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Citation: García-Alonso, M. D. C. & Garcia-Marinoso, B. (2007). The strategic interaction between firms and formulary committees: effects on the prices of new drugs (07/16). London, UK: Department of Economics, City University London.

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The strategic interaction between firms and formulary committees: Effects on the prices of new drugs

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Department of Economics
Discussion Paper Series
No. 07/16

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The strategic interaction between firms and formulary committees: Effects on the prices of new drugs

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May 9, 2007

Abstract

We study the strategic interaction between the pricing decisions of a pharmaceutical firm and the reimbursement decisions of a government agency which grants reimbursement rights to patients for whom new drugs are most cost-effective. If the reimbursement decision precedes pricing, the agency only reimburses some patients if the drug's private and public health benefits diverge. This is, there are consumption externalities and the variable cost of the drug exceeds the alternative's. Contrarily, if the firm can commit to a price before reimbursement, a strategic effect implies that by setting a sufficiently high price, the firm can make the agency more willing to reimburse than without commitment.

Keywords: Drug formularies, subsidies.
Jel classification: I10, I18, L65, H42.

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‡This paper was presented on the 5th World Congress of IHEA (2005), and on the 5th European Health Economics Worshop held at the University of York (2004). We wish to thank the audiences in those conference sessions. We also wish to acknowledge the seminar participants at City University of London and Universidad Carlos III de Madrid. All their comments benefitted the paper.

1 Introduction

New drugs and medical devices are valuable goods that provide welcomed health benefits. However, they are also very expensive. According to the OECD, pharmaceutical costs are the major drivers of health care expenditures[1]. Given that in most countries the consumption of medicines is subsidized,[2] the growth in the prices of new drugs has resulted in increases in public spending. In a situation where resources are limited and there is competition for public funds, governments have had to find ways to rationalise the use and dissemination of these new products. Agencies have been set up to decide which drugs are "value for money". These agencies are constituted by committees of experts, who in consultation with the different parties (patients, providers and firms) decide which drugs are cost-effective. Some examples are: the National Institute for Clinical Excellence (NICE) in the UK, Pharmac in New Zealand, Fasi in Austria, the Pharmaceutical Benefits Advisory in Australia or the Commission of Transparence in France. The decisions these agencies take are based on clinical and economic evidence which is usually summarised in a cost effectiveness analysis. The analysis measures the health benefit associated with increasing access to a drug, places a monetary value on this benefit and compares it with the provision cost of provision. The analysis may identify the group of patients for whom the drug will result in benefits that compensate the cost as the same drug may result in differing health benefits for patients, depending on the severity and strand of the illness and the possibility of side effects. For example, in NICE's published guidelines, one can see that sometimes a specific group of patients is selected based on a threshold of a diagnostic test, such as in the case of drugs for obesity, diabetes or Alzheimer's disease, or in other occasions a specific group is selected based on the description of certain symptoms. In March 2001, NICE considered Orlistat, a drug which fights obesity. The decision was that the drug should be prescribed to patients who had lost at least 2.5 kilos in weight by dieting and who either had a body mass index of 30 kg/m2 or a body mass index of 28 kg/m2 and the presence of significant co-morbidities. In the report, one can find considerations about the 1998 direct costs and indirect costs to the NHS associated with obesity, a summary of the results of several clinical trials of Orlistat, and a cost effectiveness analysis which estimates the total annual drug costs of implementing the guidance, based on the current drug price.

The impact of a favourable cost-effectiveness analysis varies in each jurisdiction. It usually implies that national guidelines are issued for public providers to encourage the use of the drug. In occasions, a positive result will directly imply that the drug is listed for reimbursement. For example, in the UK, since January 2002, the NHS is obliged to provide funding for NICE approved drugs

[1] For example, pharmaceutical expenditure has doubled in real terms in Sweden and Australia between 1990 and 2001, and increased by more than 70% in Canada, Finland, Ireland, and the US. See OECD, 2004.

[2] Reimbursement policies vary from country to country. In the UK for example, patients must pay £6.40 per prescription. In Austria patients pay a fixed amount and a fraction of the price of the drug. In France patients pay 0%, 65% or 35% of the price of the drug, depending on the drug's class.

after 3 months of the publication of the listing decision. Sometimes the effect of a positive result of the test on the listing of the drug for reimbursement will not be as immediate, but will feed in the considerations made in the reimbursement decision.

We model the strategic interaction between an innovator firm (monopoly) and a decision maker who chooses whether to list the drug for reimbursement and if so, which patients should be subsidized. The decision maker does this by comparing the excess health benefits and the excess costs of enlarging the patient group with reimbursement rights. The aim of this research is two-fold. Ultimately we want to understand what are the effects of the listing decision on the costs of provision (public and private[3]) and the dissemination of the drug in the presence of a strategic firm. Yet, to do this, we must study how the listing decision (and its effects) depends on: the quality of the new drug with respect to existing treatments, the existence of externalities associated with the consumption of the drug and the extent to which those are considered by the agency,[4] the possibility that the firm commits to a price before the agency makes a listing decision[5] and the possibility that doctors prescribe the drug privately (aside the public provider) generating an "unsubsidized" demand for the drug.[6] We show that if the reimbursement decision precedes the pricing decision, the agency only reimburses some patients if the private and public health benefits from the new drug diverge. That is, when (i) there are large externalities of consuming the drug and (ii) the difference in variable costs between the new drug and the alternative treatment is large. Alternatively, if the firm can commit to a price in advance of the reimbursement decision, we identify a strategic effect which implies that by committing to a high price ex ante, the firm can force a listing outcome and make the agency more willing to reimburse than in the absence of commitment.

Whilst health economists and managers have paid a lot of attention to the measurement of the benefits of drugs and the placement of their monetary value, the analysis of the costs of provision has been highly neglected. With this work, we point out that the cost of provision will depend on how drug prices are set, as this will frame the ability of firms to react to listing. Hence, we must understand how firms react to and anticipate the news that their drug is being listed for reimbursement and derive the due effect on market variables.

From an academic point of view this research is also interesting as the special

[3] Patients also directly contribute to the financing of their consumption.

[4] There are several sources of externalities. They can be due to the nature of the disease- for example infectious. They can also occur because of knock on effects on the costs on the provision of health care, families and social services budgets. For example a higher consumption of the drug may result in fewer hospitalizations.

[5] For example in the UK, the 1999-2004 Pharmaceutical Price Regulation Scheme which applies to all branded licensed NHS medicines implies that pharmaceutical firms can initially choose the price at which they introduce a drug in the market. However, after this, price changes must be approved by the Department of Health. This approval is granted only if the company can proof that its return on capital is below 8.4% (PPRS 2005). See publication in the Department of Health website.

[6] In most countries, drugs can be prescribed by private health care providers and be bought by patients who then benefit from no subsidy.

feature of these decisions is that they are decisions by which "the government" chooses to discriminate against a group, which are not based on income levels but rather on how effective the subsidized product is on the welfare of the group. This is the special feature of our model. The impact of government agencies' decisions to list medicines for patient reimbursement is an under-researched area which has focussed on reimbursement for low income patients rather than patients with high medical needs (e.g., Scott Morton, 1997). Therefore, we concentrate on decision making that is based on medical grounds, focusing on patients´ distinct medical needs, rather than on income levels. This novelty is crucial and feeds in through the results. However, it implies that our paper is most relevant for situations where there is limited income heterogeneity within the patients of an illness.

Our paper belongs to the small literature on drug formularies which analyzes health need based prioritization. Formularies list the drugs which consumers are to be reimbursed for, and, by exclusion, the drugs off the reimbursement list. They have been used by private (such as American HMOs) and public providers (such as European public providers) to limit their expenditure on drugs. Our paper analyzes how the existence of a drug formulary may affect the prices of a new drug. The works of Olmstead and Zeckhauser (1999) and Borrell (2003) are directly related to this paper. Olmstead and Zeckhauser (1999) show how menu setting techniques can be used to design optimal formularies, in recognition that patients are free to choose the drugs they consume. In their setting, an optimal formulary maximizes the health care benefits of patients given exogenously set prices for drugs and a budget constraint. They focus on the problem of encouraging "efficient consumption" when drugs have differing effects on patients who are free to choose. Our object of analysis is different, as we focus on the impact that formularies might have on price setting, (this is in our setting prices are endogenous), and also because we address the issue that institutions implement restrictions on patient choice.

Olmstead and Zeckhauser (1999) describe the main criticism on formularies as items that "often include only those drugs that are cost effective for the average patient"[7]. This refers to the fact that committees typically examine these decisions by grouping patients according to their disease and by grouping drugs according to their therapeutic class. Nowadays it is possible to make finer definitions within a patient group, in accordance to diagnostic tests and others, and to place more sophisticated restrictions on the reimbursement of the drug, which our paper addresses. Borrell (2003) also studies the impact of the existence of drug formularies on drug prices. However, his paper reflects a mature market were drugs are horizontally differentiated a la Dixit-Stiglitz and listed for reimbursement. In his paper, an "exogenous" threat that drugs are de-listed can be diminished by reducing the price.[8] We consider that such paper is not suited to describe the interaction between innovators competing with lower quality off-patent products.

[7] Olmstead and Zeckhauser (1999), page 6.

[8] Borrell (2003) does not model the decision making of the formulary commitee as pursuing an objective function.

There exists an early and relatively extensive literature on the determinants of the prices of new drugs, which is reviewed in the introductory section of Lu and Comanor (1998). The literature describes two possible pricing strategies: penetration pricing by which the initial price is low and then increases, and skimming pricing, the opposite. Its theoretical findings relate to the theory of signalling of quality through prices, with contributions of Schmalensee (1982), Shapiro (1983) and Bagwell and Riordan (1991) between others. Lu and Comanor (1998) provide empirical evidence that price skimming takes place when the new drug is a substantial therapeutic improvement on existing drugs. We ignore these signalling issues on the pricing of the new drug. The reason for this is that the role of the agencies mentioned is to establish precisely which drugs are cost effective and to disseminate this information. The measurements of the benefits and the "quality" of the drug are made available to patients and providers, which mitigates the need for signalling. Instead, we concentrate on the strategic interaction between the pricing decision and the listing decision-focussing on the later as a determinant of the prices of new drugs.

Our paper models the interaction between the listing decision of an agency and the drug price decision of a monopoly as a multiple stage game. We consider two alternative sequences of events. The first timing, which we refer to as 'no price commitment' considers a situation in which the agency decides first, which consumers have reimbursement rights and then, the firm chooses the drug's price. In an alternative timing, which we refer to as 'price commitment', the firm can commit to a price in advance of the agency's decision.

The choice of the first timing underlines the initial motivation of the paper, to analyze how firms react to coverage news by changing prices. In analyzing this we also assess what would happen if agencies internalized in their decision-making the future market impact. Do agencies actually take future price setting behaviour of firms when they decide whether to list a drug for reimbursement? This is a difficult question to answer, as in most countries these decisions are not transparent. However, one would expect them to do so, and it is therefore important to understand what happens if they do.

Secondly, it is also important to understand what happens if firms can commit to their prices before the listing decision takes place as a first-instinct remedy to a price increase which responded to a listing outcome would be to ask the firm to commit to a price ex-ante. Hence, we explore this possibility in our model with price commitment. This is also relevant as in some countries, firms have ways to commit to their prices.

A last word of caution is that this work is as a stepping stone of a larger research project. Health care provision is highly jurisdiction specific. Because of this, any model of the health care industry suffers from the caveat that it will necessarily not apply everywhere. As we will discuss, we have tried to overcome this problem by making the benchmark model as general as possible in so that it would still have interesting results and by pinning down what would be a worst case scenario for reimbursement.

Section 2 presents the main features of the model. Sections 3 provides the solution to the Agency's reimbursement problem and the firm's pricing problem

when the firm can not commit ex ante to a price. Section 4 extends the analysis to the situation where the firm can commit to a price before the Agency decides on listing. Section 5 compares the two outcomes. Section 6 discusses the generality of the model and the sensitivity of our results to its assumptions. Section 7 concludes.

2 The model

We model the strategic interaction between a pharmaceutical firm producing a new drug and a government agency that decides whose consumption should be subsidized.

The pharmaceutical firm launches a new drug of quality q, $q > 1$. This drug is patented and the only supplier is the firm, which acts as a monopoly. The marginal cost of production of the drug is constant and equal to c. Patients differ in the improvements of health they derive from consuming the drug. In other words, the effectiveness of the drug depends on the patient type. By taking the new drug, patient type θ benefits from an improvement in health of $\theta \cdot q$. We assume that θ is uniformly distributed in the interval $[\underline{\theta}, \overline{\theta}]$.

There is a second best alternative treatment which yields an improvement in health to type θ of θ only. This alternative is not listed for reimbursement and is supplied by a competitive fringe of firms at a given price of $\underline{c}$.[9] We assume that $\underline{\theta} > \underline{c}$, which implies that all patients will either purchase the innovation or the alternative treatment[10].

We model a government agency with the power to decide which patient types can benefit from an exogenously determined subsidy on the price of the new drug.[11] We define the amount of patients with reimbursement rights as the coverage level. An crucial feature of our model is the assumption that the agency can treat patient types differently. This is the agency will select the coverage level according to the drug's effectiveness on patients.

