party payer, on the other hand, the introduction

[31] Average drug copayment is given by αp_{av} under pure coinsurance, and by $\alpha\left((1 - D_b) p_g + D_b r\right) + (p_b - r) D_b$ under reference pricing.

of endogenous reference pricing always yields a reduction in drug payments ($p_{av} - c_{av}$) in the examples considered in Tables 1 and 2.[32] Even if reference pricing leads to higher prices for all drugs, the increase in patient copayment for the brand-name drug is large enough to yield savings for the payer. This suggests that endogenous reference pricing is likely to be more beneficial for the third-party payer than for consumers.

Exogenous reference pricing

The rightmost column in Tables 1 and 2 shows the effect of introducing *exogenous* reference pricing. For each parameter configuration, we have chosen a value of the reference price such that the Nash equilibrium exists and yields an interior solution, with $p_g < r < p_b$.[33] Since the exact choice of the reference price for each case is rather arbitrary, a comparison of the effects for different values of the coinsurance rate (α) is somewhat less meaningful. Likewise, a comparison between the effects of endogenous and exogenous reference pricing must also be done with some care, since there is no obvious way of making a like-for-like comparison. Nevertheless, some apparently clear patterns can still be identified. First, exogenous reference pricing appears to have a stronger negative effect on generic entry, even if the exogenous reference price is higher than the equilibrium endogenous reference price. In addition, and partly as a result of less generic competition, the equilibrium brand-name market share is consistently higher under exogenous reference pricing. The implication for average drug prices is striking: in all but one case, going from pure coinsurance to exogenous reference pricing leads to higher average drug prices (the exception is for $\alpha = 0.4$ in Case 2). Furthermore, in 4 out of the 5 different parameter configurations where exogenous reference pricing leads to a higher average drug price, the increase in drug expenditures is paid not only by consumers, but also by the third-party payer (the only exception is for $\alpha = 0.2$ in Case 1).

In sum, these numerical examples suggest that reference pricing is more likely to yield price reductions if the reference price is endogenously determined, and if a larger weight is given to

[32] We have, unsuccessfully, tried to find numerical examples of endogenous reference pricing leading to higher expenditures also for the payer. Although we cannot rule out this possibility, the clear pattern emerging from our model is that, if endogenous reference pricing leads to an increase of total expenditures, this increase is likely to be borne by the patients and not by the payer.

[33] If r is given a sufficiently low value, all firms will optimally price above the reference price. But this is equivalent to the case of pure coinsurance with $\alpha = 1$. Such equilibria would offer little insurance to consumers and is to our knowledge not applied in practice, and are therefore disregarded.

low-priced drugs in the reference price formula.

5 Reference pricing and price cap regulation

We have so far assumed that the pharmaceutical firms freely can set prices without any constraints except for the demand-side cost sharing rules defined by the reimbursement schemes. In practice, however, most countries also apply supply-side regulations that constrain the firms' price setting in order to control the medical expenditures. The most common price control scheme is to enforce maximum prices that pharmaceutical firms can charge for a given product.[34]

In this section, we therefore analyse the effect of introducing reference pricing in markets with price cap regulation. In the previous section, we find that reference pricing always reduce generic entry due to the aggressive price response by the brand-name producer. However, in markets with price regulation, the brand-name producer's price setting is constrained by a binding price cap. A key question is therefore whether reference pricing actually can *stimulate* generic competition in the presence of price regulation.

We consider the case where drug producers are subject to price cap regulation and are not allowed to set prices in excess of $\overline{p}$, regardless of the reimbursement system. We assume that the price cap binds for the brand-name producer but not for the generics producers; otherwise generic competition will not take place. With a binding price cap, the Nash equilibrium in the price game under *pure coinsurance* (and for a given number of firms) is then a corner solution with the following prices:

$$p_b^* = \overline{p}, \tag{40}$$

$$p_g^*(\overline{p}, n) = \frac{((1-\lambda)\, t_b + 2n\alpha\lambda\overline{p})\, t_g}{n\alpha\left((1-\lambda)\, t_b + 4\lambda t_g\right)}, \tag{41}$$

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

Lemma 4 *Under pure coinsurance, and for a given number of firms, the unique Nash equilibrium in the price game is a corner solution, given by (40)-(41), if the following conditions*

[34] In Europe, price cap regulation is highly common; see Carone et al. (2012).

are satisfied: (i) $\frac{(1-\lambda)t_b t_g}{n\alpha((1-\lambda)t_b+2\lambda t_g)} < \overline{p} < \frac{((1-\lambda)t_b+2(1+\lambda)t_g)t_b}{4n\alpha((1-\lambda)t_b+3\lambda t_g)}$*; (ii)* λ *is sufficiently high or* t_g *is sufficiently low relative to* t_b*.*

