Winning the prescription: competitive tenders vs. decentralised competition*

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Abstract

Payers increasingly use competitive tendering to reduce expenditures on patent-protected pharmaceuticals. Using a duopoly model with horizontally differentiated drugs, we show that tendering can harm patients and fail to reduce costs. When demand depends on physicians' tolerance for treatment loss, tendering yields a mixed-strategy equilibrium: firms balance bidding low to win the contract against bidding high to exploit residual demand. Compared with decentralised competition, tendering worsens patient outcomes and increases expected prices unless treatment-loss tolerance is sufficiently high. Quality asymmetries and captive segments further amplify these distortions, highlighting critical trade-offs in procurement design.

Keywords: Pharmaceuticals; Procurement; Competitive tendering

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1 Introduction

Pharmaceutical expenditures are escalating. According to the IQVIA Institute (2024), global pharmaceutical spending increased from USD 1.2 trillion in 2018 to USD 1.6 trillion in 2023—an increase of more than 30 percent. Much of this growth is driven by the introduction of new medicines that offer substantial therapeutic benefits but come with very high prices, creating a sharp trade-off between access and cost containment for policymakers and payers operating under constrained budgets.

To mitigate rising pharmaceutical costs, *competitive tendering* has become an increasingly prominent procurement tool. A recent OECD study (Barrenho et al., 2023), surveying drug procurement practices across multiple countries, reports that competitive tendering is not only becoming more widespread but is also expanding from off-patent to on-patent markets.

In off-patent markets, tendering typically involves price competition among branded and generic versions of the same molecule. In on-patent markets, however, tendering entails competition among branded drugs with similar but distinct substances that may differ in efficacy and side effects across patient groups. As a result, tendering in such markets can lead to treatment losses when the winning drug is suboptimal for certain patients. For this reason, tendering seldom takes the form of winner-takes-all (exclusive) contracts; instead, payers commonly adopt *preferred-provider contracts* that constrain physicians' prescribing choices while still allowing some degree of clinical discretion (Barrenho et al., 2023).

The present paper investigates how *physicians' willingness to accept therapeutic loss* affects competitive tendering outcomes. We develop a theoretical model in which substitution willingness is captured by a threshold representing the maximum acceptable loss in treatment benefits tolerated by physicians when prescribing the preferred drug. This threshold reflects physicians' tolerance for clinical suboptimality and may be influenced by payer policies— such as prescribing guidelines or administrative burdens associated with deviating from the preferred drug. In the Danish procurement model for hospital drugs, for example, this threshold is treated as a policy lever:[1]

> *'As the treatment recommendations issued through the model are standard treatments at all hospitals within a therapeutic area, individual patient treatment preferences could be challenged to the extent that some patients might be better treated with a*

[1] A similar procurement design exists in Norway; see, e.g., Dalen et al. (2021) for further discussion.

medicine other than the one recommended. The intention is that 80% of treatments follow standard recommendations. This aim is to accommodate some degree of individual freedom of choice by leaving clinicians a 20% choice to administer different medicines than the standard recommendation and to maintain competition' (Christensen et al., 2022).

Using a duopoly model with horizontally differentiated therapies, we examine producers' optimal pricing strategies when preferred-drug status is awarded to the lowest bidder and demand for the preferred and non-preferred drug is shaped by physicians' willingness to accept treatment losses. Based on this framework, we derive several insights for the procurement of patent-protected medicines.

First, competitive tendering induces a mixed-strategy equilibrium in which producers balance two incentives: bidding low to win the tender and become the preferred therapy, and bidding high to extract surplus from residual demand as the non-preferred alternative. The tolerance threshold for treatment loss is central to this trade-off. A higher threshold induces more aggressive bidding but also implies that more patients will receive a less suitable therapy, thus reducing aggregate treatment benefits. This generates a clear trade-off for the payer between cost containment and clinical outcomes. When the payer weighs treatment costs and benefits equally, raising the threshold increases the overall surplus, giving the payer an incentive to adopt policies that raise physicians' tolerance for prescribing the preferred drug.

Second, we show that competitive tendering may be counterproductive in reducing drug expenditures when compared with what we dub *decentralised competition*, where physicians make drug prescription decisions by weighing treatment benefits against costs, and thus partially internalise the payer's cost concerns. Under tendering, by contrast, physicians' role is limited to assessing whether the foregone treatment benefits of prescribing the preferred drug fall within the clinically acceptable tolerance threshold. Relative to the decentralised competition benchmark, competitive tendering lowers expenditures only if the tolerance threshold is sufficiently high. In that case, demand for the preferred drug is large, producers compete aggressively, and bids fall. But for sufficiently low thresholds, producers find it more profitable to bid high and rely on residual demand as the non-preferred provider. As a result, under competitive tendering expected prices and expenditures are inversely related to the tolerance threshold.

We also show that the relative advantage of tendering depends on the magnitude of therapeutic benefits. Whereas equilibrium prices under decentralised competition depend on substi-

tutability between therapies but not on the absolute level of therapeutic benefits, the equilibrium bidding strategies in competitive tenders are tied to the expected therapeutic benefit of each drug in such a way that expected prices under tendering increase with the benefits of the drugs. Accordingly, the scope for cost savings through tendering is greater in drug classes with lower therapeutic benefits.

Third, our results have *direct policy implications*. For a sufficiently low tolerance threshold, competitive tendering is never desirable for the payer: it reduces patient welfare and increases expenditures. Decentralised competition is preferable in this case. On the other hand, when the threshold is sufficiently high, the payer may benefit from tendering provided that the expenditure reductions outweigh the treatment losses. In such cases, policies—such as recommendations, guidelines, or administrative requirements—that influence physicians' tolerance for treatment losses can make competitive tendering a more effective procurement tool.

Finally, we extend the model in two directions. First, we introduce *asymmetric drug quality*, where one therapy offers higher expected treatment benefits, which implies that the two competing drugs are both horizontally and vertically differentiated. The superior drug then adopts a stochastically dominant mixed strategy and becomes less likely to win the tender. We show that such asymmetry may strongly amplify cost increases under tendering relative to decentralised competition, since the superior drug's demand advantage allows it to sustain high bids even when losing the tender. This extension thus produces another clear policy implication, namely that competitive tendering is more likely to be counterproductive, yielding higher procurement costs than decentralised competition, if the competing drugs are vertically differentiated.

Second, we examine the role of *captive patients*—those unlikely to switch therapies due to clinical inertia or brand loyalty. Evidence from Norway's TNFi market, for example, suggests that some patients remain on higher-cost brands despite the existence of more competitive alternatives (Brkic et al., 2023). We model this by allowing one drug to hold a loyal segment, which might be caused by early entry. A larger captive base raises the lower bound of feasible bids and increases the probability that the high-demand drug bids at the ceiling. Unlike the case of vertical differentiation, we show that decentralised competition is more exposed to these loyalty effects than competitive tendering, leading to weaker cost containment, although the difference is relatively modest.

The rest of the paper is organised as follows. In Section 2 we relate our study to existing literature. The basic assumptions of our model are presented in Section 3. Based on this

model, we analyse the benchmark case of decentralised competition in Section 4. In Section 5 we develop the competitive tendering model and compares its equilibrium outcomes with decentralised competition. In Section 6 we present the two extensions: (i) asymmetric treatment effects and (ii) captive demand. Finally, Section 7 concludes the paper.

2 Related literature

Our paper relates to several strands of the literature on competition and procurement in pharmaceutical markets. First, we contribute to the small but growing literature on competitive tendering in procurement in healthcare markets. The closest study to ours is Cao et al. (2024), who analyse competitive bidding in off-patent drug markets following a 2019 reform in China. In their setting, manufacturers bid for pre-specified procurement quantities. They show that generic drugs won most bids, leading to substantial price reductions. Average drug prices fell by 47.4 percent, with government insurance expenditures declining by 19.8 percent. Cao et al. also develop an equilibrium model to quantify the trade-off between price reductions and distortions in drug choice, showing that competitive bidding increases welfare when branded and bioequivalent generic drugs are valued equally.

While Cao et al. (2024) focus on competition for fixed quantities of homogeneous drugs, our setting differs along two key dimensions. We study on-patent markets with branded, horizontally differentiated drugs, and a procurement mechanism in which the winner is awarded preferred-provider status rather than a quantity commitment. Demand is endogenous and depends on physicians' tolerance for treatment losses, which plays a central role in shaping bidding incentives and equilibrium outcomes.

Related evidence comes from studies of competitive bidding for durable medical equipment (DME) in the United States. Ding et al. (2025) show that Medicare's competitive bidding program that replaced administrative (regulated) prices led to large spending reductions, driven primarily by price declines. Ji (2025) studies the same reform and documents significant quantity reductions linked to inefficient supply shortages, highlighting how auction design—particularly weak supply commitments—can undermine welfare gains. These studies underscore the importance of procurement design in healthcare markets.

Competitive bidding has also been gradually implemented in European healthcare systems. The OECD survey by Barrenho et al. (2023) documents increasing use of tendering beyond

off-patent markets, including preferred-provider arrangements for patent-protected drugs. Decarolis and Giorgiantonio (2015) provide a descriptive analysis of procurement of orthopedic implants and related medical devices across European countries. Christensen et al. (2022) analyse the Danish procurement model focusing on generic substitution, and Brkic et al. (2023) examine the Norwegian tendering model applied to TNFi inhibitors provided to rheumatoid arthritis patients.

Our paper also builds on the literature on competition in on-patent markets between branded drugs that treat the same indication but differ in efficacy and side effects because they are based on distinct substances. A seminal contribution is Ellison et al. (1997), who provide empirical evidence on substitution patterns across pharmaceuticals using U.S. data and document substantial within-class competition among chemically distinct branded drugs. Their analysis shows that demand responds not only to prices but also to therapeutic differences, providing a foundation for modelling branded drugs as horizontally differentiated products.[2] This literature is complemented by empirical evidence from multiple jurisdictions showing that the entry of therapeutic substitutes exerts downward pressure on drug prices (Kakani et al., 2022; Dickson et al., 2023; Feng et al., 2024; Garthwaite, 2025; Maini et al., 2021).

Building on this work, we adopt a standard framework of horizontal differentiation in which physicians trade off patient-specific treatment benefits against costs when choosing among branded therapies. Our contribution is to examine the merits of adopting competitive tendering—through the assignment of preferred-provider status—in such markets by comparing it with a standard model of decentralised branded competition. We show that competition in the market and competition for the market can yield markedly different outcomes, and that competitive tendering may perform poorly in markets for differentiated, patent-protected drugs.

Finally, our paper relates to the auction theory literature; see Klemperer (1999) for a comprehensive review. We study a procurement auction in which the winner is awarded preferred-provider status and demand is endogenous. This feature induces mixed bidding strategies, as firms trade off bidding aggressively to win the tender against bidding high to extract rents from residual demand. Relative to decentralised competition, we show that this auction format may be counterproductive for cost containment and can reduce consumer welfare. Our results have

[2] Another key study is Crawford and Shum (2005), who develop a structural model of prescription drug demand in which physicians learn over time about drug-specific match quality within a therapeutic class. Focusing on anti-ulcer medications, they show that brand–brand competition among on-patent drugs is shaped by horizontal differentiation and information frictions, leading to persistent demand heterogeneity across therapeutically similar drugs.

broader implications for the design of procurement auctions in healthcare and other markets with differentiated products.

3 Model

Consider a unit mass of heterogeneous patients who suffer from a condition that requires drug treatment. There are two patented and therapeutically substitutable drugs available, denoted by 1 and 2. For a given patient, the therapeutic benefit of being treated with (one unit of) drug 1 is given by $u_1(x) = v - \tau x$, where $v > 0$ is the maximum therapeutic benefit of the drug and x is randomly and independently drawn from a uniform distribution on $[0, 1]$. For the same patient, the therapeutic benefit of instead being treated with drug 2 is given by $u_2(x) = v - \tau(1 - x)$, which implies that the therapeutic benefits of the two drugs are negatively correlated across the patient mass.[3] We also assume that $v > \tau$, which implies that every patient has a positive treatment benefit from both drugs (i.e., each drug can treat all patients). Thus, the two drug versions are horizontally differentiated, with the degree of therapeutic substitutability inversely measured by the parameter $\tau > 0$.[4]

We assume that all patients are covered by a health plan which fully covers the treatment expenses for all drugs that are included in the plan. We adopt a simple inclusion criteria by assuming that drug i will be included in the health plan as long as the price of the drug, denoted by p_i, is not higher than its expected treatment benefit, denoted by $\overline{v}$, which then constitutes an upper bound on the price that each drug producer is able to charge; i.e., drug i will be included in the health plan as long as $p_i \leq \overline{v}$. Since the expected value of x is $1/2$, the expected treatment benefit of each drug is given by

$$\overline{v} := v - \frac{\tau}{2}. \tag{1}$$

The two drugs are produced by different profit-maximsing pharmaceutical companies. We also assume that drug production involves no fixed costs and a constant marginal cost that is the same for both drugs. For simplicity, and without further loss of generality, we set the marginal production cost to zero.

[3] Our main results are qualitatively similar if we instead assume that treatment effects are uncorrelated. This alternative assumption is discussed towards the end of Section 5.