The agency chooses the coverage level so as to maximize its objective function. This objective function captures some of the observed features of the decision processes in a number of health agencies. In addition, the objective function serves as a benchmark in the sense that it provides a worst case scenario for reimbursement. First, the agency's objective function will not include the monetary costs borne by patients or the firm's profits.[12] This aims to reflect the absence of such considerations in Nice's reports, and also implies that our model does not favour a high level of coverage. In her decision making,

[9] We can interpret this price as the cost of production of an alternative drug or as the cost of an alternative treatment for the patient. For example, an alternative to taking an obesity drug is dieting.

[10] Cabrales (2002) uses a similar model of differentiation to study the effects of price ceilings on the provision of quality.

[11] Subsidies are subject to general law and can not be changed for specific drugs. We do not model the subsidy level in our analysis.

[12] Note that this implies that the agency is not maximizing a welfare function.

the agency does not internalize the fact that as the coverage increases, profits increase and costs to patients decrease.

In taking her decision, the agency considers the public costs of reimbursement, the private health benefits from the consumption of the different available treatments- new and old and an externality which is exclusively associated with the dissemination of the new drug. We model the externality as a per capita externality. We may interpret it as the public health benefits related to the consumption of the drug[13] or the savings accrued by the health care system in terms of forgone on-going costs associated with the distribution of the drug.[14]

Taking the stand of Olmstead and Zeckhauser (1999), who describe that "the goal in health care, at least implicitly, is to spend treatment dollars where they will produce significant benefits"[15], we assume that the agency decides to reimburse the patients for whom the drug is most effective, i.e. those characterized by a larger θ. More specifically, the agency chooses a threshold θ_L, such that all patients with $\theta > \theta_L$ benefit from the subsidy. Then, the coverage level is $\overline{\theta} - \theta_L$. The objective function of the agency is described below:[16]

$$\int_{\theta_L}^{\overline{\theta}} \theta \cdot q + \int_{\underline{\theta}}^{\theta_L} \theta - \int_{\theta_L}^{\overline{\theta}} (P - S) + v \cdot (\overline{\theta} - \theta_L), \tag{1}$$

where P is the full price of the drug, S is the price paid by patients with reimbursement rights, and v is the per capita externality.

We consider a general form for the consumer price: $S = \tau + \eta \cdot P$, with $\tau / (1 - \eta) \leq c$. Here, τ represents a flat rate and η a proportional rate. Consequently, the cost per dose for the public funds is: $P - S = (1 - \eta)P - \tau$.

The pharmaceutical company chooses the drug's price. The firm can freely choose the price but cannot price discriminate between patients with and without reimbursement rights[17]. Patients with no reimbursement rights can purchase the new drug at full price if they wish to.[18]

[13] The existence of such externalities becomes evident in certain conditions like infectious diseases, serious mental illnesses and conditions involving long term incapacity, but, in general most medical conditions may in principle have an impact over labour productivity (see e.g. Francis (1997), Krieg (2002) and Laux (2000)).

[14] Due to the reduction in hospitalization episodes, specialist needs and other costs.

[15] Olmstead and Zeckhauser (1999), page 2.

[16] Assuming that all patients with reimbursement rights purchase the drug and that patients' with no reimbursement rights do not purchase the drug.

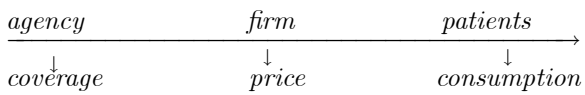
[17] This is the government implements no constraint on the firm's initial prices. This reflects the UK and US case. In other countries, there is bargaining on price between the government and the firm (in France the Comite Economique du Medicament will negotiate the price and the volumes of reimbursed drugs, or in new Zealand, Pharmac will make the reimbursement decision contingent on some agreed price). The effects of reimbursement on pricing decisions in a setting with bargaining have been studied by Jelovac (2002), where she finds that higher subsidies reduce prices when prices are negotiated.

[18] All of these assumptions also reinforce a "worst case scenario for coverage". The fact that the firm is unable to price discriminate between patients with reimbursement and without reimbursement rights restricts the ability of the firm to induce listing by increasing the price

In the following two sections, we analyze two alternative timings of events. First, we consider the case in which the coverage decision precedes the firm's pricing decision. Second, we analyze the game where the firm is able to commit to a price before the coverage decision takes place. We find the subgame perfect equilibrium of these two games and compare their outcomes. All of the computations for the results can be found in a mathematical appendix.

3 Benchmark: The game with no price commitment

In stage 1 the agency decides the coverage level $\overline{\theta} - \theta_L$, in stage 2 the firm chooses its price and in stage 3 patients make their consumption decisions. We represent this with following timeline:



3.1 Stage 3: Patient's consumption decisions

There are two groups of patients: those with reimbursement rights (if θ is such that $\theta > \theta_L$), and those without reimbursement rights (if θ is such that $\theta < \theta_L$). Patients with reimbursement rights buy the new drug if their utility $(\theta \cdot q - S)$ exceeds the utility they would obtain from the alternative treatment $(\theta - \underline{c})$. The indifferent consumer is given by: $\theta^R = \frac{S-\underline{c}}{\Delta q}$,where $\Delta q = q - 1$.[19] Similarly, for patients with no subsidy the indifferent consumer is: $\theta^F = \frac{P-\underline{c}}{\Delta \cdot q}$. Hence, the demand function for the new drug is:

$$D(P) = \begin{cases} \overline{\theta} - \theta^R; & \text{if } P > \frac{\Delta q \cdot \theta_L + \underline{c} - \tau}{\eta} \theta_L \\ \overline{\theta} - \theta_L; & \text{if } \frac{\Delta q \cdot \theta_L + \underline{c} - \tau}{\eta} \theta_L \geq P > \Delta q \cdot \theta_L + \underline{c} \\ \overline{\theta} - \theta^F; & \text{if } P < \Delta q \cdot \theta_L + \underline{c}. \end{cases} \quad (2)$$

Figure 1 depicts demand function for the new drug at a given threshold θ_L.

(INSERT FIGURE 1 AROUND HERE (DEMAND GRAPH))

The demand curve has kinks as its elasticity depends on whether consumers have access to the subsidy or not. As indicated in Figure 1, the demand function is more inelastic in the range where the price subsidy applies. It also has a range where it is completely inelastic, corresponding to prices such that $\theta^R < \theta_L < \theta^F$.

for the non-reimbursed. Similarly, that patients with no reimbursement rights can purchase the drug privately reduces the need for a subsidy.

[19] Note that there is a divergency between consumer choice and the choice desired by the agency who would hope that patients internalized the externality in their decisions. This would be the case if the equation driving patients behaviour was: $(\theta \cdot q + v - S) > (\theta - \underline{c})$.

Definition 1 $\pi_R = (P-c)(\overline{\theta}-\theta^R)$ *is the profit function when all patients have reimbursement rights (full coverage:* $\theta_L = \underline{\theta}$*) and* $\theta^{R*} = \frac{\Delta q\overline{\theta}+\eta c+\tau-\underline{c}}{2\Delta q}$ *is the indifferent consumer that maximizes* π_R*. Similarly* $\pi_F = (P-c)(\overline{\theta}-\theta^F)$ *is the profit function when no patients have reimbursement rights* $(\theta_L = \overline{\theta})$ *and* $\theta^{F*} = \frac{\Delta q\overline{\theta}+c-\underline{c}}{2\Delta q}$ *is the indifferent consumer that maximizes* π_F*.*

Note that as long as the threshold θ_L is larger than θ^{R*}, θ^{R*} will be the indifferent consumer driving demand for the new drug. Similarly, θ^{F*} will be the indifferent consumer provided that θ^{F*} falls below θ_L.

3.2 The firm's choice of price

In this section, we characterize the price that maximizes the firm's profits, P^*.[20] The following proposition summarises the main result:

Proposition 2 *There are three cases:*
(i) ***High coverage.*** *If* $\theta_L < \theta^{R*}$*, then* $P^* = P_R = \frac{1}{2\eta}(\Delta q\overline{\theta} + \underline{c} + \eta c - \tau)$*, and* $\left(\overline{\theta} - \theta^{R*}\right)$ *consumers purchase the drug. This is only some consumers with reimbursement rights purchase the drug.*
(ii) ***Intermediate coverage****. If* $\theta^{R*} < \theta_L < \alpha$*, then* $P^* = P_L = \frac{\theta_L \Delta q+\underline{c}-\tau}{\eta}$ *and* $\overline{\theta} - \theta_L$ *consumers purchase the drug: All consumers with reimbursement rights purchase the drug.*
*(iii)****Low coverage.*** *If* $\theta_L > \alpha$ *then* $P^* = P_F = \frac{1}{2}(\Delta q\overline{\theta}+\underline{c}+c)$ *and and* $\overline{\theta} - \theta^{F*}$ *consumers purchase the drug. Even consumers with no reimbursement rights purchase the drug.*[21]

INSERT FIGURE 2 AROUND HERE (PROFIT GRAPH)

Figure 2 provides a graphical representation of the result. The thicker line illustrates the maximum value of the firm's profit as a function of the reimbursement level set by the agency, $\pi(\theta_L)$. The two other functions represent π_R and π_F,as defined above.

To understand proposition 2, it is worth acknowledging that the subsidy creates a wedge between the willingness to pay of consumers with reimbursement rights and the willingness to pay of consumers with no such rights. This implies that in order to serve consumers with no rights, the firm must reduce its price substantially (so as to make the indifferent consumer θ^{F*} fall below θ_L). It will only pay to do so if the number of consumers with reimbursement rights is sufficiently low. The shape of the thicker curve in Figure 2 can now be explained.

[20] In the appendix we find the local maxima in each of the demand regions (interior or corner solutions) and then we compare those maxima to obtain a global maximum.

[21] The value of α, $\left(\alpha > \theta^{F*}\right)$, can be found in the Appendix. It is defined as the value of θ_L such that $\pi_F\left(\theta^{F*}\right) = \pi_R\left(\theta_L\right)$.

If coverage is large $\theta_L < \theta^{R*}$, the firm can reach the highest level of profit π_R^* as all the consumers who the firm serves have reimbursement rights. However, if coverage is smaller ($\theta^{R*} < \theta_L < \alpha$), it pays for the firm to adjust her prices (setting them high) so as to serve only those consumers who have reimbursement rights. Yet, there is a level of coverage ($\theta_L = \alpha$) below which it is not profitable for the firm to take notice of the small group of consumers with reimbursement rights when setting prices. In this range, the best the firm can do is to lower prices so that consumers with no rights purchase the drug as well.

The impact of listing on the access to the new drug will depend on the level of coverage. If θ_L is sufficiently high ($\theta_L > \alpha$), the firm will decide to serve $\overline{\theta} - \theta^{F*}$ patients, where only a few ($\overline{\theta} - \theta_L$) will benefit from the subsidy. In this case, listing the drug will not result in a larger number of patients consuming it. Only $\overline{\theta} - \theta^{F*}$ consumers would consume the drug, as if no subsidy existed.

For intermediate levels of coverage, $\theta^{F*} < \theta_L < \alpha$, listing has a perverse effect. Comparing this with the situation with no listing: the prices and the costs to the public funds are higher and only a few ($\overline{\theta} - \theta_L$) individuals purchase the drug, as opposed $\overline{\theta} - \theta^{F*}$ (with $\overline{\theta} - \theta_L < \overline{\theta} - \theta^{F*}$).

Finally, with a high coverage level $\underline{\theta} < \theta_L < \theta^{F*}$, listing results in an increase of the public costs but at the same time there is a larger consumption of the new drug. Which effect dominates will determine whether listing the drug is the best option for the agency or not.

3.3 The agency's coverage decision

Given Proposition 2, it is clear that in choosing the coverage level, the agency indirectly selects the price regime. Here, we identify the agency's optimal choice. We first state the objective function for the agency, which, consistently with the analysis for the profit function, has a different form for each of the three coverage levels described in Proposition 2:[22]

$$OF(\theta_L) = \begin{cases} OF_1 = \int_{\theta^{R*}}^{\overline{\theta}} q\theta d\theta + \int_{\underline{\theta}}^{\theta^{R*}} \theta d\theta - \int_{\theta^{R*}}^{\overline{\theta}} (P_R - S_R)\, d\theta + v(\overline{\theta} - \theta^{R*}) \\ \qquad\qquad \text{if } \theta_L < \theta^{R*} \\ OF_2 = \int_{\theta_L}^{\overline{\theta}} q\theta d\theta + \int_{\underline{\theta}}^{\theta_L} \theta d\theta - \int_{\theta_L}^{\overline{\theta}} (P_L - S_L)\, d\theta + v(\overline{\theta} - \theta_L) \\ \qquad\qquad \text{if } \theta^{R*} < \theta_L < \alpha \\ OF_3 = \int_{\theta^{F*}}^{\overline{\theta}} q\theta d\theta + \int_{\underline{\theta}}^{\theta^{F*}} \theta d\theta - \int_{\theta_L}^{\overline{\theta}} (P_F - S_F)\, d\theta + v(\overline{\theta} - \theta^{F*}) \\ \qquad\qquad \text{if } \theta_L > \alpha. \end{cases}$$

(3)

where $S_i = \tau + \eta P_i$.