Note that the lower bound on $\overline{p}$ is necessary to ensure that all firms are active in equilibrium, which requires that the generics 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

$$D_b\left(\overline{p}, p_g^*\left(\overline{p}, n\right)\right) = \lambda\left(\frac{t_b\left(\left(1-\lambda\right)t_b + 2\left(1+\lambda\right)t_g\right) - 2n\alpha\overline{p}\left(\left(1-\lambda\right)t_b + 2\lambda t_g\right)}{t_b\left(\left(1-\lambda\right)t_b + 4\lambda t_g\right)}\right) \tag{42}$$

and

$$\pi_b\left(\overline{p}, p_g^*\left(\overline{p}, n\right)\right) = \lambda\overline{p}\left(\frac{t_b\left(\left(1-\lambda\right)t_b + 2\left(1+\lambda\right)t_g\right) - 2n\alpha\overline{p}\left(\left(1-\lambda\right)t_b + 2\lambda t_g\right)}{t_b\left(\left(1-\lambda\right)t_b + 4\lambda t_g\right)}\right), \tag{43}$$

$$\pi_g\left(\overline{p}, p_g^*\left(\overline{p}, n\right)\right) = \frac{t_g\left(\left(1-\lambda\right)t_b + 2n\alpha\lambda\overline{p}\right)^2\left(\left(1-\lambda\right)t_b + 2\lambda t_g\right)}{n^2 t_b\alpha\left(\left(1-\lambda\right)t_b + 4\lambda t_g\right)^2} - f. \tag{44}$$

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 $\pi_g\left(\overline{p}, p_g^*\left(\overline{p}, n\right)\right)$ is monotonically decreasing in n. Thus, in a free-entry equilibrium, the equilibrium number of generics producers, n^*, is given by the highest integer number satisfying the weak inequality

$$\frac{t_g\left(\left(1-\lambda\right)t_b + 2n\alpha\lambda\overline{p}\right)^2\left(\left(1-\lambda\right)t_b + 2\lambda t_g\right)}{n^2 t_b\alpha\left(\left(1-\lambda\right)t_b + 4\lambda t_g\right)^2} - f \geq 0, \tag{45}$$

while simultaneously satisfying the conditions given in Lemma 4.[35]

5.1 Can reference pricing lead to more generic entry?

To answer this question, we compare the equilibrium under pure coinsurance with binding price cap regulation with the equilibrium under (exogenous and endogenous) reference pricing (derived

[35]Notice that the bounds on $\overline{p}$ given in Lemma 4 are endogenous, implying that whether or not the price cap binds depends on the entry decision of generics producers, which in turn depends on the anticipated equilibrium prices in the market, including the price cap itself in an equilibrium with a binding price cap. Thus, in a free entry equilibrium, the price cap binds for values of $\overline{p}$ (and other parameters) satisfying simultaneously (45) and the conditions given by Lemma 4.

in Section 4). This implies that we consider a price cap that binds only under pure coinsurance and not under reference pricing to allow for price responses by the brand-name producer.[36] Under these circumstances, the introduction of reference pricing will reduce the brand-name price by assumption. The effects on generic prices and market shares are described by the following proposition:

Proposition 2 *Suppose that the conditions given by Lemmas 2-4 are satisfied. For a given number of firms, and compared with pure coinsurance, reference pricing leads to higher generic drug prices and lower brand-name market shares if the following conditions are satisfied: (i) the price cap is sufficiently low, and (ii) either* λ *is sufficiently high or* t_g *is sufficiently low relative to* t_b*. This conclusion holds regardless of whether the reference price is exogenous or endogenous.*

We see that the previous results on the price and market share effects of reference pricing (given by Proposition 1) might be overturned if reference pricing is introduced in a situation where the firms are already subject to price cap regulation.

This possibility arises if the price cap binds to a sufficiently strong degree under pure coinsurance, before reference pricing is introduced. In this case, the price difference between brand-name and generic drugs is relatively small under pure coinsurance, and the brand-name market share is larger than it would have been with a less binding price cap. Consequently, the brand-name price reduction in response to a switch from pure coinsurance to reference pricing is relatively small (zero if the price cap binds in both equilibria) and the generics producers' incentive to increase prices under reference pricing dominates the strategic complementarity effect, leading to higher prices and higher market shares for the generics producers. The implications for generic entry follow immediately:

Corollary 2 *Suppose that the conditions given by Lemmas 2-4 are satisfied. Then, in a free entry equilibrium, the number of generic drugs is (weakly) higher under (endogenous or exogenous) reference pricing than under pure coinsurance if the conditions given in Proposition 2 are satisfied.*

[36]The alternative case is that the price cap is set such that it binds both under pure coinsurance and reference pricing. Since the results are qualitatively similar, we have left this analysis out of the paper. The results are available upon request.

This result is in stark contrast with our previous results with no price regulation, and suggests that the negative effect of reference pricing on generic entry may be mitigated in markets where price caps are already in place.

Table 3 displays a numerical example illustrating the mechanisms at play. We consider two different scenarios under pure coinsurance. In both scenarios the free-entry equilibrium has a binding price cap, but in Scenario 2 the price cap is lower ($\overline{p} = 0.35$) than in Scenario 1 ($\overline{p} = 0.3$). Note first that, under pure 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: (i) there is less competition from generic firms and (ii) 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. Increased competition from the new entrant leads to lower generic prices as a result of reference pricing. As expected, the brand-name market share also goes down.

Table 3: Reference pricing and generic entry under price cap regulation

	Pure coinsurance		Exogenous RP	Endogenous RP
	(1) $\overline{p} = 0.3$	(2) $\overline{p} = 0.35$	$r = 0.25$	$\beta = 0.8$
n^*	2	4	3	3
p_b	0.300	0.350	0.283	0.289
p_g	0.214	0.204	0.207	0.199
r	n/a	n/a	0.25	0.217
D_b	0.838	0.690	0.764	0.687
p_{av}	0.286	0.305	0.265	0.261
c_{av}	0.114	0.122	0.121	0.134
Parameter values: $\alpha = 0.4$, $\lambda = 0.9$, $t_b = t_g = 2$, $f = 0.015$				

On the other hand, in Scenario 2, where the price cap is less binding in equilibrium under pure 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.