[4] A complementary interpretation of the parameter τ is that it measures the degree of patient heterogeneity in therapeutic benefits. In the limit case of $\tau \to 0$, all patients derive the same therapeutic benefit regardless of which drug they are treated with.

The demand for the two drugs depends on physicians' prescription decisions. We assume that these decisions are constrained by the policy of the health plan, and in the following we will consider two different policy schemes. (i) As a benchmark for comparison, we consider what we will refer to as *decentralised competition*, where, for each patient, the prescribing physician chooses among the available drugs approved by the health plan by taking both the benefits and the costs of each drug treatment into account. (ii) We then compare this with the case of *competitive tendering*, where the health plan selects one of the drugs as the *preferred drug* based on a competitive bidding process. The preferred drug will then be prescribed to every patient as long as the loss in therapeutic benefit (of prescribing the preferred drug instead of the best therapeutic alternative) is below some threshold level.

4 Benchmark: Decentralised competition

Suppose that drug prescription choices are made by physicians who weigh treatment benefits against treatment costs. If the weight physicians place on drug treatment costs is given by $\beta \in (0, 1]$, a given patient will be prescribed drug 1 if

$$v - \tau x - \beta p_1 > v - \tau (1 - x) - \beta p_2, \tag{2}$$

and will be prescribed drug 2 otherwise. We find it reasonable to assume that prescribing physicians care at least as much about treatment benefits as they care about treatment costs, and this is reflected in our assumption that the parameter β is weakly less than one.[5] When drug prescriptions are made according to the decision rule in (2), demand for drug i is given by

$$q_i (p_i, p_j) = \frac{1}{2} + \frac{\beta (p_j - p_i)}{2\tau}; \quad i, j = 1, 2, \quad i \neq j. \tag{3}$$

Suppose that prices are set by the two producers in a non-cooperative simultaneous-move game. Deriving the symmetric Nash equilibrium of such a game is straightforward and the details of this derivation are thus now shown. The equilibrium drug price (equal for both drugs) is given by

$$p^* = \begin{cases} \frac{\tau}{\beta} & if \quad \beta \geq \frac{\tau}{\overline{v}} \\ \overline{v} & if \quad \beta < \frac{\tau}{\overline{v}} \end{cases}. \tag{4}$$

[5] We can think of the limit case of $\beta \to 1$ as prescribing physicians acting as perfect agents for a health plan that maximises total treatment benefits net of total treatment costs.

As is evident from (4), the scope for decentralised competition to reduce drug prices below the maximum level $\overline{v}$ depends on two factors: (i) the degree of therapeutic substitutability (inversely measured by τ) and (ii) the price sensitivity of the prescribing physician (measured by β). All else equal, a higher degree of therapeutic substitutability and/or more price-sensitive physicians will lead to lower equilibrium drug prices.

In the symmetric equilibrium, each drug has a demand of one half, and the aggregate treatment benefits are given by

$$H^* = 2\int_0^{\frac{1}{2}} (v - \tau x)\, dx = v - \frac{\tau}{4}. \tag{5}$$

Notice that therapeutic mismatch costs are minimised in the symmetric equilibrium under decentralised competition, since prescription decisions are not distorted by drug prices (which are equal for both drugs). The equilibrium allocation of drug treatments is thus efficient.

With a unit mass of patients, total treatment costs are given by the average drug price, which in a symmetric equilibrium is given by (4). In the Nash equilibrium under decentralised competition, the surplus of a health plan that maximises total treatment benefits net of total treatment costs is therefore given by

$$S^* = H^* - p^* = \begin{cases} v - \frac{(4+\beta)\tau}{4\beta} & if \quad \beta \geq \frac{\tau}{v} \\ \frac{\tau}{4} & if \quad \beta < \frac{\tau}{v} \end{cases}. \tag{6}$$

5 Competitive tendering

Suppose instead that the health plan designs a tender, in which the two producers simultaneously and non-cooperatively submit price bids, with the purpose of selecting a *preferred drug* among the two. These bids must satisfy the inclusion criterion $p_i \leq \overline{v}$, and drug i becomes the preferred drug if $p_i < p_j$. In this case, physicians are required to prescribe drug i as long as the lost treatment benefit (of prescribing the preferred drug instead of the therapeutic alternative) does not exceed a threshold given by $T > 0$. In case of a tie, $p_i = p_j$, physicians can choose drug treatments without any restrictions to maximise the patients' treatment benefits. We can think of the threshold T as reflecting individual physicians' tolerance for prescribing a therapeutically suboptimal drug treatment, which might, at least partly, be influenced by the health plan in the form of guidelines or imposed bureaucratic costs associated with prescription of another drug

than the officially preferred one.

Notice the differences in the role assigned to prescribing physicians in the two policy schemes. Under decentralised competition, the health plan's concern for cost containment is delegated to the prescribing physician, whose role is to weigh treatment benefits against treatment costs when choosing which drug to prescribe to each patient. Under competitive tendering, in contrast, the role of prescribing physicians is restricted to making a purely clinical assessment about whether or not to prescribe the preferred drug; i.e., to assess whether any foregone treatment benefit of prescribing the preferred drug is below what is deemed clinically acceptable (as measured by T in our model).

5.1 Drug demand

Suppose that drug 1 is the preferred drug. For a given patient, the net treatment gain of being treated with this drug instead of the therapeutic alternative (drug 2) is given by

$$\Delta u(x) := v - \tau x - (v - \tau(1-x)) = (1-2x)\tau. \tag{7}$$

All patients for which $\Delta u(x) \geq -T$ will be prescribed the preferred drug, while the remaining patients will be prescribed the therapeutic alternative. Drug demand is then given by

$$q_i = \frac{1}{2} + \frac{T}{2\tau} \text{ and } q_j = \frac{1}{2} - \frac{T}{2\tau} \text{ if } p_i < p_j, \tag{8}$$

and

$$q_i = q_j = \frac{1}{2} \text{ if } p_i = p_j. \tag{9}$$

Thus, as long as $T > 0$, the preferred drug has higher demand than the therapeutic alternative. However, as long as $T < \tau$, the preferred drug does not have all demand. For the remainder of the analysis, we therefore restrict attention to the more interesting (and arguably more relevant) case of $T \in (0, \tau)$.

5.2 Nash equilibrium

Which bids will the two producers submit? In order to answer this question, we start out by establishing a negative result:

Lemma 1 *If $T \in (0, \tau)$, the competitive tender does not have a Nash equilibrium in pure strategies.*

A strictly positive treatment loss threshold T implies that each producer can obtain a discrete increase in demand by reducing its bid from slightly above to slightly below the bid of the competing producer, which yields an incentive for price undercutting. On the other hand, $T < \tau$ also implies that each producer obtains positive demand even if it submits the highest possible bid, which implies that a bid equal to $\overline{v}$ is the best response to a bid sufficiently close to marginal cost by the competing producer. Thus, no equilibrium in pure strategies exists.[6]

The competitive tender has instead a Nash equilibrium in mixed strategies, which is characterised as follows:[7]

Proposition 1 *If $T \in (0, \tau)$, the competitive tender has a mixed-strategy Nash equilibrium in which each drug producer submits a bid that is a random draw from a cumulative distribution function given by*

$$F(p) = \frac{1}{2}\left(1 + \frac{\tau}{T}\right)\left(1 - \frac{p^{\min}}{p}\right), \tag{10}$$

with support $\left[p^{\min}, \overline{v}\right]$, where

$$p^{\min} := \left(\frac{\tau - T}{\tau + T}\right)\overline{v}. \tag{11}$$

The equilibrium strategies reflect the trade-off between the demand gain of winning the tender and the profit margin gain of selling a non-preferred drug at the maximum price $\overline{v}$. If T is close to zero, the demand gain of being the preferred drug is small, and the equilibrium strategy of each producer is therefore to randomise on a narrow interval of prices close to the upper bound $\overline{v}$. In the limit case of $T \to 0$, the demand gain of winning the tender converges to zero. Consequently, $p^{\min} \to \overline{v}$ and the Nash equilibrium converges monotonically to an equilibrium in pure strategies in which both producers bid the maximum price $\overline{v}$.

Conversely, a larger value of T increases the demand gain of being the preferred drug, which in turn reduces the lower bound $p^{\min}$ and simultaneously makes $F(p)$ more negatively skewed. If T is close to τ, there is a huge gain of winning the tender, so both producers randomise with most of the probability mass on prices close to marginal cost. In the limit case of $T \to \tau$, the demand for the non-preferred drug converges to zero and $F(p)$ converges to one. Consequently,

[6] See Appendix A for a more rigorous proof.

[7] See Appendix A for a formal proof of this and all subsequent Propositions.

the Nash equilibrium converges monotonically to an equilibrium in pure strategies in which both producers bid a price equal to marginal cost.

What are the expected drug purchasing costs of the health plan when drug prices are determined by competitive tendering? Let p_L^e and p_H^e denote the expected values of, respectively, the lowest and the highest bid in the tender. Taking into account that the demand for the preferred and non-preferred drugs are given by (8), expected drug expenditures will be given by what we term the *expected average drug price*, which is defined as

$$p^e := p_L^e \left(\frac{1}{2} + \frac{T}{2\tau} \right) + p_H^e \left(\frac{1}{2} - \frac{T}{2\tau} \right). \tag{12}$$

Based on the equilibrium pricing strategies presented in Proposition 1, the next proposition characterises the expected costs and benefits for the health plan under competitive tendering:

Proposition 2 *If $T \in (0, \tau)$, the expected average drug price, and thus the expected treatment costs, is given by*

$$p^e = \left(1 - \frac{T}{\tau} \right) \overline{v}, \tag{13}$$

and the aggregate treatment benefits are given by

$$H = v - \frac{\tau}{4} - \frac{T^2}{4\tau}. \tag{14}$$

The expected average drug price is monotonically decreasing in T and ranges from the maximum price $\overline{v}$ for $T \to 0$ to zero (marginal cost) for $T \to \tau$. The intuition for this follows directly from the above discussion of the equilibrium mixed strategies.

The aggregate treatment benefits are also monotonically decreasing in T, which is entirely intuitive. The larger the loss in treatment benefits that is tolerated for the preferred drug, the larger is the share of patients that are given a therapeutically suboptimal treatment. Thus, a higher treatment loss threshold T reduces the expected treatment costs at the expense of lower aggregate treatment benefits. However, it turns out that the former effect dominates the latter, which allows us to summarise the implications of Proposition 2 as follows:

Corollary 1 *As long as $T \in (0, \tau)$, an increase in the treatment loss threshold T leads to lower expected treatment costs, lower aggregate treatment benefits, and a higher expected surplus for a health plan that places equal weights on treatment costs and benefits.*

5.3 Competitive tenders vs. decentralised competition

How do the two policy schemes—competitive tenders and decentralised competition—compare in terms of expected treatment costs and benefits? The next proposition provides a complete characterisation of this comparison.

Proposition 3 *Compared with decentralised competition, competitive tenders yield (i) lower aggregate treatment benefits for all* $T \in (0, \tau)$*, (ii) higher (lower) expected treatment costs if* $T < (>) \widehat{T} \in (0, \tau)$*, and (iii) lower (higher) surplus for a health plan that gives equal weight to treatment costs and benefits if* $T < (>) \widetilde{T} \in \left(\widehat{T}, \tau\right)$.

Under decentralised competition, aggregate treatment benefits are maximised in any symmetric equilibrium. This is not the case under competitive tendering, as long as the treatment loss threshold T is strictly positive, which implies that some patients are being prescribed the preferred drug even if the therapeutic alternative would yield larger treatment benefits. Thus, competitive tendering always yields lower aggregate treatment benefits than decentralised competition. Total treatment costs, on the other hand, might be higher or lower under competitive tendering, depending on the value of T. More specifically, competitive tendering yields higher (lower) expected treatment costs than decentralised competition if T is below (above) a threshold value $\widehat{T} \in (0, \tau)$, and the intuition for this follows directly from the previous intuition given for the results in Propositions 1 and 2.

Comparing benefits and costs, it follows from Proposition 3 that competitive tendering yields both lower treatment benefits and higher expected treatment costs than decentralised competition if $T < \widehat{T}$. On the other hand, if $T > \widehat{T}$, the choice between these two policy schemes involves a trade-off, since both benefits and expected costs in this case are lower under competitive tendering. For intermediate values of T, given by $T \in \left(\widehat{T}, \widetilde{T}\right)$, the trade-off goes in favour of decentralised competition, which yields treatment benefits that more then outweigh the higher treatment costs. However, if T is sufficiently high ($T > \widetilde{T}$), the trade-off goes in favour of competitive tendering, which yields expected cost reductions that more than outweigh the lower treatment benefits.[8]

A comparison of equilibrium drug prices under the two policy schemes is illustrated in Figure 1 for a particular numerical example in which $v = 5$, $\tau = 2$ and $\beta = 3/4$. The equilibrium price under decentralised competition (p^*) is given by the solid thin curve, while the expected average

[8] See the proof of Proposition 3 in Appendix A for explicit expressions of $\widehat{T}$ and $\widetilde{T}$.

price under competitive tendering (p^e) is given by the solid thick curve. The dashed curves show the upper and lower bounds of the equilibrium mixed strategies under competitive tendering.