Finally, the welfare of not listing the drug is:

[22] An evaluation of the last expression can be found in the Appendix.

$$OF^{NL} = \int_{\theta^{F*}}^{\overline{\theta}} q\theta d\theta + \int_{\underline{\theta}}^{\theta^{F*}} \theta d\theta + v(\overline{\theta} - \theta^{F*}) = q\frac{\overline{\theta}^2}{2} - \frac{\underline{\theta}^2}{2} - \Delta q\frac{\left(\theta^{F*}\right)^2}{2} + v(\overline{\theta} - \theta^{F*}). \quad (4)$$

Note that the welfare of not listing coincides with the welfare achieved when there is no coverage $\theta_L = \overline{\theta}$.

Proposition 3 *If $\theta^{F*} < \theta_L < \overline{\theta}$, the agency does not reimburse any patients.*

Since granting subsidies is costly, the agency only wishes to do so if there are added (private and public) health benefits. These added benefits only accrue if listing the drug results in a larger consumption. However, if $\theta_L > \theta^{F*}$, listing the drug does not increase demand. As already explained, if $\theta^{F*} < \theta_L < \alpha$, demand falls as a result of listing, and if $\alpha < \theta_L < \overline{\theta}$, demand is determined by θ^{F*} and is unaffected by reimbursement. Since not reimbursing allows the agency to economise on costs, in these regions not listing is preferred by the agency to any coverage. In other words, from the point of view of the agency, there is no point in introducing a subsidy which will be made available to patients who would consume the drug even if that subsidy did not exist.[23]

As a consequence, we only must check whether the agency would rather list the drug for reimbursement and set $\theta_L < \theta^{F*}$ or not list the drug at all. To confirm this we characterize the shape of the agency's objective function. There are two forms for this function as depicted in Figures 3 and 4.[24]

(insert figures 3 and 4 around here)

The explanation of these shapes is related to the impact of listing on the demand for the drug. If there is no coverage $\left(\theta_L = \overline{\theta}\right)$, an increase in the level of coverage (a reduction in θ_L) will initially reduce the agency's payoff since, as it will not raise the consumption of the new drug and will only increase the public costs (this explains the shape of OF_3). When $\theta_L = \alpha$ is reached, there is a downwards discontinuity in the OF function. It is due to the fact that at this point, the firm prefers to set higher prices and serve only the consumers with reimbursement rights rather than setting lower prices to serve $\overline{\theta} - \theta^{F*}$ consumers. The shape of the function for decreases in θ_L beyond α will depend on the strength of the subsidy. If the subsidy is low, further increases in coverage will actually increase the payoff to the agency (see OF_2 in Figure 3). For high subsidies further increases in coverage may have an initial negative impact on the payoff to the agency (see OF_2 in Figure 4). In this range, the added health benefits of a larger coverage can not compensate for the increase in public costs.

[23] If the agency cared about economic welfare (which would include private costs and the firm's profit) there would be "more" listing. The reason is that when the agency does not list the drug, this results in larger costs for patients and/or smaller profits for firms. Given our specification of the agency's objective function, these negative effects are not internalised by the agency's decision who decides not to list the drug excessively from a welfare point of view.

[24] See Appendix for a formal proof of the shape of these figures.

Finally, increases in coverage beyond $\overline{\theta} - \theta^{R*}$ will not have any impact on the agency's payoff as for those levels demand for the new drug is fixed at $\overline{\theta} - \theta^{R*}$ (this explains the shape of OF_1).

In conclusion, the only global maximum candidates are either setting $\theta_L = \overline{\theta}$ to achieve OF^{NL}or setting any $\theta_L \in (\underline{\theta}, \theta^{R*})$ to achieve $OF_1(\theta_L)$. The decision turns out to be a binary one. We name the two options *not listing* ($\theta_L = \overline{\theta}$) and *listing* ($\theta_L \in (\underline{\theta}, \theta^{R*})$). The expression for the "incentive to list" is the difference in payoffs between listing and not listing:[25]

$$OF_1(\theta_L) - OF^{NL} = \frac{\Delta q}{2} \cdot \left(\left(\theta^{F*}\right)^2 - \left(\theta^{R*}\right)^2 \right) + v(\theta^{F*} - \theta^{R*}) - (P_R - S_R) \cdot (\overline{\theta} - \theta^{R*}). \quad (5)$$

Since $\theta^{F*} > \theta^{R*}$, the expression shows that the health benefits of listing exceed those of not listing, but as well that listing the drug is costly in terms of public funds. The balance of the health and the cost effects determines whether the agency decides to list.

Moreover, we deduce that $\frac{\partial OF_1(\theta_L) - OF^{NL}}{\partial \theta^{F*}} > 0$. In other words, as the number of people who would buy the drug if it weren't subsidized grows, the excess benefits of listing the drug for reimbursement are smaller and the incentives to list diminish. Indeed, the agency subsidizes the drug to supplement the lack of private demand. This is the case when θ^{F*} is large as then most patients would not buy the drug in the absence of a subsidy. This is the case where it might be in the interest of the agency to list the drug for reimbursement and set $\theta_L < \theta^{F*}$.[26]

3.3.1 Comparative statics on the incentive to list, $OF_1(\theta_L) - OF^{NL}$

In this section, we check how $OF_1(\theta_L) - OF^{NL}$ varies with v, c, $\underline{c}$, $\overline{\theta}$ and Δq.

Lemma 4 *The incentive to list is more likely to be positive for large v and c, and for small $\underline{c}$.*

A larger value of the externality results in a larger difference between the objective function in regime 1 and the objective function with no reimbursement. The effect is intuitive. With reimbursement more people access the drug and as the value of v grows, the difference between the objective functions grows.

As $c - \underline{c}$ grows, the difference between access to the drug with and without listing increases. As a consequence, the difference between the values of the

[25] Despite the "incentive to list" terminology, readers must be warned the readers aware that this is not a marginal incentive. The decision of the agency at this stage is binary: either to list or not to list.

[26] The derivative with respect to θ^{R*} does not always have the same sign. The reason is that as θ^{R*} grows the difference between the health benefits of listing the drug or not listing the drug are smaller, but it is unclear whether the costs of listing increase or not: on the one side, a larger θ^{R*} is associated with a large price for the drug and a smaller public cost per dose, yet fewer patients are reimbursed and this might counterbalance the previous effect. The overall outcome is ambiguous.

objective functions should increase. However, the effect of the cost difference on the difference in public costs between regimes is unclear. Given the sign of the derivative we can guarantee that even if public costs increase with listing, this adverse effect is overcome by the larger health benefits.

Lemma 5 *There exists a* $\eta^* \in (0,1)$ *such that if* $\eta < \eta^*$*, we obtain that the incentive to list is decreasing in* Δq *and* $\overline{\theta}$*. If* $\eta > \eta^*$ *then the incentive to list is increasing in* $\overline{\theta}$*.*

An increase in Δq has a number of effects on the decision to list. On the health side, quality will have a positive direct impact on the incentives to list as for a given number of extra patients treated with reimbursement the benefits will be larger. Yet, the number of patients treated is not fixed, and there is an indirect negative effect through the changes in regime demands that a higher quality results upon. With higher quality more consumers purchase the drug with no listing, and the excess access to the drug with reimbursement is smaller.[27] Moreover changes in Δq also affect the public costs of listing. The increase in Δq will have a positive impact of the unit price paid by the agency: $\frac{\partial(P_R - S_R)}{\partial \Delta q} > 0$ and in this way a positive impact on the listing costs (fewer incentives to list). However, if $\frac{\partial \theta^{R*}}{\partial \Delta q} \geq 0$ this effect might be partially compensated by a reduction in the number of patients who have reimbursement rights. The total cost effect can therefore be ambiguous. However, in the case where subsidies are large, the overall effect is that a higher quality reduces the incentives to list.

The final lemma in this section reinforces the idea that mainly it is the wedge between private willingness to pay and public willingness to pay (determined by the externality) that creates a "public" need to list the drug for reimbursement.

Lemma 6 *If* $0 < \eta < 1, v = 0, \underline{c} = 0$ *and* $\tau = 0$ *and* $c < \frac{2\Delta q \overline{\theta}}{\left(\eta + \sqrt{7\eta^2 + 2\eta}\right)}$ *we obtain that* $OF_1(\theta_L) - OF^{NL} < 0$*. This is the agency opts for not listing.*[28]

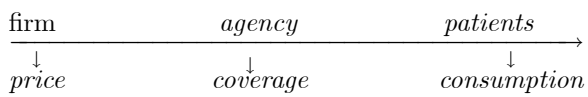
4 The game with price commitment

In this section, we analyze the outcome of the coverage decision in the case where the firm can commit to a price in advance of the agency's decision. In this game, in stage 1, the firm chooses the price, in stage 2, the agency chooses the coverage $\overline{\theta} - \theta_L$ and in stage 3 consumers make purchasing decisions. For

[27] Whether there are more consumers purchasing the drug with listing depends on the sign of $\frac{\partial \theta^{R*}}{\partial \Delta q}$. However, given that $\left|\frac{\partial \theta^{F*}}{\partial \Delta q}\right| > \left|\frac{\partial \theta^{R*}}{\partial \Delta q}\right|$ even in the case where $\frac{\partial \theta^{R*}}{\partial \Delta q} \leq 0$, we find that listing the drug results in a smaller access with higher quality. The reason is that consumers purchasing decisions are more reflective of quality when consumers pay the full price.

[28] Note that if $\Delta q \overline{\theta} > 2$ then $c < \frac{2\Delta q \overline{\theta}}{\left(\eta + \sqrt{7\eta^2 + 2\eta}\right)}$, is satisfied for all η, with $\eta \leq 1$.

simplicity, we focus on the case where $v = 0$, $\underline{c} = 0$ and $\tau = 0$, which allows a direct comparison with Lemma 6.[29]



Note that, $\theta^R = \frac{\eta P}{\Delta q}$ and $\theta^F = \frac{P}{\Delta q}$ and that in this section the price P is an ex ante commitment and therefore, ex post the price does not change, and does not depend on the agency's decision. The assumption that the firm can commit to a price generates a substantial difference in the outcome of the game. It turns out that, if the firm can commit to a price before the agency decides on coverage level, it can actually induce listing by choosing a sufficiently high price.[30]

4.1 The agency's coverage decision

In the last stage, for any given choice of the firm P, there are three possible choices of θ_L:

$$OF = \begin{cases} OF_1 = \int_{\theta^R}^{\overline{\theta}} \theta q d\theta + \int_{\underline{\theta}}^{\theta^R} \theta d\theta - (1-\eta) P(\overline{\theta} - \theta^R) \text{ if } \theta^F > \theta^R > \theta_L \\ OF_2 = \int_{\theta_L}^{\overline{\theta}} \theta q d\theta + \int_{\underline{\theta}}^{\theta_L} \theta d\theta - (1-\eta) P\left(\overline{\theta} - \theta_L\right) \text{ if } \theta^F > \theta_L > \theta^R \\ OF_3 = \int_{\theta^F}^{\overline{\theta}} \theta q d\theta + \int_{\underline{\theta}}^{\theta^F} \theta d\theta - (1-\eta) P\left(\overline{\theta} - \theta_L\right) \text{ if } \theta_L > \theta^F > \theta^R \end{cases} \quad (6)$$

We first find the choice of θ_L that maximizes the objective function of the agency, denoting it by θ_L^*. This entails finding the local maxima for each of the three regions and comparing them. Figures 5 and 6 show the shape of the objective function and indicate the candidates for global maximum.

(INSERT FIGURES 5 AND 6 AROUND HERE)

The intuition for these shapes is the same as in section 3. The change in the timing of the game only affects the shape of OF_2. For a low subsidy ($\eta > 1/2$), reductions in θ_L will have a positive effect on the objective function of the agency. In this range (see Figure 5) listing increases the consumption of the new drug by $(\theta^F - \theta_L)$ individuals. This positive impact is only partially off-set

[29] In an extended version of the paper we show that the results of this section are qualitatively very similar to the results that one would obtain with price commitment if $\tau > 0$ and $\eta = 0$. However, we can not directly compare the solution of this case with price commitment with the solution with no price comitment. In the absence of price commitment if $\eta = 0$ the profit maximization problem of the firm is unbounded as demand is fixed.

[30] In the UK, such commitment can be achieved because of the way in which pharmaceutical prices are regulated. According to the Price Regulation Scheme initially the firm is free to choose a price for the drug, but subsequent changes of price (especially price raises) need to be approved by the Scheme. Very few changes have been approved.

by the negative effect of the increase in the public cost, as the subsidy is low. As a result of a larger coverage there is an increase in the OF. Contrarily, in the case of high subsidies ($\eta < 1/2$), the cost effect dominates the access effect if θ_L is low enough: when $\theta_L > \hat{\theta}$, OF_2 is decreasing in θ_L (see Figure 6).

Hence, the optimal coverage level, $\overline{\theta} - \theta_L^*$, depends on the level of the subsidy. With a low subsidy ($\eta > 1/2$) there might be no listing ($\theta_L^* = \overline{\theta}$) or listing with $\overline{\theta} - \theta^R$ patients who purchase the drug (if $\theta_L^* < \theta^R$). With a high subsidy ($\eta < 1/2$) there can be no listing ($\theta_L^* = \overline{\theta}$) or listing where $\overline{\theta} - \theta_L^*$ patients purchase the drug with $\theta_L^* > \theta^R$.