Whereas reference pricing stimulates generic entry under strict price cap regulation (Scenario 1) and deters generic entry under more lax price cap regulation (Scenario 2), it does not follow that the price-reducing effect of reference pricing is larger in the former case. In fact, the opposite is true. The reason is simply that stricter price cap regulation implies a lower brand-name drug price, which reduces the scope for further price reduction as a result of reference pricing. Thus, the numerical examples in Table 3 shows that, if the target is to reduce average drug prices, price cap regulation and reference pricing are to a large extent *policy substitutes*. If the starting point is a situation with pure coinsurance and relatively lax price cap regulation (Scenario 2), the average drug price can be reduced either by reducing the price cap (moving to Scenario 1) or by introducing reference pricing.

Finally, if we break down the total drug expenditures and look at the average price paid by consumers and the third-party payer, respectively, we see that the cost savings from reference pricing are almost exclusively captured by the payer. In fact, in Scenario 1, consumers pay a higher average copayment after the introduction of reference pricing. It is interesting to note that this happens in the scenario where price cap regulation is relatively strict and where reference pricing stimulates generic entry. The reason is that reference pricing yields only a small drop in the brand-name drug price, implying that the dominating effect of reference pricing for consumers is that the copayment share for the brand-name drug increases. Thus, if reference pricing stimulates generic entry, this will reduce the expenditures of the payer but might, perhaps somewhat counterintuitively, increase the expenditures of consumers. This mirrors the results shown in Table 1, for the introduction of endogenous reference pricing in the absence of any price cap regulation.

6 Welfare analysis

If the regulator respects consumer preferences, the social welfare function is the sum of consumers' surplus and profits, which, under symmetry, is given by

$$SW = \lambda 2n \int_0^{x^{bb}} (v - t_b x)\, dx + \lambda 2n \int_{x^{bb}}^{1/2n} v dx + (1-\lambda)2n \int_0^{x^{bn}} (v - t_g x)\, dx - nf, \qquad (46)$$

where x^{bb} is the location of the brand-biased consumer that is indifferent between a given generic drug and the brand-name drug. Similarly, x^{bn} is location of the brand-neutral consumer that is indifferent between a given generic drug and the closest neighbouring generic drug. The first two terms in (46) represent social surplus from the brand-biased market segment. It includes the surplus generated by brand-biased consumers purchasing generics (first term) and brand-biased consumers purchasing the brand-name drug (second term). Note that, for the latter category of consumers, there are no mismatch costs. The third term in (46) is the surplus from the brand-neutral market segment, whereas the last term is the cost of having n generic drugs on the market.

6.1 The first-best solution

After calculations, we can rewrite (46) as

$$\lambda \left(v - n t_b (x^{bb})^2 \right) + (1-\lambda) 2n x^{bn} \left(v - \frac{t_g}{2} x^{bn} \right) - fn, \qquad (47)$$

In the first-best solution, the regulator can set x^{bb}, x^{bn} (or, equivalently, she can set prices and let consumers sort into different drugs) and n. The optimal x^{bb} is equal to zero (alternatively, the price of the brand is optimally set equal the price of the generics): the brand-biased consumers should purchase the brand-name drug since this minimises their mismatch costs. The optimal x^{bn} is also set as to minimise mismatch costs and is equal to $1/2n$ given that generics producers are symmetrically located.

Setting $x^{bb} = 0$ and $x^{bn} = 1/2n$ in (47), and maximising with respect to n, the optimal

number of generic firms, n^{FB}, is given by the highest integer number such that

$$(1-\lambda)\frac{t_g}{4(n^{FB})^2} \geq f, \tag{48}$$

Since total demand is inelastic, which implies that price changes are welfare neutral, the first-best level of generic entry is fully determined by a trade-off between lower mismatch costs for brand-neutral consumers and lower entry costs. Consequently, n^{FB} is increasing in the share of brand-neutral consumers. A comparison of (48) and (16) confirms that there is always (weakly) excessive entry in the equilibrium with pure coinsurance, since

$$(1-\lambda)\frac{t_g}{4n^2} < \frac{(2-\lambda)^2 t_b t_g \left((1-\lambda)t_b + 2\lambda t_g\right)}{4n^2\alpha\left((1-\lambda)t_b + 3\lambda t_g\right)^2} \tag{49}$$

for all n, and $t_b \geq t_g$

6.2 Can reference pricing be welfare enhancing?

Let us now consider the case where the regulator cannot directly control the number of entrants and consumers' allocations, but can only set coinsurance rates and reference prices. We limit the analysis to the case where the reference price is *endogenous* and try to answer the following question. Compared with pure coinsurance, can reference pricing improve welfare?