[Figure 1 here]

In this example, $p^e > (<)\, p^*$ if $T < (>)\, \widehat{T} = 2/3$. In order to interpret the magnitude of this threshold, notice that the maximum loss in therapeutic benefit of being prescribed a suboptimal drug is given by $\tau = 2$. This happens if drug 1 is given to a patient with $x = 1$, or if drug 2 is given to a patient with $x = 0$. Thus, competitive tendering yields higher expected treatment costs than decentralised competition if the loss in therapeutic benefit tolerated by the prescribing physician is less than one third ($\widehat{T}/\tau$) of the maximum potential loss. Furthermore, $p^{\min} > (<)\, p^*$ if $T < (>)\, 2/5$, which implies that competitive tendering yields for sure higher drug prices than decentralised competition if the tolerated loss in therapeutic benefit is less than 20% of the maximum potential loss.

An alternative interpretation follows from the fact that T-values of 2/3 and 2/5 are equivalent to market shares of 2/3 and 3/5, respectively, for the preferred drug.[9] Thus, for competitive tendering to yield lower expected costs than decentralised competition, more than two thirds of the patients must be prescribed the preferred drug. On the other hand, competitive tendering will for sure yield higher costs if the prescription decisions are such that less than 60% of the patients are prescribed the preferred drug.

Although not shown in the figure, it is also easily verified that $\widetilde{T} = 8 - (4/3)\sqrt{30} \approx 0.698$, which means that higher expected treatment costs under decentralised competition is outweighed by higher treatment benefits only for a very narrow range of T-values. This suggests that, in terms of overall surplus for the health plan, the relative merits of the two policy schemes are predominantly determined by the effect on expected treatment costs.

As evidenced by a comparison of (4) and (13), a key difference between decentralised competition and competitive tendering is that equilibrium drug prices depend on expected treatment benefits in the latter pricing scheme but not in the former.[10] The implications of this feature are illustrated in Figure 2, which shows a comparison of equilibrium drug prices for the same numerical example as in Figure 1, with the only exception that the maximum therapeutic benefit is increased from 5 to 10.

[9] This follows directly from (8).

[10] This is true as long as β is sufficiently high to induce an interior-solution Nash equilibrium under decentralised competition.

[Figure 2 here]

Comparing Figure 1 and Figure 2, we see that the only effect of a higher therapeutic benefit (v) is an increase in both the lower and upper bounds of the equilibrium price distribution, as well as the expected average price, under competitive tendering. In contrast, the equilibrium price under decentralised competition is unchanged. A higher therapeutic benefit therefore increases the scope for drug prices to be higher under competitive tendering. In the example given in Figure 2, $p^e > (<)\, p^*$ if $T < (>)\, \widehat{T} = 38/27$, which implies that competitive tendering yields higher expected drug expenditures than decentralised competition unless the loss in therapeutic benefit tolerated by the prescribing physician is more than 70% ($\widehat{T}/\tau = 19/27$) of the maximum potential loss. Or, alternatively, competitive tendering yields higher expected treatment costs unless more than 85% of patients are being prescribed the preferred drug.[11]

The two examples given in Figure 1 and Figure 2 are also illustrative in highlighting the implications of imposing a certain target-value of T. In the Danish model, for example, the competitive tendering policy explicitly allows for a 20% deviation from the preferred drug on average, as discussed in the Introduction. In the context of our numerical example, this corresponds to a T-value of $(3/5)\tau = 1.2$.[12] In the example in Figure 1, with a relatively low therapeutic benefit of the two drugs, competitive tendering then yields an expected equilibrium drug price of $p^e = 8/5$, whereas in Figure 2, with a higher therapeutic benefit, the expected drug price is $p^e = 18/5$. In both cases, the equilibrium price under decentralised competition is $p^* = 8/3$. Thus, compared with decentralised competition, competitive tendering with 80% market share for the preferred drug yields a 40% expected reduction in drug expenditures if $v = 5$ (Figure 1), but a 35% *increase* in expected treatment costs if instead $v = 10$ (Figure 2).

These examples illustrate that the relative merit of competitive tendering, in terms of reducing drug expenditures, crucially depends on the size of the expected therapeutic benefits of the drugs. These benefits do not affect (interior-solution) drug prices under decentralised competition, where the producers' pricing incentives are only governed by the prescribing physicians' price responsiveness and the degree of therapeutic substitutability between the two drugs. Under competitive tendering, in contrast, the equilibrium pricing strategies are tied to the therapeutic benefits of the two drugs, as explained above. All else equal, the scope for competitive tendering to yield lower drug prices is therefore inversely related to the therapeutic benefits of the drugs.

[11] This threshold market share is found by setting $\tau = 2$ and $T = 38/27$ in the expression for q_i in (8).
[12] This value is found by setting q_j in (8) equal to 1/5 and solving for T.

5.4 Optimal choice of treatment loss threshold

In the above analysis we have assumed that the treatment loss threshold T is an exogenous parameter reflecting physician characteristics (i.e., physicians' tolerance for prescribing a therapeutically suboptimal therapy), while acknowledging that this threshold might be at least partially influenced by policy. Suppose instead that T is a fully flexible policy variable that can be freely chosen to maximise a certain welfare objective. Although this might not necessarily be the most realistic assumption, it is nevertheless useful to explore its implications. What would in this case be the optimal choice of T?

The answer to this question depends crucially on the choice of objective function. From the perspective of a surplus-maximising health plan, it follows directly from Corollary 1 that the surplus is maximised at $T = \tau$, which implies that the tender is a 'winner-takes-all' competition. On the other hand, from the perspective of a social planner that maximises the total surplus in the economy, including the profits of the pharmaceutical companies, the optimal choice is at the other extreme, namely $T = 0$. The reason is that the total surplus is given by the total treatment benefits, which are maximised if no treatment loss is accepted, i.e., $T = 0$. But this means of course that competitive tenders are never welfare-superior to decentralised competition.

A more realistic welfare objective might be one in which the health plan's surplus is given larger weight than the profits of the pharmaceutical companies. This is captured by defining the following welfare function:

$$W = H - (1 - \alpha)\, p^e, \tag{15}$$

where $\alpha \in (0, 1)$ is the welfare weight given to pharmaceutical profits. Using (13) and (14), it is easily verified that there exists a threshold value $\widehat{\alpha} := (v - \tau)/\overline{v} \in (0, 1)$, such that the welfare-maximising choice of T is given by

$$T^* = \begin{cases} \tau & if \quad \alpha \leq \widehat{\alpha} \\ 2\,(1 - \alpha)\,\overline{v} & if \quad \alpha > \widehat{\alpha} \end{cases}. \tag{16}$$

Thus, as long as the weight given to pharmaceutical profits is sufficiently high, but still less than the weight given to the surplus of the health plan, i.e., for $\alpha \in (\widehat{\alpha}, 1)$, the optimal treatment loss threshold under competitive tendering is an interior solution that allows for a certain degree of deviation from the preferred treatment, optimally trading off cost reductions against treatment

benefits.

5.5 Robustness

The above analysis has been made using a demand system in which the therapeutic benefits of drug treatment are perfectly negatively correlated, meaning that, if patient A derives higher benefits than patient B from one of the drugs, then patient B derives higher benefits from the other drug than what patient A does. In order to check the robustness of our main results with respect to this particular assumption, we also perform the same analysis for an alternative demand system based on *uncorrelated* treatment benefits, where the therapeutic benefit of drug i is given by $v - \tau x_i$, $i = 1, 2$, where each patient is characterised by a pair (x_1, x_2), and where x_1 and x_2 are independent draws from a uniform distribution on $[0, 1]$. This implies that a given patient's therapeutic benefit of one of the drugs is uncorrelated with the same patient's benefit of being treated with the alternative drug.

This analysis is presented in Appendix B and shows that our main results are qualitatively robust to the application of an alternative demand system based on uncorrelated treatment effects. This is illustrated by a comparison of Figure 1 above with Figure B1 in Appendix B, which is based on the exact same parameter configuration as Figure 1. A comparison of these two figures show that the properties of the mixed strategy equilibrium, and the comparison of equilibrium prices under the two policy schemes, are qualitatively very similar for the two different demand systems. The main *quantitative* difference is that drug prices are lower in both equilibria when treatment effects are uncorrelated, but less so under competitive tendering. This implies that a comparison of the two policy schemes, in terms of expected drug expenditures and health plan surplus, is somewhat more tilted in favour of decentralised competition. In the example illustrated in Figure B1, expected drug expenditures are lower under competitive tendering if $T > 0.85$, which implies that the preferred drug must be prescribed to at least 83% of the patients. Furthermore, competitive tendering yields a higher surplus for the health plan only if $T > 0.91$, which implies that the preferred drug must be prescribed to at least 85% of the patients. In contrast, for the same parametric example in the main model (Figure 1), competitive tendering yields both lower expected drug expenditures and a higher surplus to the health plan if T is such that at least 67% percent of the patients are prescribed the preferred drug.

6 Extensions

In this section we extend our analysis in two different directions that both imply an asymmetry between the two therapeutically substitutable drugs. First, we consider the case of asymmetric treatment effects, where the maximum (and expected) treatment benefit is higher for one of the drugs. Second, we consider the case in which one of the drugs has a demand advantage due to the existence of 'captive' patients. In both extensions, we derive the Nash equilibrium under competitive tendering and analyse how such asymmetries affect expected treatment costs compared to the benchmark of decentralised competition. As shown in our analysis of the symmetric case, differences in overall health plan surplus across the two policy schemes are predominantly determined by differences in expected drug purchasing costs. In these extensions we therefore restrict attention to the relative merits of the two schemes in terms of cost efficiency.

6.1 Asymmetric treatment effects

Suppose that the two drugs are not only horizontally but also vertically differentiated. More specifically, suppose that the maximum therapeutic benefit of drug i is v_i, and that $v_1 > v_2$. The degree of vertical differentiation is then measured by

$$\Delta v := v_1 - v_2 > 0. \tag{17}$$

The expected treatment benefit of drug i is given by

$$\overline{v}_i := v_i - \frac{\tau}{2}, \tag{18}$$

which means that Δv also measures the difference in expected treatment benefits between the two drugs; i.e., $\Delta v = \overline{v}_1 - \overline{v}_2 > 0$. In the following we will therefore intermittently refer to drug 1 and drug 2 as the high-quality drug and the low-quality drug, respectively.

With asymmetric treatment effects, the demand for the preferred and non-preferred drugs depends on the identity of the winner of the tender. Suppose that drug 1 is the preferred drug. For a given patient, the net treatment gain of being treated with this drug instead of the therapeutic alternative is given by

$$\Delta u_1(x) = v_1 - \tau x - (v_2 - \tau(1-x)) = \Delta v + (1-2x)\tau. \tag{19}$$

All patients for which $\Delta u_1(x) \geq -T$ will be prescribed the preferred drug, while the remaining patients will be prescribed the other drug. Drug demand when *drug 1 is the preferred drug* is then given by

$$q_1 = \frac{1}{2} + \frac{\Delta v + T}{2\tau} \text{ and } q_2 = \frac{1}{2} - \left(\frac{\Delta v + T}{2\tau}\right). \tag{20}$$

If instead drug 2 is the preferred drug, the net treatment gain of being treated with this drug instead of the therapeutic alternative is given by

$$\Delta u_2(x) = -\Delta v + (2x - 1)\tau. \tag{21}$$

When all patients for which $\Delta u_2(x) \geq -T$ are prescribed the preferred drug, drug demand when *drug 2 is the preferred drug* is given by

$$q_1 = \frac{1}{2} + \frac{\Delta v - T}{2\tau} \text{ and } q_2 = \frac{1}{2} - \left(\frac{\Delta v - T}{2\tau}\right). \tag{22}$$

6.1.1 Nash equilibrium

With asymmetric treatment effects, the competitive tender has an asymmetric Nash equilibrium in either pure or mixed strategies, depending on the exact parameter configuration. The next proposition provides a complete characterisation of each possibility:

Proposition 4 *Let Δv and T be characterised by*

$$0 < \Delta v < \frac{(\overline{v}_1 + \overline{v}_2)\tau}{2v_1}, \tag{23}$$

and

$$0 < T < \tau - \Delta v, \tag{24}$$

so that both drugs have positive demand regardless of the outcome of the tender.

(i) If $T \leq \overline{T}$, where

$$\overline{T} := \frac{(\tau + \Delta v)\Delta v}{\overline{v}_1 + \overline{v}_2} < \tau - \Delta v, \tag{25}$$

the competitive tender has an asymmetric pure-strategy Nash equilibrium in which $p_i = \overline{v}_i$, $i = 1, 2$.