Proposition 7 *If $\eta > 1/2$ and $P > \frac{2\Delta q\overline{\theta}}{1+3\eta}$ or $\eta < 1/2$ and $P > P^{LIM} = \frac{2(1-\eta)\Delta q\overline{\theta}}{2+\eta^2-2\eta}$, the agency lists the drug for reimbursement. Otherwise she does not.*

Proposition 7 states that, by setting a sufficiently high price, the drug company can guarantee a listing outcome. At first glance, this might seem counter-intuitive because, as the price rises, the unit cost of listing grows. However, it is also true that as the price rises the difference between the health benefits of listing and not listing grows. The latter effect of a price increase on the excess health benefits of listing exceeds the former effect on the costs of listing. Therefore, by committing to a high price, the firm can "threaten" the agency with a very small level of access to the drug in the case where there is no reimbursement and force a listing outcome.

4.2 The firm's choice of price

In this setting the firm chooses the price taking into consideration the agency's response. Clearly, low prices result in no coverage, and high prices result in some coverage. What matters for the choice of the optimal price P^*, is the comparison of the profits of each situation.

As we have established, high prices induce the agency to list. Since coverage raises the firm's profit, normally the monopoly will choose "high prices" in order to achieve a listing outcome. The only exception to this is the case where, to force a listing, the firm needs to distort the price upwards excessively- this is, the distortion results in a profit smaller than the profit of no listing.

4.2.1 Low subsidies ($\eta > 1/2$)

If listing occurs, the firm positions herself in π_R as opposed to π_F in Figure 2. This does not directly imply that profits are larger with listing as this really depends on how large is the price needed to induce listing. Yet, the following proposition establishes that with low subsidies, the firm can chose the price that maximizes π_R and that this price is sufficiently large so that the agency lists the drug.

Proposition 8 *If $\eta > 1/2$, the firm sets $P^* = \frac{\Delta q\overline{\theta}+\eta c}{2\eta}$,*[31] *which yields profits:*

[31] Note that $P^* = P_R$ for $\underline{c} = 0$ and $\tau = 0$.

$\pi_R^* = \frac{1}{4\eta\Delta q}(\Delta q\overline{\theta} - \eta c)^2$, *the drug is listed for reimbursement, and the demand for the new drug is* $(\overline{\theta} - \theta^{R*})$. *All consumers who purchase the drug are reimbursed.*

Recall that lemma 6 tells us that with no price commitment and for $c < \frac{2\Delta q\overline{\theta}}{\left(\eta+\sqrt{7\eta^2+2\eta}\right)}$ the drug would not be listed for reimbursement. Here, with $c = 0$ and price commitment listing takes place. The reason is that with such high price and in the absence of a subsidy the demand for the drug is too small. On the face of such event the agency lists.

4.2.2 High subsidies ($\eta < 1/2$)

With high subsidies the result is not as clear cut as Proposition 8. There are circumstances where it is in the firm's interest to induce listing, and circumstances where this is not true.

With high subsidies if the drug is listed, the firm's profits are: $(P-c)\left(\overline{\theta} - \frac{(1-\eta)P}{\Delta q}\right)$. These profits achieve a maximum value of $\frac{1-\eta}{4\Delta q}\left(\frac{\Delta q\overline{\theta}}{1-\eta} - c\right)^2$ at $P^+ = \frac{c}{2} + \frac{\Delta q\overline{\theta}}{2(1-\eta)}$ and $\theta^+ = \frac{\Delta q\overline{\theta}+(1-\eta)c}{2\Delta q}$. This value is larger that the profit when there is no listing. Therefore, if P^+ is high enough to induce listing, the firm will set this price and listing will take place (part 9.1 in the following proposition).

However, there will be situations where P^+ is too small to induce listing (see part 9.2 in the following proposition). In such cases, to strategically induce listing, the firm will need to distort upwards the optimal price P^+. In some of these cases, it will be better for the firm not to do so as the price distortion is so large that the resulting profits are smaller than without listing. The following proposition presents the conditions under which the firm will induce listing.

Proposition 9 *For* $\eta < 1/2$

9.1. If $c > c^* = \frac{\Delta q\overline{\theta}(2+3\eta^2-6\eta)}{(1-\eta)(2+\eta^2-2\eta)}$, $P^* = P^+$. *The drug is listed for reimbursement and* $\left(\overline{\theta} - \theta^+\right)$ *patients purchase it and are subsidized.*

9.2. If $0 < c < c^*$, P^+ *does not induce listing.*[32] *In this case, the firm might choose* $P^{LIM} = \frac{2(1-\eta)\Delta q\overline{\theta}}{2+\eta^2-2\eta}$ *(the smallest price that induces listing, with an indifferent consumer* θ^{LIM}*) or* $P = \frac{1}{2}(\Delta q\overline{\theta} + c)$ *the price that maximizes the no listing profits. The firm sets* $P^* = P^{LIM}$ *and forces listing if:*

$$\theta^{LIM} < z \text{ or } \theta^{LIM} - \theta^+ < \frac{\sqrt{\eta\left(\left(\Delta q\overline{\theta}\right)^2 - c^2(1-\eta)\right)}}{2\Delta q}$$

where z *is defined as the threshold value of* θ *that induces listing, this is* $z \in (\theta^+, \overline{\theta})$ *such that* $\pi^L(z) = \pi^{NL*} = \frac{1}{4\Delta q}(\Delta q\overline{\theta} - c)^2$.

[32] Note that $c^* > 0$ only if $0 \leq \eta \leq 0.42$. Hence if $0.42 \leq \eta$ we have that $c^* < 0$ and only case 9.1 is relevant.

An illustration of the proposition is provided in Figure 7. Case 9.2 occurs when $\theta^+ < \theta^{LIM}$, this is when P^+ does not result in a listing outcome. In the figure, it can be seen that if the 'indifferent consumer' θ^{LIM} falls to the right of z, the profits achieved with listing are smaller than the maximum profits that could be achieved with no listing.

(INSERT FIGURE 7 AROUND HERE)

Corollary 10 *A numerical simulation indicates that for $c = 0$, if η is smaller than approximately 0.2, the firm will choose $P = \frac{1}{2}(\Delta q\overline{\theta} + c)$ and not induce listing, otherwise the firm will choose P^{LIM} and induce listing.*

5 Comparison of commitment and non commitment outcomes

In this section we compare the outcome with price commitment with the outcome described in lemma 6 (non price commitment). The following table summarises the comparison for all cases[33].[34]

(INSERT TABLE)

The table confirms the intuition that the firm's price commitment results in more listing. This is due to the effect of an ex ante high price choice which induces a listing outcome. In most circumstances (cases b, d and e1) this benefits the firm who will commit to such high prices. However, if the subsidy is high and the cost is large (case c), the commitment of the firm results in a reduction of profits. The reason for this is that in this case in the absence of price commitment the drug would be listed anyway and there would be no rationing of the patients who can access it with a subsidy. Instead, with commitment as the price is higher, the agency rations the number of patients who have reimbursement rights and therefore the profits of the firm are smaller. In this case the firm will not commit to a price.

The comparison of the objective functions for the agency under commitment and no commitment tells the other side of the story. If the subsidy is small or if it is high but the costs of production are small, the absence of commitment favours the agency (these are cases b, e1 and partly d). If instead the subsidy is large and the production costs are large the commitment favours the agency.

[33] In the appendix we show that $\frac{2\Delta q\overline{\theta}}{\left(\eta+\sqrt{7\eta^2+2\eta}\right)} > c^*$.

[34] In this table we report the outcome where $c^* > 0$ (which can happen only if $0 \leq \eta \leq 0.42$). If $0.42 \leq \eta$, all cases in the table stay as they are but cases e and f are not relevant and should be ignored.

6 Discussion of results

In this section we discuss the sensitivity of our results to some of the assumptions which have been made. The main model considers a situation where (a) buyers with no reimbursement rights can buy the drug privately, (b) the agency can grant reimbursement rights to a specific group of patients of an illness, according to the health benefits of the drug on this group and (c) firms cannot price discriminate between buyers with and without reimbursement rights. In what follows, we analyze the impact of dropping each of these assumptions.

6.1 Non-existence of an unsubsidized demand for the drug.

The model does not assume that there is a private market, but allows for its existence. Indeed, in many of the equilibrium results there is no private market for the drug and only patients with reimbursement rights purchase it. This happens whenever $\theta_F > \theta_L$, (drugs are too expensive).

However, one could think of a situation where some exogenous restraint makes it impossible for patients to purchase the drug privately[35]. In such cases, an extension of the main work results tells us that the agency will list more frequently. Since there is no private demand, the need to subsidize the drug arises, even with no externalities in consumption, because of the need to realise private health benefits[36].

Another difference accrues with price commitment. Since there is no private demand for the drug, the value of committing to a high price by the firm to 'force' a listing outcome does not exist anymore. Here, the price that the firm chooses does not affect private demand, which always takes a value of 0. Hence, choosing a high price will only diminish the possibilities that the drug is listed.

6.2 No partial coverage option

We now consider a situation where the agency cannot distinguish a group of patients and grant those reimbursement rights. In this case, the reimbursement decision is "all or none".

Here, the results in Section 3 (no price commitment) still apply. Despite that with in Section 3 the agency could chose to distinguish a specific group of patients, the agency's reimbursement decision turned out to be "all or none"- this is, to reimburse no patients or to reimburse all the patients who would purchase the drug with the subsidy.

For the case of price commitment and low subsidies, the results in section 4.2.1 continue to apply. It could still be profitable for the firm to set a price that would induce listing. The reason is that, as before, in section 4.2.1, the

[35] Not because drugs are too expensive,as this is already incorporated in the main model, but because of an exogenous restriction such as doctors not being allowed to prescribe drugs to consumers without reimbursement rights.

[36] Proofs of this can be obtained from the authors by request.

decision of the agency is either to reimburse no-one or all the patients who would purchase the drug with the subsidy.

The only difference between the results obtained previously and the results in the case of an "all or none" decision accrues in the case of price commitment and high subsidies (figure 6, section 4.2.2), where sometimes the agency decided to reimburse a group of patients. If the agency can not distinguish a group of patients, it will chose to reimburse nobody as it is simply too expensive to subsidize all patients.

6.3 Price discrimination

Price discrimination refers to the ability of the monopoly to set a price for patients with reimbursement rights, P_R and a price for patients with no reimbursement rights, P_F. With price discrimination the firm has more "tools" to extract the rents of the consumer and the agency, and as a consequence, if anything, price discrimination can only result in more profits.

However, since patients with reimbursement rights can always buy the drug at full price if they want to, price discrimination can only effectively take place if the drug's full price exceeds the price paid by consumers with reimbursement rights. This is if $P_F > S = \tau + \eta P_R$. This sets a strong constraint on the firm's use of price discrimination to obtain more profits, as in our model, the patients who have smallest willingness to pay are precisely those who have no reimbursement rights and must pay the high price P_F.

Since we must have $P_F > S$, we find that $\theta^R = \frac{S-c}{\Delta q} < \theta^F = \frac{P_F - c}{\Delta q}$. Hence, with no price commitment the demand function of the drug is as in expression 2 and figures 3 and 4 would still apply. As a consequence, the agency may choose not to list (and then only P_F matters), or to list and reimburse all patients who would purchase the drug with a subsidy (and then only P_R matters). Therefore, the results are the same as the ones obtained in Section 3. An intuition is the following: The monopoly will only price discriminate if this is more profitable. Yet, to price discriminate, the firm must set a higher price for consumers with no rights, precisely those with the smallest willingness to pay for the drug. This restriction implies that the firm can not make more profit by price discriminating, and explains why the results in Section 3 do not change.

With price commitment, since $P_F > S$ and $\theta^R < \theta^F$ the problem for the agency is to choose the listing threshold as described in expression (6) (where P is substituted by P_R). Figures 5 and 6 remain unchanged. As in the situation with no price discrimination, by setting a high P_F , there will be a further incentive for the agency to list. Yet, with price discrimination this is easier to accomplish for the firm, as now, increasing P_F only increases the excess health benefits of listing but does not directly raise the financial costs of listing which depend on P_R. If profitable, the firm could raise P_F and keep the price with reimbursement at a certain level.

In the case with low subsidies and no price discrimination we obtained that the company achieved the highest possible profits, associated with θ^{R*} (see

section 4.2.1). Price discrimination can not improve on this, and hence, the results in section 4.2.1 remain unaltered.

In the case of high subsidies and no price discrimination (section 4.2.2), the price that maximized profits when some patients held reimbursement rights was $P_R = P^+$. When P^+ is high enough to induce listing, the firm does not need to price discriminate in order to achieve this outcome (then, proposition 9.1 still holds). The main difference with the situation with no price discrimination takes place if P^+ is not high enough to induce listing. With price discrimination, it will be easier to induce listing by raising P_F. For example, the situation with maximum incentives for reimbursement would be a situation where P_F is so high that no-one would purchase the drug privately. In these circumstances, the agency would need to compare the objective function when $P = P^+$ with the situation with no sales of the private drug.

As a consequence, we obtain that, in most circumstances, price discrimination does not affect the results obtained and, when it does, it results in more listing.