If the regulator cannot allocate consumers across drugs, demand depends on equilibrium prices. Thus, $x^{bb} = (c_b - c_g)/t_b$ and $x^{bn} = 1/2n$. For a given coinsurance rate, α, the effect on welfare of an increase $\Delta\beta$ in β is[37]

$$-2\lambda n t_b x^{bb}\frac{\Delta x^{bb}}{\Delta\beta} - \lambda t_b x^{bb}\left[x^{bb} + 2n\frac{\Delta x^{bb}}{\Delta n}\right]\frac{\Delta n}{\Delta\beta} + (1-\lambda)\frac{t_g}{4(n)^2}\frac{\Delta n}{\Delta\beta} - f\frac{\Delta n}{\Delta\beta}. \tag{50}$$

The first two terms capture the effect of an increase in β on the mismatch costs of brand-biased consumers. The first term is the direct effect of β on x^{bb} and can be shown to be positive (see our proof of Proposition 1). For a given number of firms, reference pricing, by reducing the difference $c_b - c_g$, reduces the number of brand-biased consumers purchasing generics and

[37]The equilibrium under endogenous reference pricing, as defined by (29), coincides with the equilibrum under pure coinsurance for $\beta = 0$. We can therefore evaluate the effect of reference pricing by doing comparative statics on β.

therefore reduces mismatch costs for this consumer segment. The second term is the indirect effect through the number of generics. The sign of this term can be shown to be negative.[38] Intuitively, since the market share of the brand-name drug increases in n, reference pricing, by discouraging entry, also increases mismatch costs for brand-biased consumers. Overall, the effect of reference pricing on the mismatch costs of brand-biased consumers is therefore ambiguous. The third term in (50) is the effect of β on the mismatch costs of brand-neutral consumers and is always negative. Reference pricing, by reducing entry, always harms brand-neutral consumers. Finally, the fourth term captures the fact that reference pricing reduces entry and consequently entry costs.

Since pure coinsurance leads to excessive entry, it follows that the sum of the third and fourth terms in (50) is always positive, at least when β is sufficiently close to zero. In other words, the increase in mismatch costs for brand-neutral consumers as a result of less generic entry is more than outweighed by entry cost savings. Thus, if all brand-biased consumers purchased the brand-name drug, reference pricing (with an appropriate choice of β) would always increase welfare. However, when the (market-determined) mismatch costs of the brand-biased consumers are taken into account, reference pricing may reduce welfare by pushing more of these consumers to purchase generics. This result is somewhat surprising and follows from our assumption that the regulator respects consumer preferences, and in particular biases towards the brand-name drug. Under this assumption, a positive welfare effect of reference pricing partly relies on its ability to reduce the difference between brand-name and generics copayments ($t_b x^{bb}$). This effect would be absent in the presence of a paternalistic regulator.

Since our model does not allow us to find analytical conditions for the effect of reference pricing on welfare, we proceed with some numerical examples, illustrated in Table 4.

[38] From (36) we obtain

$$\frac{\partial D_b}{\partial n} = -2\lambda \left(x^{bb} + n \frac{\partial x^{bb}}{\partial n} \right) > 0.$$

Thus, $x^{bb} + n(\partial x^{bb}/\partial n) < 0$, implying that $\partial x^{bb}/\partial n < 0$. Then, it must also be true that $x^{bb} + 2n(\partial x^{bb}/\partial n) < 0$.

Table 4: Endogenous reference pricing and welfare

	Pure coinsurance	Endogenous reference pricing ($\alpha = 0.4$)		
	$\alpha = 0.4$	$\beta = 0.2$	$\beta = 0.5$	$\beta = 0.8$
n^*	5	4	3	3
p_b	0.348	0.348	0.355	0.289
p_g	0.196	0.215	0.234	0.215
p_{av}	0.292	0.301	0.315	0.264
c_b	0.139	0.155	0.178	0.158
c_g	0.079	0.086	0.093	0.080
$p_b - c_b$	0.209	0.193	0.177	0.130
$p_g - c_g$	0.118	0.129	0.140	0.120
x^{bb}	0.066	0.035	0.042	0.039
SW	0.878	0.920	0.929	0.931
CS	0.854	0.856	0.831	0.847
SW_ϕ, with marginal cost of public funds ϕ				
$\phi = 1.1$	0.863	0.903	0.913	0.918
$\phi = 1.5$	0.805	0.835	0.848	0.867
$\phi = 2$	0.732	0.750	0.765	0.804
Parameter values: $\lambda = 0.9, \quad t_b = t_g = 2, \quad f = 0.0146, \quad v = 1$				

In each specification, both n and x^{bb} are smaller under reference pricing. As a result, reference pricing reduces mismatch costs for brand-biased consumers and is therefore welfare enhancing. Interestingly, we are able to show that, even when reference pricing is counter-productive in terms of total expenditures (as is the case for $\beta = 0.2$ and $\beta = 0.5$), it nevertheless improves social welfare.

In Table 4 we also compute the consumer surplus, CS, which is defined as

$$CS = \lambda 2n \int_0^{x^{bb}} (v - c_b - t_b x)\, dx + \lambda 2n \int_{x^{bb}}^{1/2n} (v - c_b)\, dx + (1-\lambda) 2n \int_0^{x^{bn}} (v - c_g - t_g x)\, dx. \quad (51)$$

The consumer surplus depends on the mismatch costs – which partly depends on the relative copayments (affecting x_{bb}) and partly depends on the number of number of generic firms –

but also the copayment levels. In our numerical examples in Table 4, we see that reference pricing also increases consumer surplus in all parameter configurations considered. Thus, even if reference pricing leads to higher average copayments, this is more than outweighed by lower mismatch costs for brand-biased consumers.