(ii) If $T \in \left(\overline{T}, \tau - \Delta v\right)$, the competitive tender has an asymmetric mixed-strategy Nash equilibrium in which both producers randomise their bids over the interval $\left[p^{\min}, \overline{v}_2\right]$ according

to the cumulative distribution functions

$$F_1(p) = \frac{1}{2}\left(1 + \frac{\tau - \Delta v}{T}\right)\left(1 - \frac{p^{\min}}{p}\right) \tag{26}$$

and

$$F_2(p) = \frac{1}{2}\left(1 + \frac{\tau + \Delta v}{T}\right)\left(1 - \frac{p^{\min}}{p}\right) > F_1(p), \tag{27}$$

where

$$p^{\min} := \left(\frac{\tau - T + \Delta v}{\tau + T + \Delta v}\right)\overline{v}_1, \tag{28}$$

and the producer of the high-quality drug 1 additionally bids $\overline{v}_1$ with a strictly positive probability given by

$$\Pr(p_1 = \overline{v}_1) = \frac{\left[\left(2\left(\overline{v}_1 + \overline{v}_2\right) - T\right)T + \tau^2 - (\Delta v)^2\right]\Delta v}{2\left(\tau + T + \Delta v\right)T\overline{v}_2}. \tag{29}$$

In this equilibrium, the producer of the low-quality drug 2 also bids its maximum price, $\overline{v}_2$, with a strictly positive probability given by

$$\Pr(p_2 = \overline{v}_2) = \frac{(\tau - T + \Delta v)\Delta v}{2T\overline{v}_2}. \tag{30}$$

When the two drugs have different maximum (and expected) treatment benefits, the two drug producers are faced with different upper price bounds in the competitive tender (i.e., $\overline{v}_1 > \overline{v}_2$). This, in turn, facilitates the existence of a pure-strategy Nash equilibrium when T is sufficiently low. The reason is that, if the producer of the high-quality drug bids $p_1 = \overline{v}_1$, the price-undercutting response $p_2 = \overline{v}_1 - \varepsilon$ is no longer a feasible bid. Instead, the best response (from the set of feasible bids) to $p_1 = \overline{v}_1$ is $p_2 = \overline{v}_2$, which is a discretely lower bid. And as long as T is sufficiently low, the demand gain for the high-quality producer of having the preferred drug is not large enough to outweigh the profit loss associated with the price reduction needed to win the tender. In other words, $p_1 = \overline{v}_1$ is also the best response to $p_2 = \overline{v}_2$ if $T < \overline{T}$, establishing the existence of a pure-strategy Nash equilibrium in which each producer bids its maximum price and the low-quality drug becomes the preferred drug.

On the other hand, if $T > \overline{T}$, it is more profitable for the producer of the high-quality drug to be the preferred drug with a price $p_1 = \overline{v}_2 - \varepsilon$ than to be the non-preferred drug with a price $p_1 = \overline{v}_1$. In this case, a pure-strategy Nash equilibrium does not exist, as in the symmetric case analysed in Section 5. Instead, there is a mixed-strategy Nash equilibrium in

which both producers randomise their bids over the price interval $\left[p^{\min}, \overline{v}_2\right]$, and the producer of the high-quality drug additionally bids $p_1 = \overline{v}_1$ with a positive probability. Within the parameter set for which the mixed-strategy Nash equilibrium exists, a lower treatment loss threshold T increases the lower bound $p^{\min}$ and also increases the probability mass that the low- and high-quality producers place on the upper bounds $\overline{v}_2$ and $\overline{v}_1$, respectively, in the mixed-strategy equilibrium (i.e., $\partial F_1\left(\overline{v}_2\right)/\partial T > 0$ and $\partial F_2\left(\overline{v}_2\right)/\partial T > 0$). When T approaches $\overline{T}$ from above, $p^{\min}$ approaches $\overline{v}_2$ while $F_1\left(\overline{v}_2\right)$ and $F_2\left(\overline{v}_2\right)$ approach zero. Thus, the mixed-strategy equilibrium presented in the second part of Proposition 4 converges monotonically towards the pure-strategy equilibrium presented in the first part of the proposition when the treatment loss threshold T approaches $\overline{T}$ from above.

If we compare the mixed-strategy Nash equilibrium given by the second part of Proposition 4 with the symmetric mixed-strategy equilibrium given by Proposition 1, there are at least two notable differences. Importantly, the mixed strategy of the high-quality producer first-order stochastically dominates the mixed strategy of the low-quality producer, i.e., $F_1(p) < F_2(p)$, implying that *the tender is most likely won by the low-quality drug.* There are two different effects that contribute to this. First, compared with the case of symmetric treatment effects (i.e., $\Delta v = 0$), vertical differentiation implies that a certain amount of demand (given by $\Delta v/2\tau$) is shifted towards the high-quality drug regardless of whether it is has the status of preferred drug or not. For any $\Delta v > 0$, the *relative demand gain* of having its treatment status changed from non-preferred to preferred is therefore smaller for the high-quality drug than for the low-quality drug. This implies in turn that the producer of the former (latter) drug has weaker (stronger) incentives to win the tender and will thus more likely bid a higher (lower) price. Second, vertical differentiation also implies that the expected treatment effect, and thus the maximum accepted price, is higher for the high-quality drug than for the low-quality drug, i.e., $\overline{v}_1 > \overline{v}_2$, which in turn means that the producer of the high-quality drug can potentially sell its drug with a higher profit margin than what the producer of the low-quality drug can do. However, this advantage can only be fully exploited by setting a price $p_1 = \overline{v}_1 > \overline{v}_2$, which will make the low-quality drug the preferred drug. Thus, the first-order stochastic dominance of the high-quality producer's equilibrium strategy is also partly caused by the fact that the bid $p_1 = \overline{v}_1$ is made with a strictly positive probability.

Another, and perhaps more striking, characteristic of the mixed-strategy equilibrium is that the lower price bound, $p^{\min}$, is monotonically increasing in $\overline{v}_1$ and monotonically *decreasing* in

$\overline{v}_2$. This implies that increased vertical differentiation *in itself* will lead to a higher minimum drug price in the market, even if such differentiation is purely caused by a lower treatment benefit of the low-quality drug. The reason is that a larger difference in treatment benefits makes it relatively more profitable for the producer of the high-quality drug to sell a non-preferred drug at the maximum price $p_1 = \overline{v}_1$. In turn, this increases the minimum price needed to make it equally profitable for the same producer to sell a preferred drug, thus increasing the minimum bound $p^{\min}$ in the producers' equilibrium mixed strategies.

6.1.2 Competitive tenders vs. decentralised competition

We proceed by exploring how the presence of asymmetric treatment benefits affects the relative merits of competitive tendering versus decentralised competition in terms of expected treatment costs. We restrict attention to cases in which the parameters β and T are such that there is *de facto* therapeutic competition (with equilibrium prices below the maximum levels) under both policy schemes.

The Nash equilibrium under *decentralised competition* is derived in Appendix C, where we show that an interior solution exists if

$$\beta > \frac{3\tau + \Delta v}{3\overline{v}_1}. \tag{31}$$

In this case, the *average* equilibrium drug price is given by

$$p^* = \frac{\tau}{\beta} + \frac{(\Delta v)^2}{9\beta\tau}, \tag{32}$$

which implies that vertical differentiation is anti-competitive and leads to higher treatment costs. This is driven by a reallocation of demand towards the more expensive (higher-quality) drug. As is evident from (C3) in Appendix C, an increase in the degree of vertical differentiation (Δv) leads to an increase (decrease) in the price of the high-quality (low-quality) drug in such a way that the *unweighted* average drug price remains constant. However, since $\Delta p := p_1^* - p_2^*$ is smaller than Δv, a larger share of patients will be prescribed the high-quality drug in equilibrium, thus contributing to a higher average drug price.

The expected average drug price under *competitive tendering* is highly involved and thus not reported explicitly. A precise characterisation of this price can be found in Appendix C. The complexity of the asymmetric mixed-strategy equilibrium makes an analytical comparison

infeasible and we therefore resort to numerical simulations. Figure 3 shows how the (expected) average drug price depends on the degree of vertical differentiation under each of the two policy schemes in a specific numerical example where $v_1 = 5 + (\Delta v/2)$ and $v_2 = 5 - (\Delta v/2)$. The degree of vertical differentiation is thus measured as a mean-preserving spread around an expected therapeutic benefit of $5-(\tau/2)$. The other parameters are given by $\tau = 2$, $T = 2/3$ and $\beta = 3/4$, and we restrict attention to interior-solution Nash equilibria, which in this example exist for $\Delta v \in (0, 4/3)$. The average price under decentralised competition (p^*) is given by the solid thin curve whereas the expected average price under competitive tendering (p^e) is given by the solid thick curve. The dashed curves show the boundaries of the equilibrium mixed strategies under competitive tendering. In order to highlight the equilibrium price effects of vertical differentiation, the parameters are chosen such that $p^* = p^e$ for $\Delta v = 0$.

[Figure 3 here]

We know from (32) that the average drug price under decentralised competition increases with the degree of vertical differentiation between the drugs. However, Figure 3 reveals that the magnitude of this positive relationship is rather negligible. Even if $\Delta v = 4/3$, which implies that the expected therapeutic benefit of the high-quality drug is 40% higher than the expected benefit of the low-quality drug, this only yields an average price increase of less than 5% compared with the symmetric case of $\Delta v = 0$. The small magnitude of this effect is caused by the fact that increased vertical differentiation does not affect the unweighted average drug price under decentralised competition, as previously mentioned. The average price increase is solely due to a (relatively modest) shift in demand towards the high-quality drug.

In stark contrast, increased vertical differentiation yields a much stronger increase in the expected average price under competitive tendering. An increase in Δv from 0 to 4/3 yields an increase in the expected average price, and thus an increase in expected treatment costs, of more than 47%. Two factors contribute to this. First, increased vertical differentiation implies a higher upper price bound $\overline{v}_1$ for the high-quality drug. This has no effect on drug pricing under decentralised competition, but increases the expected price under competitive tendering since the high-quality producer bids $p_1 = \overline{v}_1$ with positive probability in the mixed-strategy Nash equilibrium. Second, increased vertical differentiation also increases the lower price bound $\overline{v}_2$, which again has no effect on drug pricing under decentralised competition, but clearly contributes to a higher expected price under competitive tendering. Thus, the

numerical example shown in Figure 2 suggests that differences in therapeutic benefits between competing drugs have a much stronger cost-driving effect under competitive tendering than under decentralised competition.

6.2 Captive patients

Suppose that drug 1 has been longer on the market than drug 2 and therefore has been able to obtain a captive demand segment consisting of patients who are reluctant (or whose prescribing physician is reluctant) to switch to a new therapeutic alternative.[13] More specifically, suppose that, for each value of x, a share λ of the patients will be prescribed drug 1 regardless of whether this is officially the preferred drug or not. In order to avoid confounding effects, we return here to our main assumption that the two drugs are horizontally but not vertically differentiated.

The presence of such a captive patient segment implies a modification of the demand functions in (8). More specifically, if *drug 1 is the preferred drug* (i.e., if $p_1 < p_2$), the demand for the two drugs is given by

$$q_1 = \lambda + (1-\lambda)\left(\frac{1}{2} + \frac{T}{2\tau}\right) \text{ and } q_2 = (1-\lambda)\left(\frac{1}{2} - \frac{T}{2\tau}\right). \tag{33}$$

Otherwise, if *drug 2 is the preferred drug* (i.e., if $p_1 > p_2$), the demand functions are given by

$$q_1 = \lambda + (1-\lambda)\left(\frac{1}{2} - \frac{T}{2\tau}\right) \text{ and } q_2 = (1-\lambda)\left(\frac{1}{2} + \frac{T}{2\tau}\right). \tag{34}$$

6.2.1 Nash equilibrium

As for the symmetric case analysed in Section 5, the competitive tender has a Nash equilibrium only in mixed strategies also when some patients are captive to one of the drugs. The next proposition characterises the mixed-strategy Nash equilibrium in this case.

Proposition 5 *If $T \in (0, \tau)$ and a share $\lambda > 0$ of the patients are captive to drug 1, the competitive tender has an asymmetric mixed-strategy Nash equilibrium in which both producers randomise their bids over the interval $\left[p^{\min}, \overline{v}\right]$, according to the following cumulative distribution functions:*

$$F_1(p) = \frac{1}{2}\left(1 + \frac{\tau}{T}\right)\left(1 - \frac{p^{\min}}{p}\right), \tag{35}$$

[13] This assumption was introduced in the canonical generic entry model by Frank and Salkever (1992) in their study of generic competition in the presence of brand-loyal patients. Maini et al. (2021) incorporate the same assumption into their analysis of biosimilar competition in the US..

and

$$F_2(p) = \frac{1}{2}\left(1 + \frac{1+\lambda}{1-\lambda}\frac{\tau}{T}\right)\left(1 - \frac{p^{\min}}{p}\right) > F_1(p), \tag{36}$$

where

$$p^{\min} = \frac{(1+\lambda)\tau - (1-\lambda)T}{(1+\lambda)\tau + (1-\lambda)T}\overline{v}. \tag{37}$$

In this equilibrium, the producer of drug 1 bids $\overline{v}$ with a strictly positive probability, given by

$$\Pr(p_1 = \overline{v}) = \frac{2\lambda\tau}{(1+\lambda)\tau + (1-\lambda)T}. \tag{38}$$

The existence of a captive demand segment implies that the two drug producers compete for a smaller share of the market, given by $1-\lambda$. The logic of Lemma 1 still applies and a Nash equilibrium in pure strategies does not exist for $T \in (0, \tau)$. However, the mixed-strategy Nash equilibrium is now asymmetric for $\lambda > 0$ in the sense that $F_1(p)$ first-order stochastically dominates $F_2(p)$, implying that the tender is most likely won by the producer of drug 2. Thus, as for the case of asymmetric treatment effects, the disadvantaged producer has a higher probability of ending up selling the preferred drug. This is explained by a demand effect similar to the first of the two effects explaining the qualitatively equivalent result in case of asymmetric treatment effects (cf. the second part of Proposition 4). The demand advantage of having captive patients implies that the *relative demand gain* of selling a preferred drug is smaller for the producer of the drug with captive patients. This producer will therefore have weaker incentives to win the tender than the producer of the drug without captive patients, and will therefore submit the maximum bid $\overline{v}$ with a strictly positive probability, which in turn implies $F_1(p) < F_2(p)$ for all $p \in \left(p^{\min}, \overline{v}\right)$. Relatedly, the existence of captive patients also increases the lower bound of the producers' equilibrium bids, since it increases the minimum price at which winning the tender is as profitable for the producer of drug 1 as bidding $\overline{v}$ and selling a non-preferred drug. In the limit case of $\lambda \to 1$, drug 1 has all demand regardless of the outcome of the tender, and the lower bound $p^{\min}$ therefore converges to the maximum price $\overline{v}$.