7 Conclusions

This paper identifies the effects of the strategic interaction between a government agency making decisions to subsidize consumption of drugs based on how effective these drugs are on different patient groups and firms making decisions about drug prices. We focus the analysis on the costs of drug provision, a relatively under-researched area, as most of the literature has considered the measurement of health benefits and its monetary value. Our remit is to make two simple points about this cost:

1. The cost of provision can not be based on historical prices and sales as the reimbursement decision may have an impact on market prices and quantities. A prospective analysis is needed.

2. Because of the former, it is crucial to understand how drug prices are set, and how firms react to and anticipate "reimbursement news".

The paper deals with these two points in a specific setting. The main analysis is based on a situation where patients can purchase the drug at full price if they have no reimbursement rights, where the pharmaceutical firm is free to choose prices but can not price discriminate between subsidized and unsubsidized consumers, and where the agency chooses a level of coverage (or group of consumers to subsidize) taking into consideration the excess health benefits of doing so (including private benefits and externalities) and balancing those against the excess public costs. In the model, the agency chooses an effectiveness threshold, and patients who fall in this range are subsidized.

In our benchmark scenario, the agency takes the listing decision first and then the firm chooses the price. Here, the main reason for listing the drug for reimbursement is to expand the benefits of the drug to consumers who would not purchase it privately, despite the public cost. Given the agency's aim of reducing public costs, subsidizing a few needy consumers makes no sense if those

consumers would have purchased the drug at full price. Hence, the agency's decision will be either to subsidize no patients at all, or to subsidize some, but in this case it will give reimbursement rights as well to patients who would not have purchased the drug at full price.[37] It pays to do this whenever the private and public benefits from drug consumption really diverge- this is when consumers purchase too little privately. This might happen for several reasons: (i) patients are not willing to pay for the drug, but there are large externalities of them consuming the drug and (ii) the difference in costs between the new drug and the alternative treatment is large. Indeed, if there is the difference between the costs is small and there is no externality, the agency reimburses no consumers. It is also interesting to note that if the subsidy is high, the more effective the new drug is (higher quality), the fewer are the incentives to list it. The reason for this is that as the quality increases, the patients are more willing to purchase the drug privately.

In a second scenario, we study what the outcome would be if the firm could commit to a price before the agency decided on the listing decision. We prove that in this situation, for most parameter configurations, the firm decides to increase prices as this is a means to induce listing. The mechanism is the following: by committing to a high price ex ante, the firm is "promising" small consumption levels if there is no reimbursement. If the promise is credible, the agency is more willing to reimburse. We do not identify in the paper what makes the promise credible, but we note that regulations which imply some stickiness in prices will make those commitments possible. This is the case with the UK regulation for drug prices, the Pharmaceutical Price Regulation Scheme, which allows initial free pricing for a drug but then makes prices very difficult to change.

Our model can be extended to analyze other cases. In particular, the case when firms can price discriminate between consumers who have or do not have reimbursement rights and the case that the agency cannot distinguish specific groups of patients and must reimburse all patients or none. In both cases, the main results are only affected if subsidies are large and firms can commit to prices. In these circumstances, price discrimination makes listing more probable, but the inability of the agency to distinguish sub-groups of patients makes listing less probable.

Our model considers a world of mixed public/private provision of health care where patients can purchase drugs privately. Alternatively, with no private demand, listing would be more probable, as in the main model one of the motivations for the agency not to list is that some patients would buy the drug even with no subsidy. Also, with no private demand, committing to high prices would not result in a smaller private demand ex post. As a consequence, promises of high prices, only result in a larger public unit cost and hence, a smaller probability of listing.

Finally, in this paper we have assumed that all consumers have the same or

[37] This is, in the end, the choice of an optimal coverage level, boils down to a binary decision: either the agency does not list, or it lists and gives reimbursement rights to a "large" amount of patients.

similar income (no patient is income constrained) and that the variation in their willingness to pay for the drug is only linked to health effects. In addition, we have not considered the insurance role of public health subsidies.

Although restrictive, these assumptions can be justified within the context of this paper's objective. Our aim is only to analyze the interaction between an agency that decides on listing and a firm setting prices for the drug. The level of subsidy is exogenous and not decided by the agency. Our observation is that in many countries, the subsidy level and which social group is entitled to a subsidy (level of income, age or status) is decided by parliament, precisely with the aim of homogenizing purchasing power when it comes to health markets. However, the listing decision and the decision on which specific groups of patients should have subsidized access to drugs is delegated to a separate agency, that advises doctors on who to prescribe drugs. This is reasonable, as there are many new drugs and the degree of detail and types of analysis that these decisions need cannot be undertaken in a general law. Moreover, given the costs that new drugs impose on public health systems, one can also think that the reason to delegate the decision stems from an idea that the agency will be cautious in its decision making, and will not take into consideration non-health benefits of the drug access.

To continue, our results will be fully operational in circumstances where there is a strong correlation between the occurrence of an illness and income levels, so that the patients suffering from the illness have similar income[38]. If this was not the case, we would find that for certain price levels, the demand of either group would vary. This is, some consumers who would be equally ill, but would be poorer, would not purchase the drug at full price (and perhaps at the reimbursed price). This would create more kinks in the demand function, (and discontinuities in the profit and objective function) further complicating the analysis.

Concluding, as mentioned in the introduction, health care provision is highly jurisdiction specific. Because of this, the analysis of the interaction between different agencies setting prices, degree of coverage and other related variables is an interesting future line of research.

[38] Clearly, also if the **income level of the population is similar.**

8 Appendix

Section 3.1: Full derivation of the firm's demand function.

Since $\theta^F > \theta^R$, there are 3 regimes:

Regime 1, $(\theta_L < \theta^R)$: The demand of patients with reimbursement rights is $D^R = \overline{\theta} - \theta^R$. There is no demand of patients with no reimbursement rights.
Regime 2, $(\theta^R < \theta_L < \theta^F)$: The demand of patients with reimbursement rights is $D^R = \overline{\theta} - \theta_L$. There is no demand of patients with no reimbursement rights.
Regime 3, $(\theta^F < \theta_L)$: The demand of patients with no reimbursement rights is $D^F = \theta_L - \theta^F$. All patients with reimbursement rights purchase the drug: $D^R = \overline{\theta} - \theta_L$.

Finally the demand function is:

$$D = \begin{cases} \min\left\{\overline{\theta} - \theta^R,\ \overline{\theta} - \theta_L\right\} & if \quad \theta^F > \theta_L \\ (\overline{\theta} - \theta_L) + (\theta_L - \theta^F) = \overline{\theta} - \theta^F & if \quad \theta^F < \theta_L \end{cases}$$

■

Proposition 2.

We start by finding optimal decisions of the firm for each coverage regime:

Regime 1, $(\theta_L < \theta^R)$: The profit maximization problem is: $\underset{\{\theta^R\}}{max}\left[\pi_R(\theta^R) = \frac{1}{\eta}\left(\Delta q\theta^R + \underline{c} - \tau - \eta c\right)\left(\overline{\theta} - \theta^R\right)\right]$ such that $\theta^R > \theta_L$. The interior solution is $\theta^{R*} = \frac{\Delta q\overline{\theta} + \eta c + \tau - \underline{c}}{2\Delta q}$ and $P_R = \frac{1}{2\eta}\left(\Delta q\overline{\theta} + \underline{c} + \eta \cdot c - \tau\right)$. The value of profits at this solution is: $\pi_R^* = \frac{1}{4\eta\Delta q}\left(\Delta q\overline{\theta} - \eta c - \tau + \underline{c}\right)^2$. Note that $\theta^{R*} > \theta_L$ implies that $\frac{\overline{\theta}}{2} + \frac{\eta c + \tau - \underline{c}}{2\Delta q} > \theta_L$ (condition A1).

Regime 2, $(\theta^R < \theta_L < \theta^F)$: The profit maximization problem is: $\underset{\{P\}}{max}\ \left[\pi_L(\theta_L) = (P - c)\left(\overline{\theta} - \theta_L\right)\right]$. Since $\pi_L(\theta_L)$ is increasing in P, the optimal price is the largest price that guarantees that consumer θ_L purchases the drug. Hence: $P_L = \frac{\theta_L\Delta q + \underline{c} - \tau}{\eta}$. The value of profits at this solution is $\pi_L^* = \frac{\theta_L\Delta q + \underline{c} - \tau - \eta c}{\eta}\left(\overline{\theta} - \theta_L\right)$.

Regime 3, $(\theta^F < \theta_L)$: The profit maximization problem is: $\underset{\{\theta^F\}}{max}\left[\pi_F(\theta^F) = \left(\Delta q\theta^F + \underline{c} - c\right)\left(\overline{\theta} - \theta^F\right)\right]$ such that $\theta^F \leq \theta_L$. The solution is $P_F = \frac{1}{2}\left(\Delta q\overline{\theta} + \underline{c} + c\right)$ and $\theta^{F*} = \frac{\Delta q\overline{\theta} + c - \underline{c}}{2\Delta q}$. The profits evaluated at this solution are: $\pi_F^* = \frac{1}{4\Delta q}\left(\Delta q\overline{\theta} + \underline{c} - c\right)^2$. Note that $\theta^{F*} \leq \theta_L$ is satisfied if $\frac{\Delta c}{2\Delta q} < \theta_L$ (condition A3).

Boundary Conditions

An interior solution in Regime 1 (respectively, Regime 3) requires A1 (A3) to hold. If A1 (A3) is not satisfied, the corner solution for the regime is a price such that $\theta^R = \theta_L$, (respectively, $\theta^F = \theta_L$). This corner solution yields profits of $\pi_R(\theta_L) = \frac{1}{\eta}\left(\Delta q\theta_L + \underline{c} - \tau - \eta c\right)\left(\overline{\theta} - \theta_L\right)$, $\left(\pi_F(\theta_L) = \left(\Delta q\theta_L + \underline{c} - c\right)\left(\overline{\theta} - \theta_L\right)\right)$.

Note that, $\theta^{R*} < \theta^{F*}$ since $\tau/(1-\eta) < c < \Delta q\overline{\theta}$. Hence, A1 and A3 are incompatible. If one holds, the other does not. Note also that if, $\theta^{F*} < \theta_L < \theta^{R*}$ neither θ^{F*} nor θ^{R*} are valid solutions. As a consequence we can establish the candidate solutions for each of the following cases:

Case 1. If $\theta_L > \theta^{R*}$ we must compare: $\pi_R\left(\theta_L\right), \pi_L^*$ and π_F^*.
Case 2. If $\theta^{F*} < \theta_L < \theta^{R*}$ we must compare: $\pi_R\left(\theta_L\right), \pi_L^*$, and $\pi_F\left(\theta_L\right)$.
Case 3. If $\theta_L < \theta^{F*}$, we must compare: π_R^*, π_L^* and $\pi_F\left(\theta_L\right)$.

Since $\pi_R\left(\theta_L\right) = \pi_L^* > \pi_F\left(\theta_L\right)$,in Case 2 the global solution is π_L^*. For the other cases, the comparison simplifies to: Case 3. $\{\pi_R^*, \pi_L^*\}$, and Case 1. $\{\pi_L^*, \pi_F^*\}$.

In Case 3 the global solution is π_R^* since $\pi_R^* > \pi_R\left(\theta_L\right) = \pi_L^*$.

In Case 1 we obtain that there exists an α, with $\alpha > \theta^{R*}$ such that if $\theta_L > \alpha$ then the global solution is π_F^*. Otherwise, the global solution is π_L^*. The value of α is:

$$\alpha = \theta^{R*} + \frac{\sqrt{\left(\Delta q\overline{\theta} + \eta c + \tau - \underline{c}\right)^2 - \eta\left(\Delta q\overline{\theta} + \underline{c} - c\right)^2 - 4\Delta q\overline{\theta}(\tau + \eta c - \underline{c})}}{2\Delta q}.$$

The proof of this last result is in three steps:

Step 1. If $\theta_L = \overline{\theta}$, then $\pi_L^* = 0$ and $\pi_F^* - \pi_L^* > 0$.

Step 2. $\pi_F^* - \pi_L^* = \frac{1}{4\Delta q}\left(\Delta q\overline{\theta} + \underline{c} - c\right)^2 - \frac{1}{\eta}\left(\overline{\theta} - \theta_L\right)\left(\Delta q\theta_L + \underline{c} - \tau - \eta c\right)$. Then: $\frac{\partial(\pi_F^* - \pi_L^*)}{\partial\theta_L} = -\frac{1}{\eta}\cdot\left(-2\Delta q\cdot\theta_L + \Delta q\overline{\theta} + \eta c + \tau - \underline{c}\right) = \frac{2\Delta q}{\eta}\cdot\left(\theta_L - \theta^{R*}\right)$. A3 implies that $\frac{\partial(\pi_F^* - \pi_L^*)}{\partial\theta_L} > 0$.

