Online Appendix
Price Dynamics of Swedish Pharmaceuticals

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Contents

A Extension of the Model: Triopoly

For $N = \{1,2,3\}$, I derive a general MPE for the two most common situations of the pharmaceutical market, namely (1) when three generics with equal shares of patients with a brand preference are competing such that $l_1 = l_2 = l_3 = l^L$ and (2) when two generic products compete with a branded product such that $l_1 = l^H > l^L = l_2 = l_3$ (i.e., one firm has a greater share of patients with brand preference than the other firms have).

In the first case, the three firms selling generics complete equally.

Proposition 3. *The game $\mathscr{G}(x^1)$ with $N = \{1,2,3\}$, $l_1 = l_2 = l_3 = l^L = l$, $\delta \in (0,1)$ given any initial state $x^1 \in \mathscr{L}$ has an MPE defined by the following conditions:*

1. *Strategies $\mathscr{S}_j$ for all $j \in N$:*

$$S_j : \begin{cases} p_j = R & \text{if } x = j \\ p_j \sim F(p) = \frac{p(1+l)+\delta V(\cdot|x=j)-V(\cdot|x\neq j)}{p+\delta(V(\cdot|x=j)-V(\cdot|x\neq j))} \quad \text{for } p \in [\underline{p}, R] & \text{if } x \neq j \end{cases}$$

2. *Valuation functions:*

$$V(\underline{p}|x\neq j) = \frac{\underline{p}(1+l)+\delta R(\theta+l)}{1-\delta^2} \qquad \text{where } \underline{p} = \frac{R(l-\delta\theta)}{1+l}$$
$$V(\underline{p}|x=j) = \frac{R(\theta+l)+\delta \underline{p}(1+l)}{1-\delta^2}$$

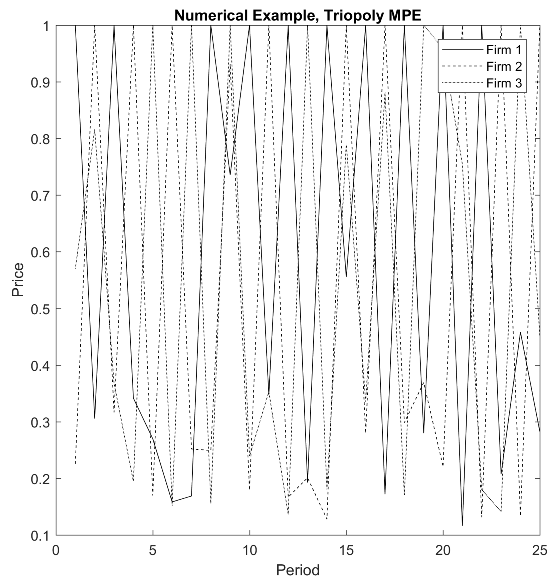
Proof. The proof for the mixed strategy equilibrium of those firms in state $x \neq j$ is analogous to the presented proof in Proposition 1 and is therefore omitted. The major difference is that two firms in state $x \neq j$ have no habit persistent patients. Therefore their valuation function given p and the probability distribution of the opponent in a state without habit persistent patients, donated by $F(p)$ can be written as $V(\cdot|x \neq j) = p[(1-F(p))+l] + \delta[(1-F(p))V(\cdot|x = j) + F(p)V(\cdot|x \neq j)]$. This equation equals $F(p) = \frac{p(1+l)+\delta V(\cdot|x=j)-V(\cdot|x\neq j)}{p+\delta(V(\cdot|x=j)-V(\cdot|x\neq j))}$. For $p = \underline{p}$ we get $F(\underline{p}) = 0$ and therefore $V(\cdot|x \neq j) = \underline{p}(1+l) + \delta V(\cdot|x = j)$. On the other side the firm with habit persistent patients (in state $x = j$) has a valuation of $V(\cdot|x = j) = R(\theta+l) + \delta V(\cdot|x \neq j)$ as she plays a pure strategy by setting the price equal to the price ceiling with certainty. Substitution gives $V(\cdot|x \neq j) = \frac{\underline{p}(1+l)+\delta R(\theta+l)}{1-\delta^2}$ and $V(\cdot|x = j) = \frac{R(\theta+l)+\delta \underline{p}(1+l)}{1-\delta^2}$. The firms without habit persistent patients are indifferent to setting a price equal to R and to $\underline{p}$ if $Rl + \delta V(\cdot|x \neq j) = \underline{p}(1+l) + \delta V(\cdot|x = j)$ which can be rearranged to $\underline{p} = \frac{R(l-\delta\theta)}{1+l}$. One concludes that the firm without habit persistent patients will never set a price lower than this lower bound.

Finally, the Markov Perfect Equilibrium requires that the firm with habit persistent patients (state $x = j$) does not deviate from his pure strategy of setting a price equal to R. Deviating would give a continuation payoff of $V(\cdot|x = j)^{DEV} = \underline{p}(1+l+\theta) + \delta V(\cdot|x = j)$. The firm in state $x = j$ does not deviate if $V(\cdot|x = j) \geq V(\cdot|x = j)^{DEV}$. The condition is satisfied if $\underline{p} \leq \frac{R(\theta(1-\delta)+l)}{1+\theta+l}$. As the minimum support of the strategies from the firms without habit persistent patients is represented by $\underline{p} = \frac{R(l-\delta\theta)}{1+l}$, the condition is always satisfied.

□

Numerical Example. I present a numerical example of the Markov perfect equilibrium. Again, I simulate the prices of the presented strategy with the following parameter values which are the same as before: $l = \frac{1}{3}$, $\theta = .2$, $\delta = .95$ and $R = 1$. Figure 1 shows the price simulation for 50 periods.

Figure 1: Example MPE



Example of Markov Perfect equilibrium with $l = \frac{1}{3}$, $\theta = .2$, $\delta = .95$ *and* $R = 1$.

The firm with habit-persistent patients is charging the maximum price R with certainty. The two remaining firms compete for the new patients. As in the duopoly MPE, the two firms without habit-persistent patients randomize their prices. At the same time, the firm with habit-persistent patients has no incentive to deviate given the minimum support $\underline{p}$. As both randomizing firms have no habit-persistent patients, the minimum support is lower than in the MPE of a duopoly. The essential difference from the MPE of duopolists is that the firm with the lowest price always increases its price in the following period.