Finally, we consider the case where raising taxes to provide (or subsidise) health insurance entails distortions. In addition to the effect of reference pricing on mismatch costs (through its effect on prices and generic entry), the social planner in this case also takes into account the direct effect on average prices and public expenditures. This scenario is particularly relevant for the problem at hand, since curbing public expenditures seems to be the main goal of regulators of the pharmaceutical sector. If the marginal cost of public funds is equal to $\phi > 1$, the social welfare function has the form

$$SW_\phi = \lambda 2n \int_0^{x^{bb}} (v - t_b x - (\phi - 1)(p_g - c_g))\, dx + \lambda 2n \int_{x^{bb}}^{1/2n} (v - (\phi - 1)(p_b - c_b))\, dx$$
$$+(1-\lambda)2n \int_0^{x^{bn}} (v - t_g x - (\phi - 1)(p_g - c_g))\, dx - nf. \tag{52}$$

In our simulations (see the last 3 rows of Table 4), reference pricing always reduces the insurance reimbursement for brand-name drugs. This is true even when reference pricing has a positive effect on the price of brand-name drugs. However, the market shares of brand-name drugs increase with reference pricing. We find the opposite effect for generic drugs. Overall, social welfare is always higher with reference pricing. In conclusion, our results suggest that reference pricing, by shifting the brand-name price burden towards consumers, may negatively affect consumer surplus. For the same reason, it may increase social welfare if raising public funds is costly.

7 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. 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 and expenditures. 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. This result is robust 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, reducing the expected profits for generic firms entering the market.

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. Thus, reference pricing and price regulation are policy complements for the regulator.

We also find that reference pricing may be welfare enhancing even if it deters generic entry and leads to higher drug prices and expenditures. The reason for this is two-fold. First, there is excessive generic entry under pure coinsurance. Second, reference pricing may induce a larger share of brand-biased consumers to purchase the brand-name drug, reducing the mismatch costs in this consumer segment. However, it is worth noting that excessive entry is partly due to total demand being inelastic. Moreover, if the regulator is paternalistic and ignores the preferences of the brand-biased consumers, then the second effect is no longer present.

Our model provides a framework to evaluate the impact of reference pricing in different markets. The overall effect on drug prices is generally ambiguous and ultimately an empirical question. The main empirical predictions of the model are that, (i) without price caps, generic entry should decrease by the introduction of reference pricing, and (ii) if price caps are present, the introduction of reference pricing may encourage generic entry if price caps are sufficiently binding.

By way of conclusion, we would like to mention some limitations of our study. First, we

place our analysis after patent expiration, and thus ignore the effect of regulation on research and development and incentives for originator to launch drugs in a given country (see, e.g., Kyle, 2007). Second, we also ignore non-price strategies that the brand producer can use to affect the generic firms' entry decision, including the launch of "me-too" versions or pseudo-generics (see, e.g., Gonçalvez et al., 2014). Finally, we abstract from the vertical relationship between producers and distributors, and pharmacies' incentives for promoting generic drug versions (see, e.g., Brekke et al., 2013). While analysing these aspects is out of the scope of this paper, it is in our research agenda.

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

$$\pi_b\left(p_b^*(n), p_g^*(n)\right) - p_g^*(n) = \frac{\begin{pmatrix} \lambda(1-\lambda)^2 t_b^2 + 8(2\lambda-1) t_b t_g \\ -4\lambda\left(5(1-\lambda) t_g + \lambda t_b + \lambda^2(t_b - t_g)\right) t_g \end{pmatrix} t_b}{8n\alpha\left((1-\lambda) t_b + 3\lambda t_g\right)^2} > 0.$$

This condition holds if either λ is sufficiently high or t_g is sufficiently low relative to t_b, which is confirmed by considering the limits:

$$\lim_{\lambda \to 1}\left(\pi_b\left(p_b^*(n), p_g^*(n)\right) - p_g^*(n)\right) > \frac{t_b}{18\alpha n} > 0,$$

$$\lim_{t_g \to 0}\left(\pi_b\left(p_b^*(n), p_g^*(n)\right) - p_g^*(n)\right) = \frac{\lambda t_b}{8\alpha n} > 0.$$

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): First, a restriction on parameter values is needed to ensure that the interval of r established in the first part of the Lemma is non-empty:

$$\overline{r} - \underline{r} = \frac{t_b\left((1-\lambda) t_b + 3\lambda t_g\right)\left(t_b \alpha(1-\lambda) - 2t_g(1-\lambda(1+\alpha))\right)}{2n\left((1-\lambda)(1+\alpha) t_b + 2\lambda(2+\alpha) t_g\right)\left((1-\lambda) t_b \alpha + \lambda t_g(2\alpha+1)\right)} > 0.$$

This condition holds if $t_b\alpha(1-\lambda) - 2t_g(1-\lambda(1+\alpha)) > 0$, which requires that either λ is sufficiently high or t_g is sufficiently low relative to t_b. Second, we need 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

$$\pi_b\left(p_b^*(r,n), p_g^*(r,n)\right) - p_g^*(r,n) > 0.$$

Using (24) and (26), it is possible to show that this condition holds if λ is sufficiently high or if t_g is sufficiently low relative to t_b. Consider first the following limit:

$$\lim_{\lambda\to 1}\left[\pi_b\left(p_b^*(r,n), p_g^*(r,n)\right) - p_g^*(r,n)\right] = \frac{\left[\begin{array}{c}(4\alpha-3)\,t_b^2 \\ +2nr(1-\alpha)\left((4\alpha+3)\,t_b + 2n\alpha(1-\alpha)\,r\right)\end{array}\right]}{18\alpha n t_b}.$$

Notice that this expression is monotonically increasing in r. By setting r at the lower bound, $r = \underline{r}$, the expression reduces to

$$\frac{\alpha^2 t_b}{2n(2\alpha+1)^2} > 0,$$

which implies that $\lim_{\lambda\to 1}\left[\pi_b\left(p_b^*(r,n), p_g^*(r,n)\right) - p_g^*(r,n)\right] > 0$ for all $r \in (\underline{r}, \overline{r})$. Consider next the following limit:

$$\lim_{t_g\to 0}\left[\pi_b\left(p_b^*(r,n), p_g^*(r,n)\right) - p_g^*(r,n)\right] = \frac{\lambda\left(2(1-\alpha)nr + t_b\right)^2}{8t_b n} > 0.$$