Step 3. Finally, we find α, defined as the value θ_L such that $\theta_L > \theta^{R*}$ and $\pi_F^* - \pi_L^* = \pi_F^* - \pi_R(\theta_L) = 0$. Note that: $\pi_F^* - \pi_L^* = 0$ implies that:
$\theta_L^2\Delta q - \theta_L\left[\Delta q\overline{\theta} + \eta c + \tau - \underline{c}\right] + \left[\frac{\eta}{4\Delta q}\left(\Delta q\overline{\theta} + \underline{c} - c\right)^2 + \overline{\theta}\left(\tau + \eta c - \underline{c}\right)\right] = 0$. This is:

$$\theta_L^{\pi_F^* = \pi_L^*} = \frac{\left[\Delta q\overline{\theta} + \eta c + \tau - \underline{c}\right] \pm \sqrt{\left(\Delta q\overline{\theta} + \eta c + \tau - \underline{c}\right)^2 - 4\Delta q\left[\frac{\eta}{4\Delta q}\left(\Delta q\overline{\theta} + \underline{c} - c\right)^2 + \overline{\theta}(\tau + \eta c - \underline{c})\right]}}{2\Delta q} =$$

$$\theta^{R*} \pm \sqrt{\left(\theta^{R*}\right)^2 - \frac{\eta\left(\Delta q\overline{\theta} + \underline{c} - c\right)^2 + 4\Delta q\overline{\theta}(\tau + \eta c - \underline{c})}{(2\Delta q)^2}}.$$

Since $\alpha > \theta^{R*}$, we eliminate the negative root: α is the positive root. Finally, we show that $\alpha > \theta^{F*}$. Recall that: (i) θ^{F*} maximizes π_F^*, (i) θ^{R*} maximizes π_R^*, (iii) for any z, $\pi_R\left(z\right) > \pi_F\left(z\right)$ and (iv) $\theta^{R*} < \min\{\alpha, \theta^{F*}\}$. Assume that $\alpha < \theta^{F*}$.Then there exists a z, such that $\alpha < z < \theta^{F*}$ and $\pi_R\left(z\right) = \pi_F\left(z\right)$. This contradicts (iii).

■

Section 3.3: Analysis of the objective function.

The value of the objective function is:

$$OF(\theta_L) = \begin{cases} OF_1 = \frac{q\overline{\theta}^2}{2} - \frac{\theta^2}{2} - \frac{\Delta q {\theta^{R*}}^2}{2} - \frac{\overline{\theta}-\theta^{R*}}{2\eta}\cdot(1-\eta)\left(\Delta q\,\overline{\theta} + \underline{c} + \eta c\right) - \\ -(1+\eta)\,\tau + v\left(\overline{\theta} - \theta^{R*}\right) & \text{if } \theta_L < \theta^{R*} \\ OF_2 = \frac{q\overline{\theta}^2}{2} - \frac{\theta^2}{2} - \frac{\Delta q \theta_L^2}{2} - \frac{1}{\eta}\cdot\left(\overline{\theta} - \theta_L\right)\cdot\left((1-\eta)\left(\underline{c} + \Delta q \theta_L\right) - \tau\right) + \\ v\left(\overline{\theta} - \theta_L\right) & \text{if } \theta^{R*} < \theta_L < \alpha \\ OF_3 = \frac{q\overline{\theta}^2}{2} - \frac{\theta^2}{2} - \frac{\Delta q {\theta^{F*}}^2}{2} - \frac{\overline{\theta}-\theta_L}{2}\left((1-\eta)\left(\underline{c} + \Delta q \theta^{F*} + c\right) - 2\tau\right) + \\ +v\left(\overline{\theta} - \theta^{F*}\right) & \text{if } \theta_L > \alpha \end{cases}$$

Shape of the objective function.

Note that θ^{F*} and θ^{R*} do not depend on θ_L. As a consequence, OF_1 is constant in θ_L and OF_3 is increasing in θ_L.

We now study the shape of OF_2. Note that:

$\frac{\partial OF_2}{\partial \theta_L} = -\Delta q \theta_L + \frac{1}{\eta}\left((1-\eta)\left(\underline{c} + \Delta q \theta_L\right) - \tau\right) - \frac{1-\eta}{\eta}\Delta q\left(\overline{\theta} - \theta_L\right) - v.$

Thus, $\frac{\partial OF_2}{\partial \theta_L} = 0$ if $\theta_L = \theta_L^{MIN} = \frac{(1-\eta)\left(\Delta q \overline{\theta} - \underline{c}\right) + \tau + v\eta}{(2-3\eta)\Delta q}$.

Note also that: $\frac{\partial^2 OF_2}{\partial \theta_L^2} = -\Delta q + \frac{1-\eta}{\eta}\Delta q + \frac{1-\eta}{\eta}\Delta q = \Delta q \frac{2-3\eta}{\eta}$.

Therefore:

a. If $\eta < \frac{2}{3}$, $\frac{\partial^2 OF_2}{\partial \theta_L^2} > 0$ and $\theta_L^{MIN} \in (\theta^{R*}, \alpha)$ is a minimum for OF_2.

b. If $\eta > \frac{2}{3}$, $\frac{\partial OF_2}{\partial \theta_L} < 0$ and $\frac{\partial^2 OF_2}{\partial \theta_L^2} < 0$. OF_2 is decreasing and convex in $\theta_L \in (\theta^{R*}, \alpha)$. To see this, note that since $\eta > \frac{2}{3}$ and $\Delta q \overline{\theta} - \underline{c} > 0$ we have that $\frac{2-3\eta}{\eta}\Delta q \theta_L - \frac{1-\eta}{\eta}\left(\Delta q \overline{\theta} - \underline{c}\right) < 0$, which implies that $\frac{1-\eta}{\eta} 2\Delta q \theta_L - \Delta q \theta_L + \frac{1-\eta}{\eta}\underline{c} - \frac{1-\eta}{\eta}\Delta q \overline{\theta} < 0$, i.e.: $\frac{\partial OF_2}{\partial \theta_L} < 0$.

Finally, we note that $OF_1 = OF_2(\theta^{R*})$, i.e., OF is continuos at θ^{R*}. However, OF has a discontinuity at α. ■

Lemma 4. The following expression is the difference in payoffs between listing and not listing:

$\frac{\Delta q}{2}\cdot\left(\left(\theta^{F*}\right)^2 - \left(\theta^{R*}\right)^2\right) + v\left(\theta^{F*} - \theta^{R*}\right) - (\overline{\theta} - \theta^{R*})\left(\frac{1-\eta}{\eta}(\Delta q \theta^{R*} - \tau + \underline{c}) - \tau\right)$

which after some algebra we can rewrite as:

$\frac{1}{4\Delta q}\cdot[(c(1-\eta) - \tau)(\Delta q \overline{\theta} + 2v) + c^2/2(1+2\eta) - 3/2\cdot(c\eta + \tau)^2 -$
$\frac{1}{\eta}(\Delta q \overline{\theta} + \underline{c} - \tau)^2 + (\Delta q \overline{\theta} + \underline{c})^2 - \underline{c}(c(1-\eta) - \tau))]$

Then:

$\frac{\partial OF_1(\theta_L) - OF^{NL}}{\partial v} = \frac{1}{2\Delta q}\left(c(1-\eta) - \tau\right) > 0.$

$\frac{\partial OF_1(\theta_L) - OF^{NL}}{\partial c} = \frac{1}{4\Delta q}[(1-\eta)\cdot(\Delta q \overline{\theta} + 2v) + c(1 + 2\eta - 3\eta^2) - 3\eta\tau -$

$(1-\eta)\,\underline{c}] =$

$= \frac{1}{4\Delta q}\left[(1-\eta)\left(\Delta q\overline{\theta}+2v+c-\underline{c}\right)+3\eta\cdot((1-\eta)\,c-\tau)\right] > 0.$

$\frac{\partial OF_1(\theta_L)-OF^{NL}}{\partial \underline{c}} = -\frac{1}{\eta}(\Delta q\overline{\theta}+\underline{c}-\tau)+(\Delta q\overline{\theta}+\underline{c})-(c(1-\eta)-\tau)) =$

$-\frac{1}{\eta}[(\Delta q\overline{\theta}+\underline{c})(1-\eta)-\tau]-(c(1-\eta)-\tau)) < 0$, since $\tau < (1-\eta)\cdot(\Delta q\overline{\theta}+\underline{c})$. ■

Lemma 5.

Note that the denominator of $OF_1(\theta_L)-OF^{NL}$ is increasing in Δq. Define the numerator of the $OF_1(\theta_L)-OF^{NL}$ as: $Num(\Delta q\overline{\theta}) = (c(1-\eta)-\tau)(\Delta q\overline{\theta}+2v)+ c^2/2(1+2\eta)-3/2\cdot(c\eta+\tau)^2-$
$\frac{1}{\eta}(\Delta q\overline{\theta}+\underline{c}-\tau)^2+(\Delta q\overline{\theta}+\underline{c})^2-\underline{c}(c(1-\eta)-\tau))$.

Changes in Δq and $\overline{\theta}$ have an identical effect on $Num(\Delta q\overline{\theta})$. If $Num(\Delta q\overline{\theta})$ is decreasing in $\Delta q\overline{\theta}$, then $OF_1(\theta_L)-OF^{NL}$ is decreasing in Δq and $\overline{\theta}$. If $Num(\Delta q\overline{\theta})$ is increasing in $\overline{\theta}$ then $OF_1(\theta_L)-OF^{NL}$ is increasing in $\overline{\theta}$. We check under which conditions $Num(\Delta q\overline{\theta})$ is decreasing in $\Delta q\overline{\theta}$.

$\frac{\partial Num(\Delta q\overline{\theta})}{\partial(\Delta q\overline{\theta})} = (c(1-\eta)-\tau)-\frac{2}{\eta}(\Delta q\overline{\theta}+\underline{c}-\tau)+2(\Delta q\overline{\theta}+\underline{c}) =$
$\frac{1}{\eta}[\eta(c(1-\eta)-\tau)-2(\Delta q\overline{\theta}+\underline{c}-\tau)+2\eta(\Delta q\overline{\theta}+\underline{c})] =$
$= \frac{1}{\eta}[\eta(c(1-\eta)-\tau)-2(1-\eta)\Delta q\overline{\theta}-2((1-\eta)\underline{c}-\tau)].$

If this last expression is negative, then $Num(\Delta q\overline{\theta})$ is decreasing in $\Delta q\overline{\theta}$. However, note that $\frac{\partial Num(\Delta q\overline{\theta})}{\partial(\Delta q\overline{\theta})}$ can have either a negative or a positive sign. For example, if $\eta=0$, then $\frac{\partial Num(\Delta q\overline{\theta})}{\partial(\Delta q\overline{\theta})} \to \lim_{\eta\to 0}[\frac{1}{\eta}[-2\Delta q\overline{\theta}-2[\underline{c}-\tau]] < 0$ and if $\eta=1$, then $\frac{\partial Num(\Delta q\overline{\theta})}{\partial(\Delta q\overline{\theta})} = [-\eta\tau+2\tau] > 0$. Indeed $\frac{\partial Num(\Delta q\overline{\theta})}{\partial(\Delta q\overline{\theta})}$ is increasing in η :
$\frac{\partial}{\partial\eta}\left(\frac{\partial Num(\Delta q\overline{\theta})}{\partial(\Delta q\overline{\theta})}\right) = -c+2(\Delta q\overline{\theta}+\underline{c}-\tau)/\eta^2 = \frac{2(\Delta q\overline{\theta}+\underline{c}-\tau)-\eta^2 c}{\eta^2} > 0.$
Hence, for small values of η we obtain that $\frac{\partial Num(\Delta q\overline{\theta})}{\partial(\Delta q\overline{\theta})} < 0$ and for large values of η, $\frac{\partial Num(\Delta q\overline{\theta})}{\partial(\Delta q\overline{\theta})} > 0$.

■

Lemma 6.

Here:

$OF_1(\theta_L)-OF^{NL} =$
$= \frac{1}{4\Delta q}[c(1-\eta)(\Delta q\overline{\theta})+c^2/2(1+2\eta)-3/2\cdot(c\eta)^2-\frac{1}{\eta}(\Delta q\overline{\theta})^2+(\Delta q\overline{\theta})^2)] =$
$= \frac{1}{4\Delta q\eta}[-(1-\eta)(\Delta q\overline{\theta})^2+(1-\eta)\eta\Delta q\overline{\theta}c+c^2/2(\eta+2\eta^2-3\eta^3)] =$
$= \frac{(1-\eta)}{4\Delta q\eta}[-(\Delta q\overline{\theta})^2+\eta c\Delta q\overline{\theta}+c^2/2(\eta+3\eta^2)].$

Hence, if $-(\Delta q\overline{\theta})^2+\eta c\Delta q\overline{\theta}+c^2/2(\eta+3\eta^2) < 0$ then $OF_1(\theta_L)-OF^{NL} < 0$. Studying the last expression we obtain that $OF_1(\theta_L)-OF^{NL} < 0$ is negative

if $\Delta q\overline{\theta}$ exceeds $c/2(\eta+\sqrt{7\eta^2+2\eta})$ (the positive root of the polynomial). Note that $c/2(\eta+\sqrt{7\eta^2+2\eta})$ is increasing in η. Hence, $OF_1(\theta_L)-OF^{NL}$ is least likely to be negative when $\eta=1$. Note that in this case $c/2(\eta+\sqrt{7\eta^2+2\eta})$ $=2c$. In conclusion, if $\Delta q\overline{\theta}>2c=\max_\eta\{c/2(\eta+\sqrt{7\eta^2+2\eta})\}$, $0\leq\eta<1$, then $\Delta q\overline{\theta}>c/2(\eta+\sqrt{7\eta^2+2\eta})$ for all η, $0\leq\eta<1$, and we can conclude that $OF_1(\theta_L)-OF^{NL}<0$.