In the second case, one branded firm (firm 1) has a higher mass of patients with a brand preference than two generic firms (firm 2 and 3).

Proposition 4. *The game* $\mathscr{G}(x^1)$ *with* $N = \{1,2,3\}$, $l_1 = l^H > l^L = l_2 = l_3$, $\delta \in (0,1)$ *given any initial state* $x^1 \in \mathscr{L}$ *has an MPE defined by the following conditions:*

1. *Strategies $\mathscr{S}_j$ for $j \in N$:*

$$S_1 : p_1 = R$$

$$S_j : \begin{cases} p_j \sim F(p) = \frac{p(1+l^L+\theta)-V(\cdot|x=j)(1-\delta)}{p+\delta(V(\cdot|x=j)-V(\cdot|x\neq j))} & \text{for } p \in [\underline{p}, R] \quad \text{if } x \neq j \quad \text{for all } j \in \{2,3\} \\ p_j \sim F_1^j(p) = \frac{p(1+l^L)+\delta V(\cdot|x=j)-V(\cdot|x\neq j)}{p+\delta(V(\cdot|x=j)-V(\cdot|x\neq j))} & \text{for } p \in [\underline{p}, R] \quad \text{if } x = j \quad \text{for all } j \in \{2,3\} \end{cases}$$

2. *Valuation functions:*

$$V_j = \frac{Rl^H}{1-\delta} \qquad \text{for } j = 1$$

$$V_j(\underline{p}|x \neq j) = \frac{\underline{p}(1+l^L+\theta\delta)}{1-\delta} \qquad \text{for all } j \in \{2,3\}$$

$$V_j(\underline{p}|x = j) = \frac{\underline{p}(1+l^L+\theta)}{1-\delta} \qquad \text{for all } j \in \{2,3\}$$

3. *Where $\underline{p}$ satisfies:*

$$\underline{p} = \frac{(\theta+l^L)}{1+l^L+\theta+\delta\theta} \leq \frac{R(l^H-\delta\theta)}{1+l^H}{}^{1} \tag{1}$$

Proof. The proof for firms $j=2$ and $j=3$ which are playing mixed strategies is identical to those strategies of the firms in a duopoly presented in Proposition 1. Therefore I omit the repetition. It remains to show that the pure strategy of firm $j=1$ is sustainable in the equilibrium. Firm A sets a price of R independent of the state which gives a valuation function of $V_1 = \frac{Rl^H}{1-\delta}$. A one shot deviation would give $V_1^{DEV} = \underline{p}(l^H+1) + \delta R(l^H+\theta) + \frac{\delta^2 Rl^H}{1-\delta}$. Firm $j=1$ does not deviate if $V_1 \geq V_1^{DEV}$. This condition can be rewritten as $\underline{p} \leq \frac{R(l^H-\delta\theta)}{1+l^H}$. Given the minimum support and this upper bound of $\underline{p}$ the we get the condition for $\underline{p}$, namely: $\underline{p} = \frac{R(\theta+l^L)}{1+l^L+\theta+\delta\theta} \leq \frac{R(l^H-\delta\theta)}{1+l^H}$. □

In this MPE, the supplier of a branded product charges the highest possible price R. The two remaining firms with a generic product set their price as in a duopoly. Both randomize their prices, and the firm with habit-persistent patients has a higher possibility of charging a higher price. To guarantee the existence of this equilibrium, the firm of the branded product should have no incentive to deviate from charging R. Given a sufficiently low minimum support $\underline{p}$, the branded product firm has no incentive to deviate. Thus, relative to the value of the habit-persistent patients, the differential between the share of patients with a brand preference for the branded product and the share of patients with a brand preference for the non-branded product has to be sufficiently large.

[1] If all parameters are positive, this expression reduces to $l^H - l^L \geq (1+\delta)\theta$.

Collusion between generics: In a triopoly, one may observe a different kind of collusion scheme.[2] A collusion scheme with two firms is achievable if one focuses on the case of heterogeneous bases of patients with a brand preference. In the following, I present an SPE in which the two firms with l^L implement a tacit collusion scheme in which they rotate prices. At the same time, the firm with a higher base of patients with a brand preference $l^H > l^L$ has no incentive to deviate from charging a price equal to the price ceiling. The punishment of deviation is reversion to the previous MPE, defined in Proposition 4.

Proposition 5. *The game $\mathscr{G}^{SP}(x^1)$ with $N = \{1,2,3\}$, $l_1 = l^H > l^L = l_2 = l_3$, $\delta \in (0,1)$ given any initial state $x^1 \in \mathscr{L}$ has SPE of the following strategies:*

$$\mathscr{S}_j^t : p_j^t = R \quad \text{for } j = 1$$

$$\mathscr{S}_j^t : \begin{cases} p_j^t = R & \text{if } x^t = j \text{and } t = 1 \quad \text{for all } j \in \{2,3\} \\ p_j^t = \underline{p} & \text{if } x^t \neq j \text{and } t = 1 \quad \text{for all } j \in \{2,3\} \\ p_j^t = R & \text{if } p_j^{t-1} = \underline{p} \text{ and } p_{-j}^{t-1} = R \quad \text{for all } t > 1 \quad \text{and } j \in \{2,3\} \\ p_j^t = \underline{p} & \text{if } p_j^{t-1} = R \text{ and } p_{-j}^{t-1} = \underline{p} \quad \text{for all } t > 1 \quad \text{and } j \in \{2,3\} \\ \text{Reversion to MPE} & \text{otherwise} \quad \text{for all } j \in \{2,3\} \end{cases}$$

Where in each equilibria $\underline{p}$ satisfies:

$$\underline{p} \in \left(R(1 - \frac{\delta^2(1+\delta\theta)}{1+l^L+\theta+\delta\theta}, \frac{R(l^H - \delta\theta)}{1+l^H} \right)$$