6.2.2 Competitive tenders vs. decentralised competition

Let us once more compare the two policy schemes in terms of expected treatment costs, this time with a captive demand segment for drug 1. As before, we restrict attention to interior-solution equilibria, which under decentralised competition requires that the relative size of the

captive segment is limited to

$$\lambda < \frac{3\left(\beta\overline{v} - \tau\right)}{3\beta\overline{v} + \tau}. \tag{39}$$

In Appendix C we show that the average drug price under *decentralised competition* in this case is given by

$$p^* = \left(\frac{9 + \lambda^2}{9\left(1 - \lambda\right)}\right)\frac{\tau}{\beta}. \tag{40}$$

It follows directly from (40) that the average price is monotonically increasing in λ. Thus, the presence of captive patients is anti-competitive and leads to higher treatment costs. The reason is that the demand for drug 1 becomes less price-elastic, which in turn means that profits are maximised at a higher price. Due to strategic complementarity, this will also lead to a higher price for drug 2.

In Appendix C we also show that, under *competitive tendering*, the expected average drug price is given by

$$p^e = \frac{\left(1 - \lambda\right)T\eta - \left(\tau + T\right)\left(\left(1 + \lambda\right)\tau - \left(1 - \lambda\right)T\right)\left(\left(1 + \lambda\right)\tau + \left(1 - \lambda\right)\frac{T}{2}\right)\left(\ln\frac{p^{\min}}{\overline{v}}\right)\left(\lambda\tau\right)^2}{\left(1 - \lambda\right)\tau\overline{v}^{-1}\left(\left(1 + \lambda\right)\tau + \left(1 - \lambda\right)T\right)^2 T^2}, \tag{41}$$

where

$$\begin{aligned}\eta \;\; : \;\; &= \left(1 - \lambda\right)\left(\left(1 + 2\lambda\left(1 + \lambda\right)\right)T + \left(1 + 3\lambda\left(1 + \lambda\right)\right)\tau\right)T\tau^2 \\ &\quad - \left(1 - \lambda\right)^2\left(\tau + \left(1 - \lambda\right)T\right)T^3 - 2\left(1 + \lambda\right)\lambda^2\tau^4.\end{aligned} \tag{42}$$

The complexity of (41) makes an analytical comparison infeasible and we therefore once more resort to a numerical example.

In Figure 4 we show how equilibrium drug prices under decentralised competition and competitive tendering depend on the size of the captive demand segment (λ) for the same numerical example as we have used previously, with $v = 5$, $\tau = 2$, $T = 2/3$ and $\beta = 3/4$. We restrict once more attention to interior-solution equilibria, which in this example exist for $\lambda \in (0, 3/11)$. As before, the solid thin curve depicts the average drug price under decentralised competition (p^*), the solid thick curve shows the expected average drug price under competitive tendering (p^e), while the dashed curves show the upper and lower bounds of the equilibrium mixed strategies. In order to isolate the effect of captive patients, the value of T is chosen such that $p^* = p^e$ for $\lambda = 0$.

[Figure 4 here]

We already know from (40) that a larger captive segment yields a higher average drug price under decentralised competition. The example shown in Figure 4 confirms that a similar relationship exists under competitive tendering. This is no surprise, given the previously discussed characteristics of the mixed-strategy Nash equilibrium given by Proposition 5. A larger captive segment implies that the lower price bound $p^{\min}$ increases and that the producer with the demand advantage bids the maximum price $\overline{v}$ with a higher probability. Both effects contribute to a higher expected average price. However, in contrast to the case of asymmetric treatment benefits (shown in Figure 3), the effects of captive patients on average drug prices are much more similar across the two policy schemes. A difference in expected treatment costs only becomes somewhat pronounced if the size of the captive segment is at least 15%, and the cost-driving effect is in this case larger under decentralised competition. Still, if $\lambda = 3/11$, which implies that more than 27% of the patients are captive to drug 1, expected treatment costs are only 9.7% higher under decentralised competition than under competitive tendering.

7 Concluding remarks

This paper has analysed the economic consequences of centralised competitive tendering in pharmaceutical markets where patented drugs are therapeutic substitutes. Using a standard duopoly model with horizontally differentiated treatment effects of the two drug therapies, we introduce physicians' willingness to accept treatment loss as a key factor governing substitution in tender-based procurement.

We show that decentralised competition, in which physicians balance therapeutic benefits against drug costs at the individual patient level, always yields efficient allocation and thus maximises aggregate treatment benefits. By contrast, competitive tendering distorts treatment allocations whenever substitution is tolerated, but may reduce expected drug expenditures if the substitution threshold is sufficiently high. Tendering therefore involves an inherent trade-off: lower costs at the expense of lower treatment benefits.

A key insight is that competitive tenders generate mixed-strategy bidding behaviour. Because the non-preferred drug retains some demand, producers balance the value of winning the tender against the profits from pricing at the upper bound. The expected tender price is decreasing in the tolerated loss of therapeutic benefit, while expected clinical benefits move in the

opposite direction. Consequently, tendering outperforms decentralised competition only when the physician substitution threshold is sufficiently large. Moreover, the scope for tender-based cost savings declines as the therapeutic benefits—and thus the maximum admissible prices—of the drugs increase.

Two extensions highlight how market asymmetries interact with procurement design. With vertical product differentiation, the lower-quality drug is more likely to win the tender, amplifying expected expenditure relative to decentralised competition. With captive patient segments, both procurement schemes become more costly, though decentralised competition is somewhat more exposed.

Overall, our analysis underscores that the performance of competitive tendering critically depends on the extent to which clinicians and policymakers are willing to accept therapeutic substitution. This substitution tolerance shapes bidding incentives, price outcomes, and the balance between cost containment and treatment efficiency.

By way of conclusion, we would like to highlight a couple of avenues for future research. First, many drug therapies treat multiple indications, implying that firms must balance marginal revenues and competitive conditions across different markets when setting prices. Our analysis abstracts from these complexities by focusing on single-indication drugs (or multi-indication drugs with similar demand and competitive environments across indications). In related work (Brekke et al., 2025), we examine multi-indication pricing incentives under decentralised competition. Extending the present framework to analyse competitive tendering for multi-indication drugs is a natural next step, but it would add substantial analytical complexity and, in our view, warrants a separate investigation.

Second, we have not considered how competitive tendering affects innovation incentives. Although modelling the R&D stage is beyond the scope of this paper, our analysis offers some suggestive implications. Competitive tendering distorts prescribing away from the efficient allocation, which is likely to distort innovation incentives as well. Moreover, tendering generates asymmetric profit distributions between preferred and non-preferred products—even when drugs are *ex ante* symmetric—and may also reduce patent rents by inducing lower prices than decentralised competition. These mechanisms suggest that decentralised competition might be more conducive to socially desirable innovation incentives than competitive tendering, although it is impossible to derive any strong conclusions without a full-fledged analysis, which is left for further research.

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Appendix A: Proofs

Proof of Lemma 1

From (8), the demand gain of winning the tender is given by T/τ. Thus, for any $T \in (0, \tau)$, each producer can obtain a discrete increase in demand by reducing its bid from marginally above to marginally below the bid of the competing producer. Such price undercutting is therefore profitable for all bids strictly higher than marginal cost. Furthermore, since demand for the non-preferred drug is strictly positive for all $T \in (0, \tau)$, the best response for producer i to any bid $p_j \in [0, \overline{v}]$ is either to price undercut by bidding $p_i = p_j - \varepsilon$ or to bid the maximum price $p_i = \overline{v}$. The latter strategy is clearly optimal if p_j is sufficiently close to marginal cost, whereas the former strategy is clearly optimal if p_j is sufficiently close to the maximum price $\overline{v}$. This means that no pair of prices for which both producers play their best response exists. Consequently, a Nash equilibrium in pure strategies does not exist.

Proof of Proposition 1

In a mixed-strategy Nash equilibrium, the two producers must necessarily randomise their bids over the same interval $\left[p^{\min}, p^{\max}\right]$. Since the bid $\overline{v}$ yields the highest profits of all non-winning bids, the upper bound $p^{\max}$ must necessarily be equal to $\overline{v}$. Suppose that one of the producers plays such a mixed strategy and randomises on $\left[p^{\min}, \overline{v}\right]$ according to a cumulative distribution function $F(p)$. The expected profits of the other producer, if it plays p as a pure strategy, are then given by

$$\pi^e(p) = p\left(\frac{1}{2} - \frac{T}{2\tau}\right) F(p) + p\left(\frac{1}{2} + \frac{T}{2\tau}\right)(1 - F(p)). \tag{A1}$$

$F(p)$ is an equilibrium strategy if $\pi^e(p)$ is constant for all $p \in \left[p^{\min}, \overline{v}\right]$. Solving (A1) for $F(p)$ yields

$$F(p) = \frac{\tau + T}{2T} - \frac{\tau \pi^e}{Tp}. \tag{A2}$$

The expected equilibrium profits are then found by setting $p^{\max} = \overline{v}$ and using $F(\overline{v}) = 1$, yielding

$$\pi^e = \left(\frac{\tau - T}{2\tau}\right)\overline{v}. \tag{A3}$$

By inserting the value of π^e from (A3) into (A2), we derive the equilibrium mixed strategy given by (10) in Proposition 1. Finally, the lower bound $p^{\min}$ is found by setting $p = p^{\min}$ in (10) and solving $F\left(p^{\min}\right) = 0$ for $p^{\min}$, yielding the expression given by (11) in Proposition 1. Finally,

since each producer wins the tender for sure by setting a price equal to $p^{\min}$, which yields a profit π^e, it follows directly that setting any price $p < p^{\min}$ yields a profit strictly lower than π^e if the competing producer plays the mixed strategy given by (10).

Proof of Proposition 2

Notice first that the equilibrium distribution function $F(p)$, given by (10), has an associated probability density function given by

$$f(p) = \frac{\partial F(p)}{\partial p} = \frac{(\tau - T)\,\overline{v}}{2Tp^2}. \tag{A4}$$

Let the lowest bid be denoted by $p_L := \min(p_1, p_2)$. The probability that the lowest bid is below some threshold value p is equal to the probability that at least one of the bids is below p, and is thus given by

$$\Pr(p_L \leq p) = 1 - [\Pr(p_1 > p) * \Pr(p_2 > p)]. \tag{A5}$$

The cumulative distribution function of p_L, denoted by F_L, is therefore given by

$$F_L(p) = 1 - (1 - F(p))^2, \tag{A6}$$

with the following associated probability density function:

$$f_L(p) = \frac{\partial F_L(p)}{\partial p} = 2(1 - F(p))\, f(p). \tag{A7}$$

The expected value of the lowest price, denoted by p_L^e, is then given by

$$p_L^e = \int_{p^{\min}}^{\overline{v}} p f_L(p)\, dp = \frac{(\tau - T)\left[2T + (\tau - T)\ln\left(\frac{\tau - T}{\tau + T}\right)\right]\overline{v}}{2T^2}. \tag{A8}$$

Similarly, let the highest bid be denoted by $p_H := \max(p_1, p_2)$. The probability that the highest bid is below some threshold value p is equal to the probability that both bids are below p, and is thus given by

$$\Pr(p_H \leq p) = \Pr(p_1 \leq p) * \Pr(p_2 \leq p). \tag{A9}$$

The cumulative distribution function of p_H, denoted by F_H, is therefore given by

$$F_H(p) = (F(p))^2, \tag{A10}$$

with the following associated probability density function:

$$f_H(p) = \frac{\partial F_H(p)}{\partial p} = 2F(p) f(p). \tag{A11}$$

The expected value of the highest bid, denoted by p_H^e, is then given by

$$p_H^e = \int_{p^{\min}}^{\overline{v}} p f_H(p)\, dp = -\frac{(\tau - T)\left[2T + (\tau + T)\ln\left(\frac{\tau - T}{T + \tau}\right)\right]\overline{v}}{2T^2}. \tag{A12}$$

The producer with the lowest price wins the tender and the preferred drug obtains demand equal to $1/2 + T/2\tau$. With a unit mass of patients, the expected average price is therefore given by

$$p^e = \left(\frac{1}{2} + \frac{T}{2\tau}\right) p_L^e + \left(\frac{1}{2} - \frac{T}{2\tau}\right) p_H^e = \left(1 - \frac{T}{\tau}\right)\overline{v}. \tag{A13}$$

Since the preferred drug obtains a demand equal to $1/2 + T/2\tau$, the aggregate treatment benefits are given by

$$H = \int_0^{\frac{1}{2}+\frac{T}{2\tau}} (v - \tau x)\, dx + \int_0^{\frac{1}{2}-\frac{T}{2\tau}} (v - \tau x)\, dx = v - \frac{\tau}{4} - \frac{T^2}{4\tau}. \tag{A14}$$

Proof of Corollary 1

The effects of T on p^e and H follow directly from (13) and (14), respectively. As for the surplus of a health plan that places equal weights on treatment benefits and treatment costs, this is given by

$$S = H - p^e = \frac{T}{\tau}\left(\overline{v} - \frac{T}{4}\right) + \frac{\tau}{4}. \tag{A15}$$

From (A15) we easily derive

$$\frac{\partial S}{\partial T} = \frac{1}{\tau}\left(\overline{v} - \frac{T}{2}\right) = \frac{1}{\tau}\left(v - \left(\frac{\tau + T}{2}\right)\right) > 0, \tag{A16}$$

where the positive sign is ensured by the assumption that all patients have positive treatment benefits of both drugs; i.e, $v > \tau$.