■

Section 4: Price commitment. Local maximization of OF with respect to θ_L.

We start by finding the value of θ_L that maximizes each region of OF.

1. $\theta_L<\theta^R$. Here: $OF_1=q\frac{\overline{\theta}^2}{2}-\frac{\theta^2}{2}-\Delta q\frac{\theta^{R^2}}{2}-(1-\eta)P\left(\overline{\theta}-\theta^R\right)$, and $\frac{\partial OF_1}{\partial\theta_L}=0$.

Therefore, the agency is indifferent between any θ_L, for any $\theta_L\in(\underline{\theta},\theta^R)$

2. $\theta^R<\theta_L<\theta^F$. Here: $\frac{\partial OF_2}{\partial\theta_L}=-\Delta q\theta_L+(1-\eta)P=0\Rightarrow\hat{\theta}=\frac{(1-\eta)P}{\Delta q}$and $\frac{\partial^2 OF_2}{\partial\theta_L}=-\Delta q<0$. Hence: $OF_2^*=q\frac{\overline{\theta}^2}{2}-\frac{\theta^2}{2}-\Delta q\frac{\hat{\theta}^2}{2}-(1-\eta)P\left(\overline{\theta}-\hat{\theta}^2\right)$.

Note that $\theta^F>\hat{\theta}>\theta^R$ implies that $\eta P<(1-\eta)P<P$. If $\eta<1/2$, we have that $\theta^F>\hat{\theta}>\theta^R$ but if $\eta>1/2$, we have that $\theta^F>\theta^R>\hat{\theta}$, which invalidates OF_2^* as a solution as consumer $\hat{\theta}$ does not purchase the drug.

3. $\theta^F<\theta_L$. Here: $\dfrac{\partial OF_3}{\partial\theta_L}=(1-\eta)P>0\Rightarrow\theta_L^{*3}=\overline{\theta}$ and $OF_3^*=q\frac{\overline{\theta}^2}{2}-\frac{\theta^2}{2}-\Delta q\frac{\theta^{F^2}}{2}$.

■

Proposition 7.

1. $\eta>1/2$. We compare OF_1^* and OF_3^*:

$OF_1^*-OF_3^*=\left(\left(\theta^F\right)^2-\left(\theta^R\right)^2\right)-P(1-\eta)\left(\overline{\theta}-\theta^R\right)=$

$\left(\theta^F-\theta^R\right)\left(\theta^F+\theta^R\right)\dfrac{\Delta q}{2}-P(1-\eta)\left(\overline{\theta}-\theta^R\right)=\frac{(1-\eta)}{\Delta q}P\left(\frac{(1+\eta)P}{2}-\left(\Delta q\overline{\theta}-\eta P\right)\right)$.

Note that $\frac{(1-\eta)}{\Delta q}P\left(\frac{(1+3\eta)P}{2}-\Delta q\overline{\theta}\right)>0$ iff $P>\frac{2\Delta q\overline{\theta}}{(1+3\eta)}$.

Recall that $\eta P<\Delta q\overline{\theta}$. This condition is compatible with $P>\frac{2}{(1+3\eta)}\Delta q\overline{\theta}$ as $2\eta-3\eta<1$.

2. $\eta<1/2$. We compare OF_2^* and OF_3^*:

$OF_2^*-OF_3^*=\dfrac{\Delta q}{2}\left(\left(\theta^F\right)^2-\left(\hat{\theta}\right)^2\right)-(1-\eta)P\left(\overline{\theta}-\hat{\theta}\right)=$

$\frac{\Delta q}{2}\left(\theta^F+\hat{\theta}\right)\left(\theta^F-\hat{\theta}\right)-(1-\eta)P\left(\overline{\theta}-\hat{\theta}\right)=$

$\frac{P}{\Delta q}\left(\frac{1}{2}(2-\eta)P\eta-(1-\eta)\left(\Delta q\overline{\theta}-(1-\eta)P\right)\right)>0.$
Note that $OF^{2*}-OF^{3*}>0$ iff $P>\frac{(1-\eta)\Delta q\overline{\theta}2}{2+\eta^2-2\eta}$.

Recall that $\eta P<\Delta q\overline{\theta}$. This last condition is compatible with $P>\frac{(1-\eta)\Delta q\overline{\theta}2}{2+\eta^2-2\eta}$ since $\eta<\frac{1}{2}$ implies that $\frac{2(1-\eta)}{2+\eta^2-2\eta}<\frac{1}{\eta}$.

■

Proposition 8.

If the drug is listed for reimbursement the firm's profits are: $(P-c)(\overline{\theta}-\theta^R)=(P-c)(\overline{\theta}-\frac{\eta P}{\Delta q})$. These profits are maximized when $P^*=\frac{\Delta q\overline{\theta}+\eta c}{2\eta}$. Their value is $\frac{1}{4\eta\Delta q}(\Delta q\overline{\theta}-\eta c)^2$. This value exceeds the maximum value of the profits achieved with no reimbursement: $\frac{1}{4\Delta q}(\Delta q\overline{\theta}-c)^2$. Moreover, $P^*=\frac{\Delta q\overline{\theta}+\eta c}{2\eta}>\frac{2\Delta q\overline{\theta}}{1+3\eta}$, since $\Delta q\overline{\theta}(1-\eta)+\eta(1+3\eta)c>0$. This implies Proposition 8.

■

Proposition 9.

Recall that for $\eta<\frac{1}{2}$, if $P>P^{LIM}$ the agency sets $\theta_L^*=\frac{(1-\eta)P}{\Delta q}$, but if $P<P^{LIM}$, the agency sets $(\theta_L=\overline{\theta})$. For P^+ to encourage listing, it must be that $P^+>P^{LIM}$, this is that $c>\Delta q\overline{\theta}\left(\frac{2-6\eta+3\eta^2}{(1-\eta)(2+\eta^2-2\eta)}\right)$. If this last inequality holds, Proposition 9.1 follows.
However, if $c<\Delta q\overline{\theta}\left(\frac{2-6\eta+3\eta^2}{(1-\eta)(2+\eta^2-2\eta)}\right)$, P^+ does not induce the agency to list the drug and the firm's optimal choice will either be P^{LIM} (which induces listing) or $\frac{1}{2}\left(\Delta q\overline{\theta}+c\right)$, which maximizes the profit with no listing (π_F). Proposition 9.2 provides the condition under which P^{LIM} is best. The following steps yield such condition.

Step 1: We define the profits of no listing $(\theta_L=\overline{\theta})$ and of listing $(\theta_L=\theta_L^*)$ as a function of the indifferent consumer I. With no listing $I=P/\Delta q$ so: $\pi^{NL}[I]=(\Delta qI-c)\left(\overline{\theta}-I\right)$. With listing, $I=\theta_L^*=(1-\eta)P/\Delta q$ so: $\pi^L[I]=(P-c)\left(\overline{\theta}-I\right)=\dfrac{1}{1-\eta}(\Delta qI-(1-\eta)c)\left(\overline{\theta}-I\right)$.

Step 2: We proof that for any fixed $I\in[0,\overline{\theta})$, $\pi^L[I]>\pi^{NL}[I]$.[39] Note that: $\pi^L-\pi^{NL}=(\frac{1}{1-\eta}(\Delta qI-(1-\eta)c)-(\Delta qI-c))\left(\overline{\theta}-I\right)$. Hence if $\overline{\theta}>I$, then $\pi^L-\pi^{NL}>0$.
Step 3: We define z as the value of θ that induces listing, this is $z\in(\theta^+,\overline{\theta})$ such that $\pi^L(z)=\pi^{NL*}=\frac{1}{4\Delta q}(\Delta q\overline{\theta}-c)^2$. Therefore, z is such that: $\left(\frac{\Delta qz}{(1-\eta)}-c\right)\left(\overline{\theta}-z\right)=\frac{\left(\Delta q\overline{\theta}-c\right)^2}{4\Delta q}$.This equation has two roots:
$\left(\frac{\Delta q\overline{\theta}+(1-\eta)c}{2\Delta q}\right)\pm\frac{\sqrt{\eta\left(\left(\Delta q\overline{\theta}\right)^2-c^2(1-\eta)\right)}}{2\Delta q}=\theta^+\pm\frac{\sqrt{\eta\left(\left(\Delta q\overline{\theta}\right)^2-c^2(1-\eta)\right)}}{2\Delta q}.$

[39] If $\overline{\theta}=I$, then $\pi^{NL}[I]=\pi^L[I]$.

Note that the smallest root is smaller than θ^+, therefore it can not induce listing. Hence, $z = \theta^+ + \frac{\sqrt{\eta\left(\left(\Delta q\overline{\theta}\right)^2 - c^2(1-\eta)\right)}}{2\Delta q}$. Note for any $\theta > z$, $\pi^L < \pi^{NL*}$ and for any $\theta < z$, $\pi^L > \pi^{NL*}$.
Step 4: If the price is P^{LIM}, the indifferent consumer is $\theta^{LIM} = \theta_L\left(P^{LIM}\right) = \frac{(1-\eta)P^{LIM}}{\Delta q} = \frac{1-\eta}{\Delta q}\left(\frac{2(1-\eta)\Delta q\overline{\theta}}{2+\eta^2-2\eta}\right) = \frac{2(1-\eta)^2\overline{\theta}}{2+\eta^2-2\eta}$. Note that $\theta^{LIM} > \theta^+$ since $P^{LIM} > P^+ = \frac{c}{2} + \frac{\Delta q\overline{\theta}}{2(1-\eta)}$.
Step 5: Given steps 3 and 4 we can conclude that: if $\theta^{LIM} < z$, then, the firm will prefer to induce listing and P^{LIM} will be the global maximum. This is the condition stated in proposition 9.2.

■

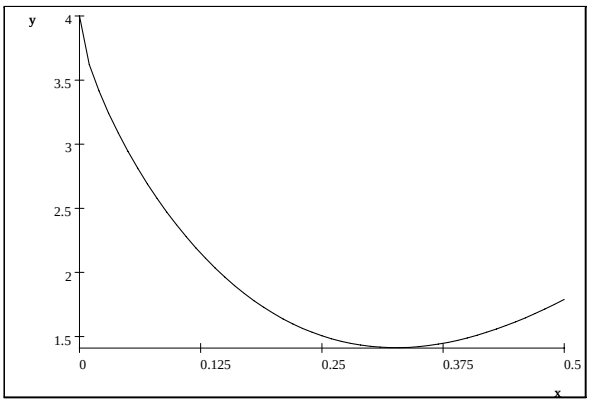
Corollary 10. Note that: $\theta^{LIM} < z \Leftrightarrow \frac{2(1-\eta)^2\overline{\theta}}{2+\eta^2-2\eta} - \frac{\overline{\theta}}{2} < \frac{c(1-\eta)}{2\Delta q} + \frac{\sqrt{\eta\left(\left(\Delta q\overline{\theta}\right)^2 - (1-\eta)\right)c^2}}{2\Delta q}$, which can be rewritten as: $\Delta q\overline{\theta}\frac{2+3\eta^2-6\eta}{(2(1-\eta)+\eta^2)(1-\eta)} - c < \frac{1}{1-\eta}\sqrt{\eta\left(\left(\Delta q\overline{\theta}\right)^2 - (1-\eta)c^2\right)}$.
The above inequality can revert sign depending on the value of η. For example if $c = 0$, the condition simplifies to $2 + 3\eta^2 - 6\eta - \left(2 + \eta^2 - 2\eta\right)\sqrt{\eta} < 0$.This is satisfied when $\eta > 0.2$.

■

Section 5.

We first prove that $\frac{2\Delta q\overline{\theta}}{\left(\eta + \sqrt{7\eta^2+2\eta}\right)} > c^*$. This implies that:
$2(1-\eta)(2+\eta^2-2\eta) - (\eta + \sqrt{7\eta^2+2\eta})(2+3\eta^2-6\eta) > 0$

This expression holds for $\eta = 0$ and $\eta = 1/2$.Below, we provide a numerical evaluation of the expression for $0 < \eta < 1/2$:



The expression has a minimum at $\eta = 0.326$. We evaluate the expression in this point to obtain its positive value 1.4134.