Proof. Firstly, notice that the punishment strategy is the reversion to the MPE in Proposition 4. Therefore the equilibrium is based on the assumption that $\frac{R(\theta+l^L)}{1+l^L+\theta+\delta\theta} \leq \frac{R(l^H-\delta\theta)}{1+l^H}$ as presented before. We will see that this assumption is also incorporated by the condition on $\underline{p}$.
The proof for the existence of the presented SPE for firm $j = 2$ and $j = 3$ is the same as the one presented in Proposition 2. Correspondingly the lower bound of the price for which the equilibria are possible is $\underline{p} > \max(\frac{R(l^L+\theta)}{1+l^L+\theta+\delta\theta}, R(1 - \frac{\delta^2(1+\delta\theta)}{1+l^L+\theta+\delta\theta}))$. It remains to show that firm $j = 1$ has no incentive to deviate. The profit of firm $j = 1$ from sticking to the pure strategy of playing R is the same as in the MPE presented in Proposition 4, namely $V_1 = \frac{Rl^H}{1-\delta}$. Deviating from his strategy would give $j = 1$ an initial profit of $(\underline{p} - \varepsilon)(1 + l^H)$ with $\varepsilon \to 0$ as she would undercut marginally. In the following periods all players play the MPE of Proposition 4. Therefore firm $j = 1$ plays the pure strategy of playing A. Note that firm $j = 1$ has a profit from habit persistent patients in the initial period after deviation such that the overall continuation function from deviation can be described as $V_1^{DEV} = (\underline{p} - \varepsilon)(1 + l^H) + \delta R(l^H + \theta) + \delta^2 \frac{R(1+l^H)}{1-\delta}$. The condition that firm $j = 1$ does not deviate is expressed by $V_1 \geq V_1^{DEV}$ which is equivalent to $\underline{p} \leq \varepsilon + \frac{R(l^H-\delta\theta)}{1+l^H}$. As $\varepsilon \to 0$ we

[2] It may be possible that three firms take part in a collusion scheme. In the analysis, I focus on the analysis of collusion schemes with two firms. In line with previous research, the coordination of three firms requires more patience by firms, all else being equal.

can rewrite the condition as $\underline{p} \in \left(\max\left\{\frac{R(l^L+\theta)}{1+l^L+\theta+\delta\theta}, R(1-\frac{\delta^2(1+\delta\theta)}{1+l^L+\theta+\delta\theta})\right\}, \frac{R(l^H-\delta\theta)}{1+l^H}\right)$ equilibria are sustainable. As it holds that

$$R\left(1-\frac{\delta^2(1+\delta\theta)}{1+l^L+\theta+\delta\theta}\right)-\left(\frac{R(l^L+\theta)}{1+l^L+\theta+\delta\theta}\right)=\frac{R(1-\delta^2)(\theta\delta+1)}{l^L+\theta+\theta\delta+1}>0,$$

one may write the lower bound as:

$$\underline{p} \in \left(R(1-\frac{\delta^2(1+\delta\theta)}{1+l^L+\theta+\delta\theta}, R\right)$$

□

One restriction of such an SPE is that $\underline{p}$ is bounded from below as well as from above. On the one side, the firm with l^L patients with a brand preference and no habit-persistent patients should have no incentive to increase its price from $\underline{p}$, which results in a lower bound. On the other side, the firm with l^H should have no incentive to decrease its price from R, which leads to the upper bound. Due to the tight bounds, existence of the equilibrium is not guaranteed. A comparison of the upper and lower bound shows that the set of equilibria is non-empty if $l^H > \frac{3-2\delta^2+2\theta(1+\delta)}{1+2\delta^2}$.[3] Thus, the original manufacturer would need a relatively large amount of patients with a brand preference.[4]

Oligopoly with more than three firms

In the case of $|N| \geq 4$, I do not completely characterize the MPE and possible collusion schemes in SPE. However, I will highlight some main features that will hold even with $|N| \geq 4$. First, consider Markov strategies. A firm with locked-in patients has an incentive to increase its price up to the maximum price. The intuition is the same as for three competitors, where all suppliers are offering generic products: at least two firms without locked-in patients offer a generic product. These firms compete for new patients. Correspondingly, the firm with locked-in patients has no incentive to lower its price given the higher base of price-inelastic patients. I expect that the price of the cheapest product (product of the month) will increase in the forthcoming month.

I already have noted that rotation schemes that form a SPE have more requirements for three firms than for two firms. However, the reasoning that one original brand product competes with two generics and that an original brand product has a higher mass of loyal consumers leads to the possibility of a rotational SPE where the generic products share the market but the original brand solely sets the highest possible price. If there are at least three firms that offer generic products, a collusion scheme will require a higher degree of coordination. A possible collusion scheme would

[3] I am grateful to an anonymous referee for suggesting this transformation.

[4] To get to the expression, subtract the upper from the lower bound and substitute demand of the generic firm by $l^L = (1-l^H)/2$.

be based on the three generics that share the market. Such a collusion mechanism increases the incentive to deviate. Within this paper, I focus on the collusion schemes of two firms. I predict that in markets with more than three firms, these collusion schemes would be less likely.

B Proof of Lemma 1

A monopolist sets $p^t = R$ in each time t independent of the history $\mathscr{H}_t$. The valuation for the monopolist is $V = \frac{R(1+l+\theta)}{1-\delta}$. By definition the equilibrium is Markov perfect as well as a Subgame perfect.

A monopolist faces a demand of $1+\theta+l$, which is price inelastic. The continuation value of a monopolist is solely the same payoff discounted by δ such that one may write the maximization problem for the monopolist can be described as:

$$\begin{aligned} \max_{p} \quad & \frac{p(1+\theta+l)}{1-\delta} \\ \text{subject to} \quad & p \in [0,R] \end{aligned}$$

Given $\theta \geq 0$ and $l > 0$, the optimal price for a monopolist is equal to the price ceiling $p^* = R$. The valuation of the monopolist is therefore equal to $V = \frac{R(1+l+\theta)}{1-\delta}$. Price setting forms an equilibrium as each period the monopolist is maximizing its profits.

C Proof of Lemma 2

The game $\mathscr{G}(x^1)$ with $N = \{1,2\}$ has no Markov perfect equilibrium in pure strategies.

I divide the proof into two parts. Firstly, I consider the situation with $\theta = 0$, i.e., no habit persistent patients. Secondly, I show that the claim is true for $\theta > 0$. In both cases I consider firms $i, j \in N$ where $i \neq j$. Note that the base of patients with a brand preference can be either the same such that $l_i = l_j = l$ or different, i.e., $l_i \neq l_j$.