Proof of Proposition 3

(i) A comparison of (5) and (14) yields

$$H - H^* = -\frac{T^2}{4\tau} < 0. \tag{A17}$$

(ii) A comparison of (4) and (13) yields

$$p^e - p^* = \left(1 - \frac{T}{\tau}\right)\overline{v} - \frac{\tau}{\beta} < (>)\, 0 \text{ if } T > (<)\, \widehat{T} := \left(1 - \frac{\tau}{\beta\overline{v}}\right)\tau, \tag{A18}$$

where $\widehat{T} > 0$ for all parameter values that yield an interior-solution Nash equilibrium under decentralised competition (which requires $\beta > \tau/\overline{v}$).

(ii) A comparison of (6) and (13)-(14) yields

$$\Delta S := (H - p^e) - S^* = \frac{2\,(2+\beta)\,\tau^2 - \beta\,(T+2\tau)\,T}{4\beta\tau} - \left(1 - \frac{T}{\tau}\right)v. \tag{A19}$$

From (A19) it is easily confirmed that ΔS is monotonically increasing in T:

$$\frac{\partial\,(\Delta S)}{\partial T} = \frac{1}{\tau}\left(v - \left(\frac{\tau + T}{2}\right)\right) > 0, \tag{A20}$$

where the positive sign of (A20) is ensured by the assumption $v > \tau$. Furthermore, it also follows from (A19) that

$$\lim_{T\to 0} \Delta S = -\left(v - \left(\frac{2+\beta}{2\beta}\right)\tau\right) < 0 \tag{A21}$$

and

$$\lim_{T\to \tau} \Delta S = \frac{(4-\beta)\,\tau}{4\beta} > 0, \tag{A22}$$

where the negative sign of (A21) is confirmed by imposing the condition for an interior-solution Nash equilibrium under decentralised competition ($\beta > \tau/\overline{v}$). Thus, there exists a threshold value of T, given by $\widetilde{T} \in (0, \tau)$, such that $\Delta S < (>)\, 0$ if $T < (>)\, \widetilde{T}$. Moreover, since $H < H^*$ and $p^e = p^*$ for $T = \widehat{T}$, and since $\Delta S = (H - H^*) - (p^e - p^*)$, it necessarily follows that $\widetilde{T} > \widehat{T}$.

Proof of Proposition 4

(i) Suppose that the low-quality producer bids $p_2 \in [0, \overline{v}_2]$. The high-quality producer's best response to such a bid is either $p_1 = p_2 - \varepsilon$ or $p_1 = \overline{v}_1$. In turn, the low-quality producer's

best response to the former bid is either $p_2 = p_1 - \varepsilon$ or $p_2 = \overline{v}_2$, while the same producer's best response to the latter bid is $p_2 = \overline{v}_2$. Thus, if a pure-strategy Nash Equilibrium exists, it must necessarily be given by $p_1 = \overline{v}_1$ and $p_2 = \overline{v}_2$. Since $p_2 = \overline{v}_2$ is always a best response to $p_1 = \overline{v}_1$, this equilibrium exists if $p_1 = \overline{v}_1$ is a best response to $p_2 = \overline{v}_2$, which requires

$$\pi_1 \left(p_1 = \overline{v}_1, p_2 = \overline{v}_2 \right) \geq \pi_1 \left(p_1 = \overline{v}_2 - \varepsilon, p_2 = \overline{v}_2 \right). \tag{A23}$$

Using the demand functions given by (20) and (22), and letting $\varepsilon \to 0$, this condition is given by

$$\overline{v}_1 \left(\frac{1}{2} + \left(\frac{\Delta v - T}{2\tau} \right) \right) \geq \overline{v}_2 \left(\frac{1}{2} + \frac{\Delta v + T}{2\tau} \right), \tag{A24}$$

which reduces to $T \leq \overline{T}$, where $\overline{T}$ is given by (25) in Proposition 4.

(ii) Suppose that $T > \overline{T}$, such that no pure-strategy Nash Equilibrium exists. In this case, a candidate mixed-strategy Nash Equilibrium is that the low-quality producer randomises over an interval $\left[p^{\min}, \overline{v}_2 \right]$ while high-quality producer randomises over the same price interval and additionally plays $p = \overline{v}_1$ with some positive probability. For each producer, playing the pure strategy $p^{\min}$ when the competing producer plays the equilibrium mixed strategy yields higher profits than setting a price marginally below $p^{\min}$ only if the tender is won for sure by setting a price $p^{\min}$. Thus, the equilibrium strategies cannot have a mass point on $p^{\min}$. This implies in turn that the high-quality producer will win the tender for sure by playing the pure strategy $p_1 = p^{\min}$, yielding a profit of

$$\pi_1 \left(p_1 = p^{\min} \right) = p^{\min} \left(\frac{1}{2} + \frac{\Delta v + T}{2\tau} \right), \tag{A25}$$

while the low-quality producer will win the tender for sure if the high-quality producer plays the pure strategy $p_1 = \overline{v}_1$, yielding a profit for the latter producer of

$$\pi_1 \left(p_1 = \overline{v}_1 \right) = \overline{v}_1 \left(\frac{1}{2} + \left(\frac{\Delta v - T}{2\tau} \right) \right). \tag{A26}$$

Since playing any $p_1 \in \left[p^{\min}, \overline{v}_2 \right]$ or $p_1 = \overline{v}_1$ as a pure strategy must give the high-quality producer the same profits when the low-quality producer plays the equilibrium mixed strategy, the lower bound $p^{\min}$ is implicitly given by

$$\pi_1 \left(p_1 = p^{\min} \right) = \pi_1 \left(p_1 = \overline{v}_1 \right), \tag{A27}$$

yielding the value of $p^{\min}$ given by (28) in Proposition 4.

Suppose that the high-quality producer randomises over the interval $\left[p^{\min}, \overline{v}_2\right]$ according to a cumulative distribution function $F_1(p)$. The low-quality producer's expected profits of playing a pure strategy p_2 are then given by

$$\pi_2^e(p_2) = p_2\left(\frac{1}{2} - \left(\frac{\Delta v - T}{2\tau}\right)\right)(1 - F_1(p_2)) + p_2\left(\frac{1}{2} - \left(\frac{\Delta v + T}{2\tau}\right)\right)F_1(p_2). \tag{A28}$$

If $F_1(p)$ is an equilibrium strategy, $\pi_2^e(p_2)$ must be constant for all $p_2 \in \left[p^{\min}, \overline{v}_2\right]$. Solving (A28) for $F_1(p)$ when $\pi_2^e(p_2) = \pi_2^e$ yields

$$F_1(p) = \frac{(\tau + T - \Delta v)\, p - 2\tau\pi_2^e}{2Tp}. \tag{A29}$$

Using the fact that $F_1\left(p^{\min}\right) = 0$ we derive

$$\pi_2^e = p^{\min}\left(\frac{1}{2} - \left(\frac{\Delta v - T}{2\tau}\right)\right), \tag{A30}$$

which is higher than the profits the low-quality producer can earn by setting any price $p_2 < p^{\min}$. The mixed strategy of the high-quality producer is thus found by substituting the value of π_2^e from (A30) into (A29), yielding the expression for $F_1(p)$ given by (26) in Proposition 4. It is easily confirmed that $F_1(\overline{v}_2) < 1$ for $\Delta v > 0$, which implies that the high-quality producer bids $p_1 = \overline{v}_1$ with a strictly positive probability given by

$$\Pr(p_1 = \overline{v}_1) = 1 - F_1(\overline{v}_2), \tag{A31}$$

whose explicit expression is given by (29) in Proposition 4.

Similarly, suppose that the low-quality producer randomises according to $F_2(p)$. The high-quality producer's expected profits of playing any $p_1 \in \left[p^{\min}, \overline{v}_2\right]$ as a pure strategy are then given by

$$\pi_1^e(p_1) = p_1\left(\frac{1}{2} + \frac{\Delta v + T}{2\tau}\right)(1 - F_2(p_1)) + p_1\left(\frac{1}{2} + \left(\frac{\Delta v - T}{2\tau}\right)\right)F_2(p_1). \tag{A32}$$

If $F_2(p)$ is an equilibrium strategy, $\pi_1^e(p_1)$ must be constant for all $p_1 \in \left[p^{\min}, \overline{v}_2\right]$ and equal to

$$\pi_1^e(p_1 = \overline{v}_1) = \overline{v}_1\left(\frac{1}{2} + \left(\frac{\Delta v - T}{2\tau}\right)\right). \tag{A33}$$

Setting $\pi_1^e(p_1)$ from (A32) equal to $\pi_1^e(p_1 = \overline{v}_1)$ from (A33), and solving for F_2, yields an expression for $F_2(p)$ given by (27) in Proposition 4. It is easily verified that $F_2\left(p^{\min}\right) = 0$ and that

$$F_2(\overline{v}_2) = \frac{(\overline{v}_1 + \overline{v}_2)T - (\Delta v + \tau)\Delta v}{2T\overline{v}_2} < 1 \text{ for } \Delta v > 0 \text{ and } T > \overline{T}. \tag{A34}$$

Thus, the equilibrium strategy of the low-quality producer has a mass point on $\overline{v}_2$. It is also easily verified that

$$\frac{\partial p^{\min}}{\partial T} < 0, \frac{\partial F_1(\overline{v}_2)}{\partial T} > 0 \text{ and } \frac{\partial F_2(\overline{v}_2)}{\partial T} > 0, \tag{A35}$$

and that

$$\lim_{T \to \overline{T}} p^{\min} = \overline{v}_2 \text{ and } \lim_{T \to \overline{T}} F_1(\overline{v}_2) = F_2(\overline{v}_2) = 0. \tag{A36}$$

Thus, the mixed strategy Nash Equilibrium in the second part of Proposition 4 converges monotonically to the pure strategy Nash Equilibrium given in the first part of the same proposition when T approaches $\overline{T}$ from above.

Proof of Proposition 5

An obvious candidate mixed-strategy Nash Equilibrium is that both firms randomise on the interval $\left[p^{\min}, \overline{v}\right]$, where $p^{\min}$ is such that bidding this price and winning the tender yields the same profits for the producer of the drug with captive patients (drug 1) as bidding $\overline{v}$ and letting the tender be won by the other drug. Using the demand functions in (33)-(34), $p^{\min}$ is thus implicitly given by

$$\overline{v}\left(\lambda + (1-\lambda)\left(\frac{1}{2} - \frac{T}{2\tau}\right)\right) = p^{\min}\left(\lambda + (1-\lambda)\left(\frac{1}{2} + \frac{T}{2\tau}\right)\right), \tag{A37}$$

yielding a value of $p^{\min}$ given by (37) in Proposition 5.

Suppose that the producer of drug 2 plays the mixed strategy $F_2(p)$. The expected profits of the competing producer if playing any $p_1 \in \left[p^{\min}, \overline{v}\right]$ as a pure strategy are then given by

$$\pi_1^e(p_1) = p_1\left(\lambda + (1-\lambda)\left(\frac{1}{2} - \frac{T}{2\tau}\right)\right)F_2(p_1) + p_1\left(\lambda + (1-\lambda)\left(\frac{1}{2} + \frac{T}{2\tau}\right)\right)(1 - F_2(p_1)). \tag{A38}$$

If $F_2(p)$ is an equilibrium strategy, π_1^e must be constant for all $p_1 \in \left[p^{\min}, \overline{v}\right]$. Setting π_1^e equal to $\overline{v}(\lambda + (1-\lambda)(1/2 - T/2\tau))$ and solving for F_2 yields the expression given by (36) in Proposition 5. It is easily confirmed that $F_2\left(p^{\min}\right) = 0$ and $F_2(\overline{v}) = 1$.