Thus, by continuity, the equilibrium exists for a parameter set characterised by a sufficiently large λ or a sufficiently small t_g (relative to t_b). *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

$$\pi_b\left(p_b^*(\beta,n), p_g^*(\beta,n)\right) - p_g^*(\beta,n) > 0.$$

By using (35) and (37) we can derive the sign of the following limits:

$$\lim_{\lambda\to 1}\left[\pi_b\left(p_b^*(\beta,n), p_g^*(\beta,n)\right) - p_g^*(\beta,n)\right] = \frac{\lambda t_b}{8\theta n} > 0,$$

$$\lim_{t_g \to 0} \left[\pi_b \left(p_b^* (\beta, n), p_g^* (\beta, n) \right) - p_g^* (\beta, n) \right] = \frac{t_b \left(\beta + \alpha (n - \beta) \right)^2}{2\theta n \left(\beta (1 - \alpha)(n + 2) + 3n\alpha \right)^2} > 0.$$

By continuity, it follows that $\pi_b \left(p_b^* (\beta, n), p_g^* (\beta, n) \right) > p_g^* (\beta, n)$ for a parameter set characterised by a sufficiently large λ or a sufficiently small t_g (relative to t_b). *Q.E.D.*

Proof of Proposition 1 (i) *Exogenous reference pricing versus pure coinsurance*: Comparing (23) and (11), the change in the equilibrium brand-name price is

$$p_b^* (r, n) - p_b^* (n) = -\frac{(1 - \alpha) \left(2 (1 + \lambda) t_b t_g + (1 - \lambda) t_b^2 - 2nr\alpha \left((1 - \lambda) t_b + 2\lambda t_g \right) \right)}{4n\alpha \left((1 - \lambda) t_b + 3\lambda t_g \right)}.$$

The sign of this expression depends on the sign of the numerator, which is monotonically decreasing in r and, evaluated at $r = \overline{r}$, becomes

$$(1 - \alpha) \left(\frac{t_b \left((1 - \lambda) t_b + 2 (1 + \lambda) t_g \right) \left((1 - \lambda) t_b + 4\lambda t_g \right)}{t_b (1 - \lambda)(\alpha + 1) + 2\lambda (\alpha + 2) t_g} \right) > 0.$$

Thus, $p_b^* (r, n) - p_b^* (n) < 0$ for all $r \in (\underline{r}, \overline{r})$. Comparing (24) and (12), the change in the equilibrium generic price is

$$p_g^* (r, n) - p_g^* (n) = -\frac{\lambda t_g (1 - \alpha) r}{\alpha \left((1 - \lambda) t_b + 3\lambda t_g \right)} < 0.$$

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

$$D_b \left(p_b^* (r, n), p_g^* (r, n) \right) - D_b \left(p_b^* (n), p_g^* (n) \right) = \frac{nr\lambda (1 - \alpha) \left((1 - \lambda) t_b + 2\lambda t_g \right)}{t_b \left((1 - \lambda) t_b + 3\lambda t_g \right)} > 0.$$

(ii) *Endogenous reference pricing versus pure coinsurance*: Since all equilibrium variables under endogenous reference pricing are monotonic in β, and since the equilibria under endogenous reference pricing and pure 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

$$\frac{\partial p_b^* (\beta, n)}{\partial \beta} = -\frac{(1 - \alpha) t_b \left(n\alpha^2 \Phi_1 + 2\beta\lambda t_g (1 - \alpha)(n + 2) \Phi_2 \right)}{4n\theta^2 \left(n\alpha \left(t_b (1 - \lambda) + 3\lambda t_g \right) + \beta\lambda t_g (1 - \alpha)(n + 2) \right)^2} < 0,$$

where

$$\Phi_1 := 2\lambda(2-\lambda)t_g^2 + n\left(2\lambda t_g(3(1-\lambda)t_b + t_g(1+4\lambda)) + t_b^2(1-\lambda)^2\right) > 0,$$

$$\Phi_2 := \beta t_g(1-\alpha)(n+\lambda) + \alpha n(t_b(1-\lambda) + 2(1+\lambda)t_g) > 0,$$

and

$$\frac{\partial p_g^*(\beta,n)}{\partial\beta} = -\frac{\lambda t_b t_g^2(1-\alpha)(2-\lambda)(n+2)}{2\left(n\alpha(t_b(1-\lambda)+3\lambda t_g) + \beta\lambda t_g(1-\alpha)(n+2)\right)^2} < 0,$$

$$\frac{\partial D_b\left(p_b^*(\beta,n), p_g^*(\beta,n)\right)}{\partial\beta} = \frac{n\alpha\lambda t_g(1-\alpha)(2-\lambda)(2\lambda t_g(n-1) + (1-\lambda)t_b n)}{2\left(n\alpha(t_b(1-\lambda)+3\lambda t_g) + \beta\lambda t_g(1-\alpha)(n+2)\right)^2} > 0.$$