Case with $\theta = 0$:

Firstly I show that same prices $p_j = p_i$ cannot form an equilibrium. Given that $\theta = 0$ it is sufficient to evaluate stage payoffs. Consider that firm j sets a price equal to $p_j \in P$. It is never optimal for a firm i to set the competitor's price as there (1) either exists a $\varepsilon > 0$ such that the payoff from undercutting is higher than the payoff from charging the same price, $(p_j - \varepsilon)(1+l_i) > p_j(1/2 + l_i)$ or (2) charging the upper bound price gives a higher price than marginally undercutting and therefore also changing the same price, $Rl_i > (p_j - \varepsilon)(1+l_i) > p_j(1/2+l_i)$

Secondly, I show that different prices cannot form an equilibrium. Given a price of an opponent $p_j \in P$ firm i either undercuts if $(p_j - \varepsilon)(1+l_i) > Rl_i$ or sets a price equal to the price ceiling if $(p_j - \varepsilon)(1+l_i) < Rl_i$. Consider first the case that $(p_j - \varepsilon)(1+l_i) > Rl_i$. The best reply for player i to price p_j is to set $p_i = p_j - \varepsilon$. These prices cannot form an equilibrium. *Proof by contradiction:* The equilibrium requires that firm j's profit from playing p_j is greater than undercutting $p_i = p_j - \varepsilon$ marginally. In terms of profits it requires that $p_j l_j \geq (p_j - 2\varepsilon)(1+l_j)$. Rewriting this condition gives $\varepsilon \geq \frac{p_j}{2(2+l_j)}$. As $\varepsilon \to 0$ I showed a contradiction. Secondly, suppose that $(p_j - \varepsilon)(1+l_i) < Rl_i$ such that the best reply from firm i is to charge $p_i = R$. These prices cannot form an equilibrium. *Proof by contradiction:* The equilibrium requires that firm j's profit from playing p_j is greater than undercutting $p_i = R$ marginally. In terms of profits it requires that $p_j(1+l_j) \geq (R-\varepsilon)(1+l_j)$. Rewriting this condition gives $p_j \geq R - \varepsilon$. As $\varepsilon \to 0$ and same price setting is not possible (see first part of the proof) I showed a contradiction.

Case with $\theta > 0$:

Next I consider pure strategy equilibria when with $\theta > 0$. In these cases one also considers continuation payoffs. Let V_1 and V_0 be the valuation function of a firm with and without habit persistent patients respectively. Note that the firm with habit persistent patients never undercuts as it receives the same payoff by charging the identical price as an opponent.

Firstly I show that the same prices $p_j = p_i$ cannot form an equilibrium. The reasoning is identical to the case without habit persistent patients. In detail, the firm without state dependent patients has an incentive to undercut the opponent. Consider firm j has a mass of habit persistent patients and sets a price p_j. Given that $V_1 > V_0$ firm i undercuts as there exists a ε for which undercutting gives a higher profit than setting $p_i = p_j$, i.e. $(p_j - \varepsilon)(1+l_i) + \delta V_1 > p_j l_i + \delta V_0$.

Secondly, I show that different prices cannot form an equilibrium. Again, consider that firm j has habit persistent patients ans sets a price p_j such that firm i without habit persistent patients undercuts marginally and sets $p_i = p_j - \varepsilon$. The prices cannot form an equilibrium. *Proof by contradiction:* Suppose the prices form an equilirbium. Firm j, the firm with habit persistent patients, has no incentive to deviate only if charging the same price as firm i as well as charging the maxmimum price would give a lower output. Formally, it is required that $p_j(l_j + \theta) + \delta V_0 \geq (p_j - \varepsilon)(1 + l_j + \theta) + \delta V_1$ and that $p_j(l_j + \theta) + \delta V_0 \geq R(l_j + \theta) + \delta V_0$. The first condition can be rewritten as $\varepsilon > \frac{p_j + \delta(V_1 - V_0)}{1 + l_j + \theta}$, the second as $p_j \geq R$. If $p_j \neq R$ the second condition is never fulfilled and therefore firm j has always an incentive to set a price R. If $p_j = R$, firm i undercuts marginally and the first condition is not satisfied as $\varepsilon \to 0$. I have showed a contradiction. Equal as well as different prices cannot form a pure strategy equilibrium.

D Proof of Proposition 1

The game $\mathscr{G}(x^1)$ with $N = \{1,2\}$, $l_1 = l_2 = l$, $\delta \in (0,1)$ and given any initial state $x^1 \in \mathscr{L}$ has a unique Markov perfect equilibrium in mixed strategies which is defined by the following conditions:

1. *Strategies $\mathscr{S}_j$ for $j \in N$:*

$$S_j = \begin{cases} p_j \sim F(p) & = \frac{p(1+l+\theta)-V(\cdot|x=j)(1-\delta)}{p+\delta(V(\cdot|x=j)-V(\cdot|x\neq j))} \quad for \quad p \in [\underline{p}, R] \quad if\, x \neq j \\ p_j \sim F(p) & = \frac{p(1+l)+\delta V(\cdot|x=j)-V(\cdot|x\neq j)}{p+\delta(V(\cdot|x=j)-V(\cdot|x\neq j))} \quad for \quad p \in [\underline{p}, R] \quad if\, x = j \end{cases}$$

2. *Valuation functions:*

$$\begin{aligned} V(\underline{p}, |x \neq j) &= \frac{\underline{p}(1+l+\delta\theta)}{1-\delta} \\ V(\underline{p}, |x = j) &= \frac{\underline{p}(1+l+\theta)}{1-\delta} \end{aligned} \quad where\ \underline{p} = \frac{R(\theta+l)}{1+l+\theta+\delta\theta}$$

Note first given that one may rewrite the continuation payoffs $V_j(\cdot|x \neq j)$ and $V_j(\cdot|x = j)$. Let $F_i(p_j|x = j)$ be the CDF of i's price given the price of firm j and $x = j$ for $i \in N$ $i \neq j$. Further, $F_i(p_j|x \neq j)$ is the CDF of an i's price if $x \neq j$ Therefore the continuation functions can be represent as:

$$V_j(p_j|x = j) = p_j(1 - F_i(p_j|x = j) + \theta + l_j) + \delta[(1 - F_i(p_j|x = j))V_j(\cdot|x = j) + F_i(p_j|x = j)V_j(\cdot|x \neq j)]$$
$$V_j(p_j|x \neq j) = p_j(1 - F_i(p_j|x \neq j) + l_j) + \delta[(1 - F_i(p_j|x \neq j))V_j(\cdot|x = j) + F_i(p_j|x \neq j)V_j(\cdot|x \neq j)]$$