Suppose that the producer of drug 1 plays a mixed strategy $F_1(p)$. The expected profits of the competing producer if playing any $p_2 \in \left[p^{\min}, \overline{v}\right]$ as a pure strategy are then given by

$$\pi_2^e(p_2) = p_2(1-\lambda)\left(\frac{1}{2} - \frac{T}{2\tau}\right)F_1(p_2) + p_2(1-\lambda)\left(\frac{1}{2} + \frac{T}{2\tau}\right)(1 - F_1(p_2)). \tag{A39}$$

If $F_1(p)$ is an equilibrium strategy, $\pi_2^e(p_2)$ must be constant for all $p_2 \in \left[p^{\min}, \overline{v}\right]$. Setting $\pi_2^e(p_2) = \pi_2^e$ and solving for F_1 yields

$$F_1(p) = \frac{\tau + T}{2T} - \frac{\tau \pi_2^e}{(1-\lambda)Tp}. \tag{A40}$$

Neither equilibrium strategy can have a mass point at the lower price bound $p^{\min}$. Thus, $F_1\left(p^{\min}\right) = 0$ in equilibrium. Otherwise, if $F_1\left(p^{\min}\right) > 0$, the producer of drug 2 would not be guaranteed to win the tender by bidding $p^{\min}$ and could therefore obtain higher expected profits by bidding slightly below $p^{\min}$. Setting $F_1\left(p^{\min}\right) = 0$ in (A40) and solving for π_2^e, we derive

$$\pi_2^e = (1-\lambda)\left(\frac{1}{2} + \frac{T}{2\tau}\right)p^{\min}, \tag{A41}$$

which is higher than the profits that the producer of drug 2 can obtain by bidding any price $p_2 < p^{\min}$. Inserting the value of π_2^e from (A41) into (A40) yields an expression for $F_1(p)$ given by (36) in Proposition 5. It is easily verified that

$$F_1(\overline{v}) = \frac{(1-\lambda)(T+\tau)}{(1+\lambda)\tau + (1-\lambda)T} < 1 \text{ for } \lambda > 0. \tag{A42}$$

Thus, the equilibrium strategy of the producer with captive patients has a mass point at the upper bound $\overline{v}$.

Appendix B: Uncorrelated treatment effects

Suppose that the therapeutic benefit of drug i is given by $v - \tau x_i$, $i = 1, 2$. Suppose further that each patient is characterised by a pair (x_1, x_2), where x_1 and x_2 are independent draws from a uniform distribution on $[0, 1]$. All other modelling assumptions remain the same. Notice that the expected therapeutic benefit of each drug is the same as before and given by (1).

B.1. Decentralised competition

Applying the same prescription criteria as in the main model, a patient will be prescribed drug i if

$$v - \beta p_i - \tau x_i \geq v - \beta p_j - \tau x_j, \tag{B1}$$

which is equivalent to

$$x_i - x_j \leq \frac{\beta\left(p_j - p_i\right)}{\tau}. \tag{B2}$$

In order to derive drug demand, it is useful to define $X := x_i - x_j$ and let $F_X\left(z\right)$ be the cumulative distribution function of X. This function is given by

$$\begin{aligned} F_X\left(z\right) &= P\left(X \leq z\right) = P\left(x_i - x_j \leq z\right) \\ &= \begin{cases} \int_0^{1+z} \int_{x_i - z}^{1} dx_j dx_i & if \quad -1 < z < 0 \\ 1 - \int_z^1 \int_0^{x_i - z} dx_j dx_i & if \quad 0 \leq z < 1 \end{cases} \\ &= \begin{cases} \frac{1}{2} + z + \frac{z^2}{2} & if \quad -1 < z < 0 \\ \frac{1}{2} + z - \frac{z^2}{2} & if \quad 0 \leq z < 1 \end{cases}. \end{aligned} \tag{B3}$$

Notice that this is a triangular distribution around $X = 0$, with density

$$f_X\left(z\right) = \begin{cases} 1 + z & if \quad -1 < z < 0 \\ 1 - z & if \quad 0 \leq z < 1 \end{cases}. \tag{B4}$$

If the total patient mass is equal to one, demand for drug i is then given by

$$q_i = F\left(\frac{\beta\left(p_j - p_i\right)}{\tau}\right) = \begin{cases} \frac{1}{2} + \frac{\beta(p_j - p_i)}{\tau} + \frac{1}{2}\left(\frac{\beta(p_j - p_1)}{\tau}\right)^2 & if \quad p_j < p_i \\ \frac{1}{2} + \frac{\beta(p_j - p_i)}{\tau} - \frac{1}{2}\left(\frac{\beta(p_j - p_i)}{\tau}\right)^2 & if \quad p_j \geq p_i \end{cases}. \tag{B5}$$

By maximising the profits of firm i, given by $\pi_i = p_i q_i$, and applying symmetry, $p_i = p_j = p^*$, it is fairly straightforward to verify that the unique pure-strategy Nash equilibrium is given by

$$p^* = \begin{cases} \frac{\tau}{2\beta} & if \quad \beta \geq \frac{\tau}{2\overline{v}} \\ \overline{v} & if \quad \beta < \frac{\tau}{2\overline{v}} \end{cases}. \tag{B6}$$

Thus, the equilibrium prices in the interior-solution Nash equilibrium are exactly half of the corresponding equilibrium prices in the main model, but respond in a qualitatively similar way to changes in τ or β.

In the symmetric equilibrium, each patient is prescribed the drug which yields the highest therapeutic benefit, which implies that the allocation of drug treatment is efficient. Total health benefits are therefore given by

$$H^* = 2\int_0^1 \left(\int_0^{x_i} (v - \tau s)\, ds\right) dx_i = v - \frac{\tau}{3}, \tag{B7}$$

which gives the health plan a total surplus of

$$S^* = H^* - p^* = v - \frac{\tau}{3} - \frac{\tau}{2\beta}. \tag{B8}$$

B.2. Competitive tendering

Suppose that drug i is the preferred drug. The therapeutic gain of prescribing this drug instead of drug j is given by

$$\Delta u\left(x_i, x_j\right) = v - \tau x_i - \left(v - \tau x_j\right) = \tau\left(x_j - x_i\right). \tag{B9}$$

With a treatment loss threshold of T, the preferred drug will be prescribed to all patients for whom

$$\tau\left(x_j - x_i\right) \geq -T, \tag{B10}$$

or, equivalently,

$$x_i \leq x_j + \frac{T}{\tau}. \tag{B11}$$

Demand for each drug is therefore given by

$$q_i = \int_0^{1-\frac{T}{\tau}} \left(x_j + \frac{T}{\tau}\right) dx_j + \frac{T}{\tau} = 1 - \frac{1}{2}\left(1 - \frac{T}{\tau}\right)^2 \tag{B12}$$

and

$$q_j = \int_0^{1-\frac{T}{\tau}} \left(1 - \left(x_j + \frac{T}{\tau}\right)\right) dx_j = \frac{1}{2}\left(1 - \frac{T}{\tau}\right)^2. \tag{B13}$$

It is easily confirmed that $q_i > q_j > 0$ for $T \in (0, \tau)$, $q_i = q_j = 1/2$ for $T = 0$, and $q_i = 1$ and $q_j = 0$ for $T = 0$.

As in the main model, an equilibrium in pure strategies does not exist in the symmetric case. Consider instead a mixed strategy $F(p)$ defined on $\left[p^{\min}, \overline{v}\right]$. If one of the firms plays this strategy, the expected profits of the competing firm are given by

$$\pi^e(p) = \frac{p}{2}\left(1 - \frac{T}{\tau}\right)^2 F(p) + p\left(1 - \frac{1}{2}\left(1 - \frac{T}{\tau}\right)^2\right)(1 - F(p)). \tag{B14}$$

$F(p)$ is an equilibrium strategy if $\pi^e(p)$ is constant for all $p \in \left[p^{\min}, \overline{v}\right]$. Solving (B14) for $F(p)$ yields

$$F(p) = \frac{p\left(2T\tau + \tau^2 - T^2\right) - 2\tau^2\pi^e}{2Tp(2\tau - T)}. \tag{B15}$$

The equilibrium value of π^e is found by setting $p^{\max} = \overline{v}$ and using $F(\overline{v}) = 1$, yielding

$$\pi^e = \frac{1}{2}\left(1 - \frac{T}{\tau}\right)^2 \overline{v}. \tag{B16}$$

By inserting the value of π^e from (B16) into (B15), we derive the equilibrium mixed strategy given by

$$F(p) = 1 - \frac{(T - \tau)^2(\overline{v} - p)}{2T(2\tau - T)p} \tag{B17}$$

The lower bound $p^{\min}$ is then found by setting $p = p^{\min}$ in (B17) and solving $F\left(p^{\min}\right) = 0$ for $p^{\min}$, yielding

$$p^{\min} = \left(\frac{(\tau - T)^2}{2T\tau + \tau^2 - T^2}\right)\overline{v} > 0 \quad for \quad T < \tau. \tag{B18}$$

Exactly as in the main model, it is easily confirmed that this mixed strategy Nash equilibrium exists for $T \in (0, \tau)$, and that the equilibrium prices converge to $p_1 = p_2 = \overline{v}$ if $T \to 0$, and to $p_1 = p_2 = 0$ if $T \to \tau$.

In order to derive the expected drug prices in the mixed-strategy Nash equilibrium, let the lowest bid be denoted by $p_L = \min(p_1, p_2)$. The probability that the lowest bid is below some threshold value p is equal to the probability that at least one of the bids is below p, and is thus given by

$$\Pr(p_L \leq p) = 1 - [\Pr(p_1 > p) * \Pr(p_2 > p)] \tag{B19}$$

The cumulative distribution function of p_L, denoted by F_L, is therefore given by

$$F_L = 1 - (1 - F(p))^2, \tag{B20}$$

with the associated probability density function, denoted f_L, is given by

$$f_L = \frac{\partial F_L}{\partial p} = 2\left(1 - F\left(p\right)\right) f\left(p\right). \tag{B21}$$

The expected value of the lowest price, denoted by p_L^e, is then given by

$$p_L^e = \int_{p_0}^{p_1} p f_L dp = \frac{\left(\tau - T\right)^2 \left(2T\left(2\tau - T\right) + \left(\ln\left(\frac{\left(\tau - T\right)^2}{2T\tau + \tau^2 - T^2}\right)\right)\left(\tau - T\right)^2\right)\overline{v}}{2T^2\left(2\tau - T\right)^2}. \tag{B22}$$

Similarly, let the highest bid be denoted by $p_H = \max\left(p_1, p_2\right)$. The probability that the highest bid is below some threshold value p is equal to the probability that both bids are below p, and is thus given by

$$\Pr\left(p_H \leq p\right) = \Pr\left(p_1 < p\right) * \Pr\left(p_2 < p\right). \tag{B23}$$

The cumulative distribution function of p_H, denoted by F_H, is therefore given by

$$F_H = \left(F\left(p\right)\right)^2, \tag{B24}$$

with an associated probability density function, denoted f_H, given by

$$f_H = \frac{\partial F_H}{\partial p} = 2F\left(p\right) f\left(p\right). \tag{B25}$$

The expected value of the highest bid, denoted by p_H^e, is then given by

$$p_H^e = \int_{\underline{p}}^{\overline{p}} p f_H dp = \frac{-\left(\tau - T\right)^2 \left(\left(\ln\frac{\left(\tau - T\right)^2}{2T\tau + \tau^2 - T^2}\right)\left(2T\tau + \tau^2 - T^2\right) + 2T\left(2\tau - T\right)\right)\overline{v}}{2T^2\left(2\tau - T\right)^2} \tag{B26}$$

We can then calculate the expected average price, and thus the expected total drug expenditures, as

$$p^e = \left(1 - \frac{\left(\tau - T\right)^2}{2\tau^2}\right) p_L^e + \left(\frac{\left(\tau - T\right)^2}{2\tau^2}\right) p_H^e = \left(1 - \frac{T}{\tau}\right)^2 \overline{v}. \tag{B27}$$

A comparison with the expected average price in the main model, given by (13), shows that the price in (B27) is lower, but otherwise depends on the parameters (T, τ, and $\overline{v}$) in a qualitatively identical way. Thus, the alternative demand system based on uncorrelated treatment effects

yields lower equilibrium prices both under decentralised competition and under competitive tendering.

Under competitive tendering, the aggregate health gains of patients being prescribed the preferred drug are given by

$$\begin{aligned} H_i &= \int_0^{1-\frac{T}{\tau}} \left(\int_0^{x_j+\frac{T}{\tau}} (v - \tau x_i)\, dx_i \right) dx_j + \frac{T}{\tau} \int_0^1 (v - \tau x_i)\, dx_i \\ &= \frac{3\left(2T\tau + \tau^2 - T^2\right) v - \tau^3 - \left(3\tau^2 - T^2\right) T}{6\tau^2}, \end{aligned} \tag{B28}$$

while the aggregate health gains of patients being prescribed the non-preferred drug are given by

$$H_j = \int_{\frac{T}{\tau}}^1 \left(\int_0^{x_i-\frac{T}{\tau}} (v - \tau x_j)\, dx_j \right) dx_i = \frac{(T + 3v - \tau)(\tau - T)^2}{6\tau^2} \tag{B29}$$

Total health gains are therefore

$$H = H_i + H_j = v - \frac{\tau}{3} - \frac{(3\tau - 2T) T^2}{6\tau^2}, \tag{B30}$$

while the total expected surplus of the health plan is given by

$$S^e = H - p^e = \frac{2\left(3(2\tau - T) v - 3\tau^2 + T^2\right) T + \tau^3}{6\tau^2}. \tag{B31}$$

It is easily confirmed that $\partial S^e / \partial T > 0$ for all $v > \tau$ and $T < \tau$, as in the main model.