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 $\overline{p}$ is trivial. The lower bound on $\overline{p}$ is determined by the condition that the price cap does not bind for the generics producers in equilibrium: $\overline{p} > p_g^*(\overline{p},n)$ if $\overline{p} > \frac{(1-\lambda)t_b t_g}{n\alpha((1-\lambda)t_b+2\lambda t_g)}$. Part (ii): First, we need to ensure that the interval of $\overline{p}$ defined in the first part of the Lemma is non-empty. This requires

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

It is straightforward to see that this condition holds if λ is sufficiently high or t_g is sufficiently low relative to t_b. In addition, equilibrium existence requires that it is not profitable for the brand-name producer to deviate by setting $p_b = p_g^*(\overline{p},n)$, capturing the whole market, and obtaining a profit $p_g^*(\overline{p},n)$. Such a deviation is not profitable if

$$\begin{aligned} & \pi_b\left(\overline{p}, p_g^*(\overline{p},n)\right) - p_g^*(\overline{p},n) \\ = & \frac{n\alpha\lambda\overline{p}((1-\lambda)t_b+2\lambda t_g)(t_b-2n\alpha\overline{p}) - (1-\lambda)t_b^2 t_g}{nt_b\alpha((1-\lambda)t_b+4\lambda t_g)} > 0. \end{aligned}$$

This condition holds if λ is sufficiently high or t_g is sufficiently low relative to t_b, as can

be seen by considering the following limits:

$$\lim_{\lambda \to 1} \left(\pi_b \left(\overline{p}, p_g^* \left(\overline{p}, n \right) \right) - p_g^* \left(\overline{p}, n \right) \right) = \frac{\overline{p} \left(t_b - 2n\alpha \overline{p} \right)}{2t_b} > 0,$$

$$\lim_{t_g \to 0} \left(\pi_b \left(\overline{p}, p_g^* \left(\overline{p}, n \right) \right) - p_g^* \left(\overline{p}, n \right) \right) = \frac{\lambda \overline{p} \left(t_b - 2n\alpha \overline{p} \right)}{t_b} > 0,$$

where $t_b - 2n\alpha\overline{p} > 0$ for all values of $\overline{p}$ within the interval defined by the first part of Lemma 4. *Q.E.D.*

Proof of Proposition 2 In the case of *endogenous reference pricing*, the price cap is binding under pure coinsurance, but not under reference pricing if $max\{\frac{(1-\lambda)t_b t_g}{n\alpha((1-\lambda)t_b+2\lambda t_g)}, p_b^*(\beta, n)\} < \overline{p} < \frac{((1-\lambda)t_b+2(1+\lambda)t_g)t_b}{4n\alpha((1-\lambda)t_b+3\lambda t_g)}$, where $p_b^*(\beta, n)$ is defined in (34). It is easy to check that, for λ high enough or t_g small enough, $p_b^*(\beta, n) > \frac{(1-\lambda)t_b t_g}{n\alpha((1-\lambda)t_b+2\lambda t_g)}$. The change in the equilibrium generic price is given by a comparison of (35) and (41). Since $p_g^* \left(\beta, n \right)$ does not depend on $\overline{p}$ and $p_g^* \left(\overline{p}, n \right)$ is monotonically increasing in $\overline{p}$, it follows that $p_g^* \left(\beta, n \right) - p_g^* \left(\overline{p}, n \right)$ is monotonically decreasing in $\overline{p}$. The price difference $p_g^* \left(\beta, n \right) - p_g^* \left(\overline{p}, n \right)$, when evaluated at the relevant lower bound $\overline{p} = p_b^*(\beta, n)$, $\Delta p_g^{end}|_{\overline{p}=p_b(\beta,n)}$, is given by

$$\beta\lambda t_b t_g \left(1 - \alpha \right) \frac{\left(1 - \lambda \right) \left(n\alpha t_b - 2\beta t_g \left(1 - \alpha \right) \left(n + 2 \right) \right) + 2\alpha t_g \left(n \left(2\lambda - 1 \right) - 2 + \lambda \right)}{2n\alpha \left(\left(1 - \lambda \right) t_b + 4\lambda t_g \right) \theta \left(n\alpha \left(\left(1 - \lambda \right) t_b + 3\lambda t_g \right) + \beta\lambda t_g \left(1 - \alpha \right) \left(n + 2 \right) \right)}.$$

The sign of this expression depends on the sign of the numerator and it is easily seen that this is positive if λ is sufficiently close to one or if t_g is sufficiently small. This implies that, if λ is high enough or t_g small enough, $p_g^* \left(\beta, n \right) > p_g^* \left(\overline{p}, n \right)$ for values of $\overline{p}$ sufficiently close to the lower bound. The brand-name market share difference $D_b \left(p_b^* \left(\beta, n \right), p_g^* \left(\beta, n \right) \right) - D_b \left(\overline{p}, p_g^* \left(\overline{p}, n \right) \right)$, when evaluated at the lower bound $\overline{p} = p_b(\beta, n)$, $\Delta D_b^{end}|_{\overline{p}=p_b(\beta,n)}$, is given by

$$-\beta\lambda \left(1 - \alpha \right) \frac{\left[\begin{array}{c} 4\alpha\lambda \left(2 - \lambda \right) t_g^2 + 2\beta t_g \left(1 - \alpha \right) \lambda \left(\left(1 - \lambda \right) t_b + 4t_g \right) \\ + n \left(\left(1 - \lambda \right) t_b + 2\lambda t_g \right) \left[\alpha \left(\left(1 - \lambda \right) t_b + 2 \left(2\lambda - 1 \right) t_g \right) - 2 \left(1 - \lambda \right) \left(1 - \alpha \right) \beta t_g \right] \end{array} \right]}{2 \left(\left(1 - \lambda \right) t_b + 4\lambda t_g \right) \theta \left(\beta\lambda t_g \left(1 - \alpha \right) \left(n + 2 \right) + n\alpha \left(\left(1 - \lambda \right) t_b + 3\lambda t_g \right) \right)}.$$