The equations can be rewritten as:

$$F_i(p_j|x = j) = \frac{p_j(1+\theta+l_j) - V_j(\cdot|x = j)(1-\delta)}{p_j + \delta(V_j(\cdot|x = j) - V_j(\cdot|x \neq j))}$$
$$F_i(p_j|x \neq j) = \frac{p_j(1+l_j) - \delta V_j(\cdot|x = j) - V_j(\cdot|x \neq j)}{p_j + \delta(V_j(\cdot|x = j) - V_j(\cdot|x \neq j))}$$

Considering only symmetric equilibria the distribution functions for a firm $j \in N$ given a opponents price p are equal to

$$p_j \sim F(p) = \frac{p(1+l+\theta) - V(\cdot|x=j)(1-\delta)}{p+\delta(V(\cdot|x=j) - V(\cdot|x \neq j))} \quad \text{for} \quad p \in [\underline{p}, R] \quad \text{if } x \neq j$$
$$p_j \sim F(p) = \frac{p(1+l) + \delta V(\cdot|x=j) - V(\cdot|x \neq j)}{p+\delta(V(\cdot|x=j) - V(\cdot|x \neq j))} \quad \text{for} \quad p \in [\underline{p}, R] \quad \text{if } x = j$$

I divide the proof into several steps. Firstly, I show that under some assumptions, the support of the mixing substitutions has certain characteristics. Secondly, I show that the presented strategy satisfies previous assumptions and forms a Markov Perfect Equilibrium. My approach is closely related to Padilla (1995) and Anderson (1995)

Consider $\text{supp}(F(p)) = [\underline{p}, \bar{p}]$, for $x = j$ and $x \neq j$. (1) Assume that the upper support is defined as $\bar{p} = R$. (2) Further $\underline{p}$ as well as $\bar{p}$ are assigned with zero probability. (3) $V(\cdot|x=j) > V(\cdot|x \neq j)$.

First note that for each state x, no price in the interior of the support of F, $p \in$int(supp(F)), is assigned with a positive probability. Proof by contradiction: Suppose there exists a $p \in$int(supp(F)) for $x \neq j$ which is played with positive probability. Given $\varepsilon > 0$ there is an p', $p' \in (p-\varepsilon, p+\varepsilon)$, $p' \neq p$, that is not assigned a positive probability. The reasoning stems hat masspoints are not infinite. The firm with habit persistent patients ($x = j$) has the same masspoint in p. There exists a μ for which the firm with habit persistent patients ($x = j$) shifts density from the interval $(p, p+\mu)$ to p as $p(1+l+\theta) + \delta V(\cdot|x=j) > (p+\mu)(l+\theta) + \delta V(\cdot|x \neq j)$. For the firm, without habit persistent patients, it cannot be optimal to have a masspoint at p, as it can increase its profit by shifting its mass point from p to $p+\mu$. Therefore the firm in state $x \neq j$ has not a masspoint in p. The same reasoning holds for the firm with habit persistent patients ($x = j$). In detail the firm in $x \neq j$ would reply by undercutting and the firm with habit persistent patients could increase its profit by shifting its mass point.

Secondly, we note that for each state $x \in 1,2$ the interiors of the support, int(supp(F)) is connected. The reasoning for this statement is equivalent to the proof before. The interior of the support is solely connected if and only if it is an interval. If one firm has a gap in its interval, the opponent profits from shifting its density.

Thirdly, we challenge the assumption that $\underline{p}$ has a probability of being assigned equal to zero. The same reasoning as before applies. Consider a masspoint of the firm with no mass of habit persistent patients ($x \neq j$). The opponent has the incentive to shift density to the masspoint of the opponent. For the firm with habit persistent patients, it is optimal to shift the masspoint such that it cannot be an equilibrium. The same holds for the firm with habit persistent patients.

Finally note that under assumptions (1), (2) and (3) the valuation for the firm with habit persistent patients, $V(\cdot|x \neq j) = \bar{p}(1 - F(\bar{p}) + l_j) + \delta[(1 - F(\bar{p}))V(\cdot|x=j) + F(\bar{p})V(\cdot|x \neq j)]$ is increasing in $\bar{p} \leq R$ such that the maximum is attained for $p = R$ which implies the upper bound of the support that is equal to R[5].

$F(\underline{p}) = 0$ gives us the following equations:

$$\frac{\underline{p}(1+l+\theta) - V(\cdot|x=j)(1-\delta)}{\underline{p} + \delta(V(\cdot|x=j) - V(\cdot|x\neq j))} = 0$$
$$\frac{\underline{p}(1+l) + \delta V(\cdot|x=j) - V(\cdot|x\neq j)}{\underline{p} + \delta(V(\cdot|x=j) - V(\cdot|x\neq j))} = 0$$

Solving the equations simultaneously results in:

$$V(\cdot|x\neq j) = \frac{\underline{p}(1+l+\delta\theta)}{1-\delta}$$
$$V(\cdot|x=j) = \frac{\underline{p}(1+l+\theta)}{1-\delta}$$

The firm with habit persistent patients prefers to set a price equal to R if $R(l+\theta) + \delta V(\cdot|x\neq j) \geq p(1+l+\theta) + \delta V(\cdot|x=j)$. With the valuation functions it shows that all $p \leq \frac{R(\theta+l)}{1+l+\theta+\delta\theta}$ are dominated by $p = R$. The firm without habit persistent patients will therefore never set a price lower and we get the lower bound equal to $\underline{p} = \frac{R(\theta+l)}{1+l+\theta+\delta\theta}$.

We see that $V(\cdot|x=j) > V(\cdot|x\neq j)$ which satisfies assumption (3). Furthermore, the probability distributions F for $x = j$ and $x \neq j$ are proper probability measures that satisfy assumptions (1) and (2). We have constructed an equilibrium whereby construction the strategies satisfies indifference of both players among prices in the equilibrium support. The equilibrium is stationary and Markov Perfect.

By definition it is also Subgame Perfect. Each period the probability distributions and support constitutes a Nash equilibrium. Furthermore, the equilibrium in unique as the lower bound of the equilibrium support describes the entire equilibrium strategy, which is described by the distributions $F(p)$.