B.3. Competitive tenders vs. decentralised competition

A comparison of (B7) and (B30) reveals that aggregate health gains are lower under competitive tendering than under decentralised competition as long as $T > 0$. Furthermore, a comparison of (B6) and (B27) shows that competitive tenders yield lower (higher) expected drug expenditures than decentralised competition if

$$T > (<) \left(1 - \sqrt{\frac{\tau}{2\beta\overline{v}}}\right) \tau \in (0, \tau)\,. \tag{B32}$$

Thus, the comparison of the two policy schemes is qualitatively identical under the two different demand systems. In order to illustrate this qualitative similarity, and also to measure the quantitative differences, we compare the equilibria in Figure B1 using the exact same parameter configuration as in Figure 1 in the main analysis, with $v = 5$, $\tau = 2$ and $\beta = 3/4$.

[Figure B1 here]

Using the previously derived equilibrium expressions in this Appendix, it is easily verified that $p^* > (<)\, p^e$ if $T > (<)\, 0.85$, which is equivalent to a market share of the preferred drug of more (less) than 83%. Furthermore, $S^* > (<)\, S^e$ if $T > (<)\, 0.91$, which is equivalent to a market share of the preferred drug of more (less) than 85%.

Appendix C: Supplementary calculations

This appendix contains supplementary calculations for the two extensions analysed in Section 6.

C.1. Asymmetric treatment effects

C.1.1. Decentralised competition

Under decentralised competition, drug demand is given by

$$q_1 = \frac{1}{2} + \frac{\Delta v - \beta\,(p_1 - p_2)}{2\tau} \tag{C1}$$

and

$$q_2 = \frac{1}{2} - \left(\frac{\Delta v - \beta\,(p_1 - p_2)}{2\tau}\right), \tag{C2}$$

The Nash equilibrium prices are

$$p_1 = \frac{\tau}{\beta} + \frac{\Delta v}{3\beta} \text{ and } p_2 = \frac{\tau}{\beta} - \frac{\Delta v}{3\beta}, \tag{C3}$$

which yield demand

$$q_1 = \frac{1}{2} + \frac{\Delta v}{6\tau} \text{ and } q_2 = \frac{1}{2} - \frac{\Delta v}{6\tau}. \tag{C4}$$

Thus, the higher-quality drug has both higher price and higher demand. It is easily verified that $p_i < \overline{v}_i$ for $i = 1, 2$ if the condition in (31) holds. Given that the total patient mass is equal

to one, the average price in (32) is then straightforwardly calculated as $p^* = p_1 q_1 + p_2 q_2$.

C.1.2. Competitive tendering

Notice first that the equilibrium strategies reported in the second part of Proposition 4 have the following associated probability density functions:

$$f_1(p) = \frac{\partial F_1(p)}{\partial p} = \frac{(\tau + T - \Delta v)\, p^{\min}}{2Tp^2}, \tag{C5}$$

$$f_2(p) = \frac{\partial F_2(p)}{\partial p} = \frac{(\tau + T + \Delta v)\, p^{\min}}{2Tp^2}. \tag{C6}$$

In order to find the expected value of the lowest price, define $p_L := \min(p_1, p_2)$. The probability that p_L is below some threshold level p is given by the following cumulative distribution function:

$$F_L(p) = 1 - (1 - F_1(p))(1 - F_2(p)). \tag{C7}$$

The associated probability density function is

$$f_L(p) = \frac{\partial F_L(p)}{\partial p} = f_1(p)(1 - F_2(p)) + (1 - F_1(p)) f_2(p). \tag{C8}$$

Taking into account that F_1 has a mass point at $p = \overline{v}_1$ and that F_2 has a mass point at $p = \overline{v}_2 < \overline{v}_1$, the expected value of p_L is given by

$$p_L^e = \int_{p^{\min}}^{\overline{v}_2} p f_L(p)\, dp + (1 - F_2(\overline{v}_2))(1 - F_1(\overline{v}_2))\, \overline{v}_2. \tag{C9}$$

Using the previously derived expressions for F_1, F_2 and f_L, this expected price can be written as

$$\begin{aligned} p_L^e \;=\; & \frac{(\Delta v)^2 \left((2(\overline{v}_1 + \overline{v}_2) - T)\, T + \tau^2 - (\Delta v)^2\right) \left(p^{\min}\right)^2}{4\overline{v}_1 \overline{v}_2^2 T^2} \\ & - \frac{\left(\left(\ln \frac{\overline{v}_2}{p^{\min}}\right)\left(\tau^2 - T^2 - (\Delta v)^2\right)\overline{v}_2 + ((\tau + \Delta v)\Delta v - (\overline{v}_1 + \overline{v}_2)\, T)(\tau + T - \Delta v)\right) p^{\min}}{2\overline{v}_2 T^2} \end{aligned} \tag{C10}$$

Define the highest price as $p_H := \max(p_1, p_2)$. The probability that p_H is below some

threshold level p is given by the following cumulative distribution function:

$$F_H(p) = F_1(p) F_2(p). \tag{C11}$$

The associated probability density function is

$$f_H(p) = \frac{\partial F_H(p)}{\partial p} = f_1(p) F_2(p) + F_1(p) f_2(p). \tag{C12}$$

Taking into account that $F_1(p)$ has a mass point at $p = \overline{v}_1$, the expected value of p_H is given by

$$p_H^e = \int_{p^{\min}}^{\overline{v}_2} p f_H(p)\, dp + (1 - F_1(\overline{v}_2))\, \overline{v}_1. \tag{C13}$$

Using the previously derived expressions for F_1 and f_H, this expected price can be written as

$$\begin{aligned} p_H^e &= \frac{(\tau + T - \Delta v)\left(\left(\ln \frac{\overline{v}_2}{p^{\min}}\right)(\tau + T + \Delta v)\,\overline{v}_2 - ((\overline{v}_1 + \overline{v}_2)\,T - (\tau + \Delta v)\,\Delta v)\right) p^{\min}}{2T^2 \overline{v}_2} \\ &\quad + \frac{\left((2(\overline{v}_1 + \overline{v}_2) - T)\,T + \tau^2 - (\Delta v)^2\right)(\Delta v)\, p^{\min}}{2T(\tau - T + \Delta v)\,\overline{v}_2}. \end{aligned} \tag{C14}$$

Given the equilibrium strategies $F_1(p)$ and $F_2(p)$, and taking into account that $F_2(p)$ has a mass point at $p = \overline{v}_2$, the probability that drug 1 wins the tender is given by

$$\rho := \Pr(p_1 < p_2) = \int_{p^{\min}}^{\overline{v}_2} f_2(p) F_1(p)\, dp + (1 - F_2(\overline{v}_2)) F_1(\overline{v}_2). \tag{C15}$$

Using the previously derived expressions for F_1, F_2 and f_2, this probability can be written as

$$\rho = \frac{(\tau + T - \Delta v)\left((\tau + \Delta v)\,\Delta v - (\tau + v_1 - 3v_2)\,T\right)\left((\overline{v}_1 + \overline{v}_2)\,T - (\tau + \Delta v)\,\Delta v\right)}{8(\tau + T + \Delta v)\,T^2 \overline{v}_2^2}. \tag{C16}$$

The expected average drug price is then given by

$$\begin{aligned} p^e &= \rho\left(p_L^e\left(\frac{1}{2} + \frac{\Delta v + T}{2\tau}\right) + p_H^e\left(\frac{1}{2} - \left(\frac{\Delta v + T}{2\tau}\right)\right)\right) \\ &\quad + (1 - \rho)\left(p_L^e\left(\frac{1}{2} - \left(\frac{\Delta v - T}{2\tau}\right)\right) + p_H^e\left(\frac{1}{2} + \left(\frac{\Delta v - T}{2\tau}\right)\right)\right). \end{aligned} \tag{C17}$$

C.2. Captive patients

C.2.1. Decentralised competition

Under decentralised competition, drug demand is given by

$$q_1 = \lambda + (1-\lambda)\left(\frac{1}{2} + \frac{\beta(p_2 - p_1)}{2\tau}\right) \tag{C18}$$

and

$$q_2 = (1-\lambda)\left(\frac{1}{2} - \frac{\beta(p_2 - p_1)}{2\tau}\right). \tag{C19}$$

The equilibrium drug prices are

$$p_1 = \frac{3+\lambda}{3(1-\lambda)}\frac{\tau}{\beta} \tag{C20}$$

and

$$p_2 = \frac{3-\lambda}{3(1-\lambda)}\frac{\tau}{\beta}, \tag{C21}$$

which yields equilibrium demand

$$q_1 = \frac{1}{2} + \frac{\lambda}{6} \text{ and } q_2 = \frac{1}{2} - \frac{\lambda}{6}. \tag{C22}$$

It is easily verified that $\max(p_1, p_2) < \overline{v}$ if the condition in (39) holds. The average price in (40) is then straightforwardly calculated as $p^* = p_1 q_1 + p_2 q_2$.

C.2.2. Competitive tendering

Notice first that the equilibrium strategies given by Proposition 5 have the following associated probability density functions:

$$f_1(p) = \frac{\partial F_1(p)}{\partial p} = \frac{(T+\tau)\,p^{\min}}{2Tp^2}, \tag{C23}$$

$$f_2(p) = \frac{\partial F_2(p)}{\partial p} = \frac{((1+\lambda)\tau - (1-\lambda)T)\,\overline{v}}{2T(1-\lambda)p^2}. \tag{C24}$$

In order to find the expected value of the lowest price, define $p_L := \min(p_1, p_2)$. The probability that p_L is below some threshold level p is given by the following cumulative distribution function:

$$F_L(p) = 1 - (1 - F_1(p))(1 - F_2(p)). \tag{C25}$$

The associated probability density function is

$$f_L(p) = \frac{\partial F_L(p)}{\partial p} = f_1(p)(1 - F_2(p)) + (1 - F_1(p)) f_2(p). \tag{C26}$$

The expected value of p_L is given by

$$p_L^e = \int_{p^{\min}}^{\overline{v}} p f_L(p)\, dp = \left(1 + \frac{\tau}{T} + \frac{\left((1+\lambda)\tau^2 - (1-\lambda)T^2\right)\left(\ln \frac{p^{\min}}{\overline{v}}\right)}{2(1-\lambda)T^2}\right) p^{\min}. \tag{C27}$$

Next, define the highest price as $p_H := \max(p_1, p_2)$. The probability that p_H is below some threshold level p is given by the following cumulative distribution function:

$$F_H(p) = F_1(p) F_2(p). \tag{C28}$$

The associated probability density function is

$$f_H(p) = \frac{\partial F_H(p)}{\partial p} = f_1(p) F_2(p) + F_1(p) f_2(p). \tag{C29}$$

Taking into account that $F_1(p)$ has a mass point at $p = \overline{v}$, the expected value of p_H is given by

$$p_H^e = \int_{p^{\min}}^{\overline{v}} p f_H(p)\, dp + (1 - F_1(\overline{v}))\,\overline{v}, \tag{C30}$$

which can be expressed as

$$p_H^e = \frac{2\lambda\tau\overline{v}}{(1+\lambda)\tau + (1-\lambda)T} - (T+\tau)\left(\frac{1}{T} + \frac{(1+\lambda)\tau + (1-\lambda)T}{2(1-\lambda)T^2}\left(\ln \frac{p^{\min}}{\overline{v}}\right)\right) p^{\min}. \tag{C31}$$

For any $\lambda > 0$, demand for the preferred drug is higher if $p_1 < p_2$ than if $p_2 < p_1$. This implies that, all else equal, the expected treatment costs (which are equal to the expected average price) depends on the *identity* of the winning bid. Thus, we need to calculate the probabilities that the tender is won by each of the two drugs.

Given the equilibrium strategies $F_1(p)$ and $F_2(p)$, the probability that drug 1 wins the tender is given by

$$\rho := \Pr(p_1 < p_2) = \int_{p^{\min}}^{\overline{v}} f_2(p) F_1(p)\, dp = \frac{(1-\lambda)(\tau+T)}{2((1+\lambda)\tau + (1-\lambda)T)} < \frac{1}{2}. \tag{C32}$$

The expected average drug price is then given by

$$\begin{aligned} p^e &= \rho\left(p_L^e\left(\lambda+(1-\lambda)\left(\frac{1}{2}+\frac{T}{2\tau}\right)\right)+p_H^e\,(1-\lambda)\left(\frac{1}{2}-\frac{T}{2\tau}\right)\right) \\ &\quad +(1-\rho)\left(p_L^e\,(1-\lambda)\left(\frac{1}{2}+\frac{T}{2\tau}\right)+p_H^e\left(\lambda+(1-\lambda)\left(\frac{1}{2}-\frac{T}{2\tau}\right)\right)\right). \end{aligned} \tag{C33}$$

Using the previously derived expressions for ρ_1, p_L^e and p_H^e, we derive the expression for p^e given by (41).