A sufficient condition for the sign of this expression to be negative is that the expression

in the square brackets in the last term of the numerator is positive. It is easily seen that this is true if λ is sufficiently close to one or if t_g is sufficiently small. This implies that, if λ is high enough or t_g small enough, $D_b\left(p_b^*(\beta,n), p_g^*(\beta,n)\right) < D_b\left(\overline{p}, p_g^*(\overline{p},n)\right)$ for values of $\overline{p}$ sufficiently close to the lower bound. For the case of *exogenous reference pricing*, the price cap is binding under pure coinsurance, but not under reference pricing if $max\{\frac{(1-\lambda)t_b t_g}{n\alpha((1-\lambda)t_b+2\lambda t_g)}, p_b^*(r,n)\} < \overline{p} < \frac{((1-\lambda)t_b+2(1+\lambda)t_g)t_b}{4n\alpha((1-\lambda)t_b+3\lambda t_g)}$, where $p_b^*(r,n)$ is defined in (23). It is easy to check that, for λ high enough or t_g small enough, $p_b^*(r,n) > \frac{(1-\lambda)t_b t_g}{n\alpha((1-\lambda)t_b+2\lambda t_g)}$. A comparison of (24) and (41), and a similar comparison of (25) and (42), shows that $p_g^*(r,n) > p_g^*(\overline{p},n)$ and $D_b\left(p_b^*(r,n), p_g^*(r,n)\right) > D_b\left(\overline{p}, p_g^*(\overline{p},n)\right)$ if the price cap is below a threshold value given by

$$\widehat{p} := \frac{t_b\left(t_b(1-\lambda)+2t_g(\lambda+1)\right)-2nr(1-\alpha)\left((1-\lambda)t_b+4\lambda t_g\right)}{4n\alpha\left((1-\lambda)t_b+3\lambda t_g\right)}.$$

Thus, if $\overline{p} < \widehat{p}$, exogenous reference pricing leads to higher generic prices and lower brand-name market shares (compared with pure coinsurance). It remains to show that the parameter set defined by $\overline{p} < \widehat{p}$ is non-empty. As long as λ is high enough and t_g is low enough, the relevant lower bound is $p_b^*(r,n)$, which is always lower than $\widehat{p}$. *Q.E.D.*

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Tables

Table 1: Endogenous reference pricing and generic entry (Case 1)

		Pure coinsurance	Endogenous RP		Exogenous RP
			$\beta = 0.5$	$\beta = 1$	
	n^*	7	4	3	2
	p_b	0.486	0.322	0.261	0.448
	p_g	0.259	0.259	0.190	0.381
$\alpha = 0.2$	r	n/a	0.275	0.190	0.4
	D_b	0.647	0.735	0.745	0.851
	p_{av}	0.406	0.298	0.243	0.438
	c_{av}	0.081	0.087	0.091	0.120
	n^*	5	3	3	2
	p_b	0.340	0.345	0.250	0.405
	p_g	0.181	0.214	0.166	0.295
$\alpha = 0.4$	r	n/a	0.280	0.166	0.320
	D_b	0.647	0.689	0.711	0.770
	p_{av}	0.284	0.304	0.225	0.380
	c_{av}	0.114	0.149	0.126	0.191
	n^*	4	3	3	2
	p_b	0.284	0.293	0.240	0.374
	p_g	0.151	0.170	0.147	0.274
$\alpha = 0.6$	r	n/a	0.232	0.147	0.25
	D_b	0.647	0.670	0.685	0.711
	p_{av}	0.237	0.253	0.211	0.337
	c_{av}	0.142	0.168	0.152	0.238

Parameter values: $\lambda = 0.95$; $t_g = t_b = 2$; $f = 0.0127$

Table 2: Endogenous reference pricing and generic entry (Case 2)

		Pure coinsurance	Endogenous RP		Exogenous RP
			$\beta = 0.5$	$\beta = 1$	
	n^*	7	6	5	3
	p_b	0.969	0.425	0.332	0.718
	p_g	0.151	0.156	0.165	0.211
$\alpha = 0.2$	r	n/a	0.290	0.165	0.7
	D_b	0.407	0.459	0.499	0.646
	p_{av}	0.484	0.279	0.248	0.538
	c_{av}	0.097	0.150	0.117	0.117
	n^*	4	4	4	3
	p_b	0.847	0.509	0.371	0.623
	p_g	0.132	0.125	0.119	0.131
$\alpha = 0.4$	r	n/a	0.317	0.119	0.6
	D_b	0.407	0.428	0.446	0.561
	p_{av}	0.423	0.289	0.232	0.407
	c_{av}	0.169	0.165	0.160	0.170
	n^*	4	3	3	3
	p_b	0.565	0.578	0.472	0.547
	p_g	0.088	0.114	0.111	0.101
$\alpha = 0.6$	r	n/a	0.346	0.111	0.5
	D_b	0.407	0.416	0.425	0.492
	p_{av}	0.282	0.307	0.265	0.320
	c_{av}	0.169	0.223	0.220	0.201

Parameter values: $\lambda = 0.75$; $t_g = 0.1$; $t_b = 5$; $f = 0.0127$