Numerical Example:

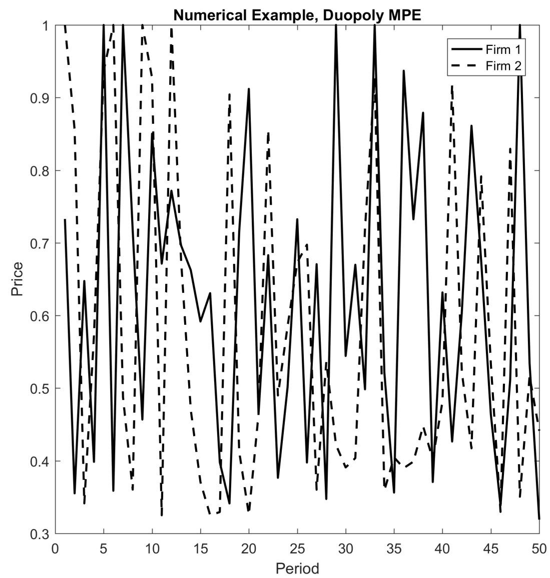
In the following, I present a brief numerical example of the final price development. I start by assigning numerical values for the parameters of the model. In detail let $l = .5$, $\theta = .2$, $\delta = .95$ and $R = 1$. Given these parameter the minimum support of prices is equal to $\underline{p} = 0.3704$ and the continuation functions for the states $x \neq j$ and $x = j$ are $V = 12.5185$ and $V = 12.5926$.

To estimate the pricing behavior, I use the inverse transform sampling method. Given the cumulative distribution functions, I am generating sample numbers at random. In detail, given a

[5] Note that this statement refers to strategies defined by the conditional distribution function and not pure strategies.

continuous variable $u \sim [0,1]$ and the invertible functions $F(p)$ for both states, I generate random prices p, as $p = F^{-1}(u)$ has a distribution of F. In short, for the price of a firm without habit persistent patients, I generate a random number u from the uniform distribution and then compute p such that $F(p) = u$. Figure 2 shows a simulation of prices for 50 periods for two firms that play the mixed Markov perfect equilibrium as presented before.

Figure 2: Example MPE



Example of Markov Perfect equilibrium with $l = .5$, $\theta = .2$, $\delta = .95$ and $R = 1$.

E MPE, Heterogenous Mass of Patients with Brand Preferences

The game $\mathscr{G}(x^1)$ with $N = \{1,2\}$, $l_1 = l^H > l^L = l_2$, $\delta \in (0,1)$ and given any initial state $x^1 \in \mathscr{L}$ has a unique Markov perfect equilibrium in mixed strategies which is defined by the following conditions:

1. *Strategies $\mathscr{S}_j$ for $j \in N$:*

$$S_1 = \begin{cases} p_1 \sim F(p) & = \frac{p(1+l^H+\theta)-V_1(\cdot|x=j)(1-\delta)}{p+\delta(V_1(\cdot|x=j)-V_1(\cdot|x\neq j))} \quad for \quad p\in[\underline{p}_2,R] \quad if\, x\neq j \\ p_1 \sim F(p) & = \frac{p(1+l^H)+\delta V_1(\cdot|x=j)-V_1(\cdot|x\neq j)}{p+\delta(V_1(\cdot|x=j)-V_1(\cdot|x\neq j))} \quad for \quad p\in[\underline{p}_1,R] \quad if\, x= j \end{cases}$$

$$S_2 = \begin{cases} p_2 \sim F(p) & = \frac{p(1+l^L+\theta)-V_2(\cdot|x=j)(1-\delta)}{p+\delta(V_2(\cdot|x=j)-V_2(\cdot|x\neq j))} \quad for \quad p\in[\underline{p}_1,R] \quad if\, x\neq j \\ p_2 \sim F(p) & = \frac{p(1+l^L)+\delta V_2(\cdot|x=j)-V_2(\cdot|x\neq j)}{p+\delta(V_2(\cdot|x=j)-V_2(\cdot|x\neq j))} \quad for \quad p\in[\underline{p}_2,R] \quad if\, x= j \end{cases}$$

2. *Valuation functions:*

$$V_1(\underline{p}_2|x=j) = \frac{\underline{p}_2(1+l^H+\theta)}{1-\delta}$$
$$V_1(\underline{p}_1,\underline{p}_2|x\neq j) = \underline{p}_1(1+l^H) + \frac{\delta\underline{p}_2(1+l^H+\theta)}{1-\delta}$$
$$V_2(\underline{p}_1|x=j) = \frac{\underline{p}_1(1+l^L+\theta)}{1-\delta}$$
$$V_2(\underline{p}_1|x\neq j) = \underline{p}_2(1+l^L) + \frac{\delta\underline{p}_1(1+l^L+\theta)}{1-\delta}$$

3. *A minimum support of the strategies:*

$$\underline{p}_1 = \frac{R(l^L+\theta)+\frac{\delta R(l^H+\theta)(1+l^L)}{(1+\delta)(1+\theta+l^H)}}{[1-\frac{\delta^2(\delta-1)^2(l^H+1)(l^L+1)}{(\delta^2-1)^2(1+\theta+l^H)(1+\theta+l^L)}](1+\delta)(1+\theta+l^L)}$$
$$\underline{p}_2 = \frac{R(l^H+\theta)+\frac{\delta R(l^L+\theta)(1+l^H)}{(1+\delta)(1+\theta+l^L)}}{[1-\frac{\delta^2(\delta-1)^2(l^H+1)(l^L+1)}{(\delta^2-1)^2(1+\theta+l^H)(1+\theta+l^L)}](1+\delta)(1+\theta+l^H)}$$

Note first that one can rewrite the continuation payoffs as in Proposition 1:

$$\begin{aligned} V_j(p_j|x=j) &= p_j(1-F_{-j}(p_j|x=j)+\theta+l_j)+ \\ &\quad \delta[(1-F_{-j}(p_j|x=j))V_j(\cdot|x=j)+F_{-j}(p_j|x=j)V_j(\cdot|x\neq j)] \\ V_j(p_j|x\neq j) &= p_j(1-F_{-j}(p_j|x\neq j)+l_j)+ \\ &\quad \delta[(1-F_{-j}(p_j|x\neq j))V_j(\cdot|x=j)+F_{-j}(p_j|x\neq j)V_j(\cdot|x\neq j)] \end{aligned}$$

One the one hand the difference to the situation of symmetric patients with brand preferences is that the distribution according to which the firms mix their prices may differ dependent if firm $j=1$ or $j=2$ is in the state with habit persistent patients. However, given that one firm is in a state with habit persistent patients ($x=j$) both firms have the same lower bound. A firm without habit persistent patients ($x \neq j$) do not sets a lower price than the minimum support of the distribution according to which the with habit persistent patients ($x = j$) is mixing. Therefore the strategies can be written as:

$$S_1 = \begin{cases} p_1 \sim F(p) & = \frac{p(1+l^H+\theta)-V_1(\cdot|x=j)(1-\delta)}{p+\delta(V_1(\cdot|x=j)-V_1(\cdot|x\neq j))} \quad \text{for} \quad p \in [\underline{p}_2, R] \quad \text{if } x \neq j \\ p_1 \sim F(p) & = \frac{p(1+l^H)+\delta V_1(\cdot|x=j)-V_1(\cdot|x\neq j)}{p+\delta(V_1(\cdot|x=j)-V_1(\cdot|x\neq j))} \quad \text{for} \quad p \in [\underline{p}_1, R] \quad \text{if } x = j \end{cases}$$

$$S_2 = \begin{cases} p_2 \sim F(p) & = \frac{p(1+l^L+\theta)-V_2(\cdot|x=j)(1-\delta)}{p+\delta(V_2(\cdot|x=j)-V_2(\cdot|x\neq j))} \quad \text{for} \quad p \in [\underline{p}_1, R] \quad \text{if } x \neq j \\ p_2 \sim F(p) & = \frac{p(1+l^L)+\delta V_2(\cdot|x=j)-V_2(\cdot|x\neq j)}{p+\delta(V_2(\cdot|x=j)-V_2(\cdot|x\neq j))} \quad \text{for} \quad p \in [\underline{p}_2, R] \quad \text{if } x = j \end{cases}$$

Given a minimum support $\underline{p}_1$ and $\underline{p}_2$, F equals zero such that the valuation functions are:

$$V_1(\underline{p}_2|x=j) = \frac{\underline{p}_2(1+l^H+\theta)}{1-\delta}$$
$$V_1(\underline{p}_1|x\neq j) = \underline{p}_1(1+l^H) + \frac{\delta \underline{p}_2(1+l^H+\theta)}{1-\delta}$$
$$V_2(\underline{p}_1|x=j) = \frac{\underline{p}_1(1+l^L+\theta)}{1-\delta}$$
$$V_2(\underline{p}_1|x\neq j) = \underline{p}_2(1+l^L) + \frac{\delta \underline{p}_1(1+l^L+\theta)}{1-\delta}$$

Solving the four equations gives us the lower supports of the distributions.

The proof is identical to the one presented in Proposition 1.

F Same Price Setting Subgame Perfect Equilibrium

As long as $\theta > 0$ the game $\mathscr{G}(x^1)$ with $N = \{1,2\}$ and $l_1 = l_2 = l$ has no Subgame Game equilibrium of the following strategies:

$$\mathscr{S}_{jt} = \begin{cases} p_j^t = R & \text{if } x^1 = j \quad \text{if } t = 1 \\ p_j^t = R & \text{if } x^1 \neq j \quad \text{if } t = 1 \\ p_j^t = R & \text{if } p_j^{t-1} = p_{-j}^{t-1} = R \quad \forall t > 1 \\ \text{Reversion to MPE} & \text{if } p_j^{t-1} \neq R \text{ or } p_{-j}^{t-1} \neq R \quad \forall t > 1 \end{cases}$$

However, such a SPE exists if $\theta = 0$.

Suppose the presented strategy is a Subgame Perfect Equilirbium and $\theta > 0$. The firm without habit persistent patients has a valuation function of $V(\cdot|x \neq j)^{SPE} = \frac{Rl}{1-\delta}$. Deviation would give the firm a one period profit of $\pi_0 = (R-\varepsilon)(1+l)$ with $\varepsilon > 0$. Given the continuation value by the Markov Perfect Equilibrium which we have described in Proposition 1 the valuation of deviation is $V(\cdot|x \neq j)^{DEV} = (R-\varepsilon)(1+l) + \delta VV(\cdot|x = j)^{MPE}$, where $V(\cdot|x = j)^{MPE}$ is the valuation of the Markov Perfect Equilibrium described in Proposition 1. There exists a sufficiently small $\varepsilon > 0$ such that it is always optimal for the firm with habit persistent patients to deviate, $V(\cdot|x \neq j)^{DEV} > V(\cdot|x \neq j)^{SPE}$. In detail, given our results from the Markov Perfect Equilibrium in Proposition 1 one may substitute valuation functions in $V(\cdot|x \neq j)^{DEV} > V(\cdot|x \neq j)^{SPE}$ and get a condition of $\varepsilon < \frac{R(1-\delta+\theta+\delta\theta(1-\delta)+l(1-\delta)+\delta\theta l(1-\delta)+\delta\theta^2)}{(1+l+\theta+\delta\theta)(1+l)(1-\delta)}$. This condition is always satisfied for a sufficient small ε as $\delta \in (0,1)$. The reason stems from the fact that the firm with habit persistent patients does not only serves the mass of habit persistent patients but also the new arriving patients. The presented Subgame Perfect Equilibrium does not exist.
Secondly, suppose that $\theta = 0$. Note that without the unit mass of habit persistent patients. New patients are randomly assigned to one of the firms if both firms play $p = R$. The valuation for one firm is therefore $V^{SPE} = \frac{R(1/2+l)}{1-\delta}$. In comparison deviation gives a firm $V^{DEV} = (R-\varepsilon)(1+l) + \delta V_1^{MPE}$ where V_1^{MPE} is the valuation of the Markov Perfect Equilibrium in Proposition 1. Given our results from the Markov perfect equilibrium $V^{SPE} \geq V^{DEV}$ if and only if $\delta \geq \frac{R(1/2(1+l))-\varepsilon(1+l)^2}{R(1+l)-\varepsilon(1+l)^2}$. So for sufficiently patient firms and sufficient small $\varepsilon > 0$ the presented Subgame Perfect Equilibrium is sustainable.

G Proof of Proposition 2

The game $\mathcal{G}^{SP}(x^1)$ with $N = \{1,2\}$, $l_1 = l_2 = l$ and $\delta \in (0,1)$ has a Subgame Perfect Game equilibrium with the following strategies:

$$\mathcal{S}_j^t : \begin{cases} p_j^t = \underline{p} & \text{if } x^1 \neq j \quad \text{if } t = 1 \\ p_j^t = R & \text{if } x^1 = j \quad \text{if } t = 1 \\ p_j^t = \underline{p} & \text{if } p_j^{t-1} = R \text{ and } p_{-j}^{t-1} = \underline{p} \quad \text{for all } t > 1 \\ p_j^t = R & \text{if } p_j^{t-1} = \underline{p} \text{ and } p_{-j}^{t-1} \quad \text{for all } t > 1 \\ \text{Reversion to MPE} & \text{otherwise} \end{cases}$$

Where in each equilibria $\underline{p}$ satisfies:

$$\underline{p} \in \left(R(1 - \frac{\delta^2(1+\delta\theta)}{1+l+\theta+\delta\theta}, R \right)$$

Secondly consider the firm in state $x = j$, in the state with habit persistent patients. Continuation payoff given the described strategy is $V(\cdot|x = j) = \frac{R(l+\theta)+\underline{p}(1+l)}{1-\delta^2}$. The payoffs in the MPE which describe the punishment are as presented before. The optimal deviation in state $s = 1$ is to undercut the opponent marginally, i.e. to set a price equal to $p-\varepsilon$ where $\varepsilon \to 0$. This price allows the firm in $x = j$ to serve the new incoming patients for the highest possible price and further continuing with the better continuation payoff in state $x = j$. Correspondingly the payoff from deviating in state $x = j$ can be written as $V(\cdot|x = j)^{DEV} = (\underline{p}-\varepsilon)(1+l+\theta)+\delta V(\cdot|x = j)^{MPE}$. In order to prevent deviation the following condition needs to be satisfied: $V(\cdot|x = j) \geq V(\cdot|x = j)^{DEV}$ which can be rewritten as $\underline{p} \geq \frac{R(l+\theta)}{1+l+\theta+\delta\theta} + \varepsilon(1+\frac{\delta(1+l)}{1+l+\theta-\delta(1+l)-\delta^2(1+l+\theta)}$. Given that $\varepsilon \to 0$ one may rewrite the condition as $\underline{p} > \frac{R(l+\theta)}{1+l+\theta+\delta\theta})$.
Note that both conditions, for state one as well as state two, need to be satisfied to have a subgame perfect equilibrium. The parameter values of l and θ determine which condition is more restrictive. Therefore the lower and upper bound of $\underline{p}$ are defined as:

$$\underline{p} \in \left(\max\left\{ \frac{R(l+\theta)}{1+l+\theta+\delta\theta}, R(1-\frac{\delta^2(1+\delta\theta)}{1+l+\theta+\delta\theta}) \right\}, R \right)$$

As it holds that

$$R\left(1-\frac{\delta^2(1+\delta\theta)}{1+l+\theta+\delta\theta}\right) - \left(\frac{R(l+\theta)}{1+l+\theta+\delta\theta}\right) = \frac{R(1-\delta^2)(\theta\delta+1)}{l+\theta+\theta\delta+1} > 0,$$

one may write the lower bound as:

$$\underline{p} \in \left(R(1-\frac{\delta^2(1+\delta\theta)}{1+l+\theta+\delta\theta}, R \right)$$

H Copayment Functions

Price	Reimbursement	Max. sum out-of-pocket payment
$p \geq 4300$	100%	
$3500 \leq p < 4300$	90%	1800 SEK
$1700 \leq p < 3500$	75%	1700 SEK
$900 \leq p < 1700$	50%	1300 SEK
$p < 900$	0	900 SEK
Price	**Reimbursement**	**Max. sum out-of-pocket payment**
$p \geq 5400$	100%	
$3900 \leq p < 5400$	90%	2200 SEK
$2100 \leq p < 3900$	75%	2050 SEK
$1100 \leq p < 2100$	50%	1600 SEK
$p < 1100$	0	1100 SEK

Table 1: *Co-payment structure for cumulative health care expenditures (including prescription drugs) before (upper table) and after (lower table) 2012. Reimbursement is calculated for expenses during an entire year, beginning with the first expenditure. Prices are in Swedish krona. 10 Swedish Krona are approximately US$1.10.*

I Trade-margins

Table 2: Trade Margins, since 2016

Purchasing Price (PP)	Retail Price
$PP \leq 75$	$PP \times 1.20 + 30.50 + 11.50$
$75 < PP \leq 300$	$PP \times 1.03 + 43.25 + 11.50$
$300 < PP \leq 50,000$	$PP \times 1.02 + 46.25 + 11.50$
$PP > 50,000$	$PP + 1,046.25 + 11.50$

Retail prices of pharmaceuticals under generic competition in dependency to purchasing prices since 04/2016 (TLV, 2016). Trade margins are implicitly defined. Note that the 11.50 KR apply due to the generic competition. Prices in Swedish krona. 10 Swedish krona are approximately 1.1 US Dollar.

Table 3: Trade Margins, before 2016

Purchasing Price (PP)	**Retail Price**
$PP \leq 75$	$PP \times 1.20 + 31.25 + 10.00$
$75 < PP \leq 300$	$PP \times 1.03 + 44.00 + 10.00$
$300 < PP \leq 6,000$	$PP \times 1.02 + 47.00 + 10.00$
$PP > 6,000$	$PP + 167.00 + 10.00$

Retail prices of pharmaceuticals under generic competition in dependency to purchasing prices before 04/2016 (TLV, 2016). Trade margins are implicitly defined. Prices in Swedish krona. 10 Swedish krona are approximately 1.1 US Dollar.

References

Anderson, E. T. Essays on pricing and advertising. *Dissertation. MIT Press, Cambridge, MA*, 1995.

Padilla, A. J. Revisiting dynamic duopoly with consumer switching costs. *Journal of Economic Theory*, 67:520–530, 1995.

TLV, . Apotekens marginaler. `http://www.tlv.se/apotek/Apotekens-marginaler/`, 2016. Accessed: 2017-02-23.