■

Section 5, Table 1: Proof of cases c, d and e

Note that in all these cases $\eta < \frac{1}{2}$

Case c (comparison of the outcomes with no price commitment (θ^{R*}) and price commitment (θ^{+})).
Note that $P^+ > P_R$ and $\theta^{R*} < \theta^+$.[40] This implies that the demand is larger with no price commitment and that the price is larger with commitment.
Profit Comparison:
Since $\pi^+ = \frac{1-\eta}{4\Delta q}\left(\frac{\Delta q\overline{\theta}}{1-\eta} - c\right)^2$ and $\pi^{R*} = \frac{1}{4\eta\Delta q}\left(\Delta q\overline{\theta} - \eta c\right)^2$: $\pi^{R*} > \pi^+ \Leftrightarrow \frac{1}{4\Delta q}(\frac{1}{\eta}\left(\Delta q\overline{\theta} - \eta c\right)^2 > \frac{1}{1-\eta}\left(\Delta q\overline{\theta} - (1-\eta)c\right)^2$.This expression holds iff $(1-2\eta)((\Delta q\overline{\theta})^2 - \eta(1-\eta)c^2) > 0$. Since $\eta < \frac{1}{2}$ and $\Delta q\overline{\theta} > c$ we conclude that $\pi^{R*} > \pi^+$, i.e.: $\pi^{NPC} > \pi^{PC}$.
Agency's objective function comparison:
Note that $OF^{NPC} = q\frac{\overline{\theta}^2}{2} - \frac{\underline{\theta}^2}{2} - \Delta q\frac{\theta^{R*^2}}{2} - (1-\eta)\,P_R\left(\overline{\theta} - \theta^{R*}\right)$ and
$OF^{PC} = q\frac{\overline{\theta}^2}{2} - \frac{\underline{\theta}^2}{2} - \Delta q\frac{\theta^{+^2}}{2} - (1-\eta)\,P^+\left(\overline{\theta} - \theta^{+}\right)$.
Hence:
$OF^{PC} - OF^{NPC} = \frac{\Delta q}{2}(\theta^{R*^2} - \theta^{+^2}) + (1-\eta)\left(P_R\left(\overline{\theta} - \theta^{R*}\right) - P^+\left(\overline{\theta} - \theta^{+}\right)\right) =$
$= \frac{\Delta q}{8(\Delta q)^2}\left(\left(\Delta q\overline{\theta} + \eta c\right)^2 - \left(\Delta q\overline{\theta} + (1-\eta)\,c\right)^2\right) +$
$+ (1-\eta)\left(\frac{\Delta q\overline{\theta}+\eta c}{2\eta}\left(\frac{\Delta q\overline{\theta}-\eta c}{2\Delta q}\right) - \frac{\Delta q\overline{\theta}+(1-\eta)c}{2(1-\eta)}\left(\frac{\Delta q\overline{\theta}-(1-\eta)c}{2\Delta q}\right)\right)$.
Note that if $\eta \to 0$ then $OF^{PC} - OF^{NPC} \to +\infty$.Recall that if $\eta \to 1/2$, $OF^{PC} - OF^{NPC} \to 0$.We now prove that $OF^{PC} - OF^{NPC} > 0$ for $0 < \eta < 1$. By simplifying the expression we obtain: $\Delta q\overline{\theta}\,(1-2\eta)\,\frac{\Delta q\overline{\theta} - \eta c}{\eta} + \frac{1-4\eta\,(1-\eta)}{2}c^2$.
To prove this, take the derivative of this expression with respect to c:
$-\Delta q\overline{\theta}\,(1-2\eta) + [1-4\eta\,(1-\eta)]c$. Since $0 < \eta < 1/2$ and $\Delta q\overline{\theta} > c$, that this derivative is negative. Hence the expression is least likely to hold for large c. A sufficient condition would be if it held for $c = \Delta q\overline{\theta}$. In this case $OF^{PC} - OF^{NPC}$ becomes: $c^2\,(1-2\eta)\,\frac{1-\eta}{\eta} + \frac{1-4\eta\,(1-\eta)}{2}c^2$. It is positive whenever $(1-2\eta)\,\frac{1-\eta}{\eta} + \frac{1-4\eta\,(1-\eta)}{2} > 0$. This is $2\,(1-2\eta)\,(1-\eta) + (1-4\eta\,(1-\eta))\eta > 0$ or $0 < 4\eta^3 - 5\eta + 2$. This expression is positive for $0 < \eta < 1/2$.Therefore, $OF^{PC} > OF^{NPC}$.

Case d. (Comparison of the outcomes with no price commitment (θ^{F*}) and price commitment (θ^{+}))
Profit Comparison:

[40] If $\eta = 1/2$, $P^+ = P_R = \frac{c+\Delta q\overline{\theta}}{2}$ and the two outcomes coincide.

Since $\pi^{+}=\frac{1-\eta}{4\Delta q}\left(\frac{\Delta q\overline{\theta}}{1-\eta}-c\right)^{2}$ and $\pi^{F*}=\frac{1}{4\Delta q}\left(\Delta q\overline{\theta}-c\right)^{2}$ we obtain that: $\pi^{+}-\pi^{F*}=\frac{1-\eta}{4\Delta q}\left(\frac{\Delta q\overline{\theta}}{1-\eta}-c\right)^{2}-\frac{1}{4\Delta q}\left(\Delta q\overline{\theta}-c\right)^{2}>0$ which clearly holds as: $\left(\Delta q\overline{\theta}-(1-\eta)c\right)^{2}>(1-\eta)\left(\Delta q\overline{\theta}-c\right)^{2}$

Agency's objective function comparison:

Note that $OF^{NPC}=q\frac{\overline{\theta}^{2}}{2}-\frac{\underline{\theta}^{2}}{2}-\Delta q\frac{\theta^{F*^{2}}}{2}$ and $OF^{PC}=q\frac{\overline{\theta}^{2}}{2}-\frac{\underline{\theta}^{2}}{2}-\Delta q\frac{\theta^{+^{2}}}{2}-(1-\eta)P^{+}\left(\overline{\theta}-\theta^{+}\right)$. Hence: $OF^{NPC}-OF^{PC}=\frac{\Delta q}{2}\left(\theta^{+^{2}}-\theta^{F*^{2}}\right)+(1-\eta)P^{+}\left(\overline{\theta}-\theta^{+}\right)$.

Substituting the different variables and simplifying the expression we get:

$$OF^{NPC}-OF^{PC}=\frac{1}{4\Delta q}\left(\frac{c^{2}\eta\left(\eta-2\right)}{2}-\eta c\Delta q\overline{\theta}+\left(\Delta q\overline{\theta}\right)^{2}-(1-\eta)^{2}c^{2}\right)=$$

$$\frac{1}{4\Delta q}\left((\eta-\tfrac{1}{2}\eta^{2}-1)c^{2}-\eta c\Delta q\overline{\theta}+\left(\Delta q\overline{\theta}\right)^{2}\right)$$

Hence $OF^{NPC}-OF^{PC}>0$ iff $\left(\Delta q\overline{\theta}\right)^{2}-\eta c\Delta q\overline{\theta}-c^{2}\left(1-\eta\left(1-\frac{1}{2}\eta\right)\right)>0$.

Note that $\frac{\partial OF^{NPC}-OF^{PC}}{\partial c}=-\eta\Delta q\overline{\theta}-2c\left(1-\eta\left(1-\frac{1}{2}\eta\right)\right)<0$

Hence, $OF^{NPC}-OF^{PC}$ is decreasing in c if $0\leq\eta\leq1/2$ and has a maximum at $c=0$, where the expression achieves a positive value of $\left(\Delta q\overline{\theta}\right)^{2}$. The positive root of $OF^{NPC}-OF^{PC}$ is

$c^{+}=\frac{1}{-2\eta+\eta^{2}+2}\left(-\Delta q\overline{\theta}\eta+\sqrt{4(\Delta q\overline{\theta})^{2}-4(\Delta q\overline{\theta})^{2}\eta+3(\Delta q\overline{\theta})^{2}\eta^{2}}\right)$.

This implies that if $c<c^{+}$ then $OF^{NPC}-OF^{PC}>0$ and otherwise $OF^{NPC}-OF^{PC}<0$.

Recall that in case (d) $\frac{\Delta q\overline{\theta}\left(2+3\eta^{2}-6\eta\right)}{(1-\eta)(2+\eta^{2}-2\eta)}\leq c\leq\frac{2\Delta q\overline{\theta}}{\eta+\sqrt{7\eta^{2}+2\eta}}$, we check the relative position of c^{+} with respect to these two values:

1. $\frac{\Delta q\overline{\theta}\left(2+3\eta^{2}-6\eta\right)}{(1-\eta)(2+\eta^{2}-2\eta)}<c^{+}$. This is that:

$\frac{\Delta q\overline{\theta}\left(2+3\eta^{2}-6\eta\right)}{(1-\eta)(2+\eta^{2}-2\eta)}<\frac{1}{-2\eta+\eta^{2}+2}\left(-\Delta q\overline{\theta}\eta+\sqrt{4(\Delta q\overline{\theta})^{2}-4(\Delta q\overline{\theta})^{2}\eta+3(\Delta q\overline{\theta})^{2}\eta^{2}}\right)\rightarrow$

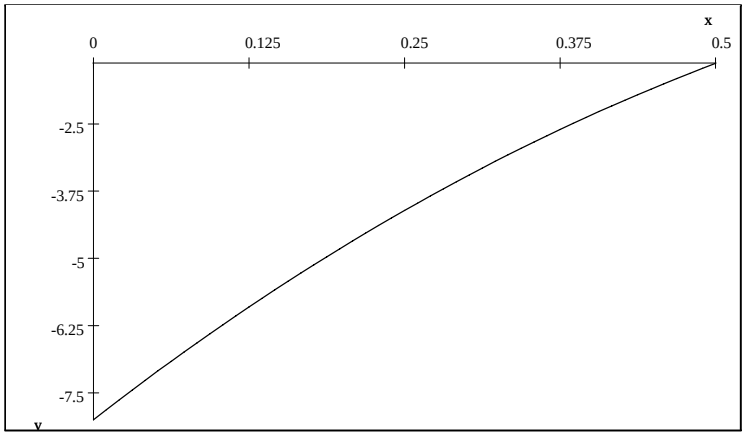
$\left(2+3\eta^{2}-6\eta\right)<(1-\eta)\left(-\eta+\sqrt{4-4\eta+3\eta^{2}}\right)\rightarrow$

$\left(2+3\eta^{2}-6\eta\right)+\eta(1-\eta)<(1-\eta)\sqrt{4-4\eta+3\eta^{2}}\rightarrow$

$2\eta^{2}-5\eta+2<(1-\eta)\sqrt{4-4\eta+3\eta^{2}}\rightarrow$

$(2\eta^{2}-5\eta+2)^{2}-(1-\eta)^{2}(4-4\eta+3\eta^{2})=18\eta^{2}-8\eta-10\eta^{3}+\eta^{4}<0\rightarrow$ $18\eta-8-10\eta^{2}+\eta^{3}<0$.

If $\eta=0$ the expression holds. If $\eta=1/2$, then the expression is-1.375. Plotting the expression we find that $18\eta-8-10\eta^{2}+\eta^{3}$ is:



2. $c^+ < \frac{2\Delta q\overline{\theta}}{\eta+\sqrt{7\eta^2+2\eta}}$. This is that:

$\frac{1}{-2\eta+\eta^2+2}\left(-\Delta q\overline{\theta}\eta+\sqrt{4(\Delta q\overline{\theta})^2-4(\Delta q\overline{\theta})^2\eta+3(\Delta q\overline{\theta})^2\eta^2}\right) < \frac{2\Delta q\overline{\theta}}{\eta+\sqrt{7\eta^2+2\eta}} \rightarrow$

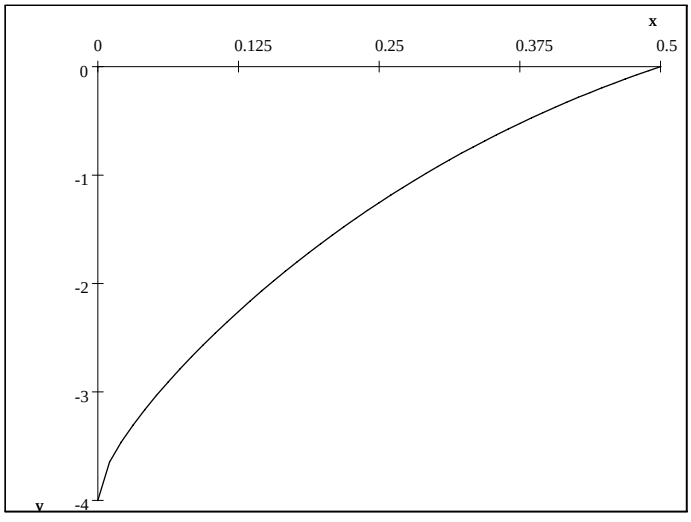
$\frac{1}{-2\eta+\eta^2+2}\left(-\eta+\sqrt{4-4\eta+3\eta^2}\right) < \frac{2}{\eta+\sqrt{7\eta^2+2\eta}}$

$(\eta+\sqrt{7\eta^2+2\eta})\left(-\eta+\sqrt{4-4\eta+3\eta^2}\right) < 2(-2\eta+\eta^2+2) \rightarrow$

$(\eta+\sqrt{7\eta^2+2\eta})\left(-\eta+\sqrt{4-4\eta+3\eta^2}\right) - 2(-2\eta+\eta^2+2) < 0 \rightarrow$

$(\eta+\sqrt{7\eta^2+2\eta})\left(-\eta+\sqrt{4-4\eta+3\eta^2}\right) - 2(-2\eta+\eta^2+2) < 0$

Note that if $(\eta+\sqrt{7\eta^2+2\eta})\left(-\eta+\sqrt{4-4\eta+3\eta^2}\right) - 2(-2\eta+\eta^2+2) = 0$ then $\eta = -2$. Indeed by plotting this expression we find that $(\eta+\sqrt{7\eta^2+2\eta})\left(-\eta+\sqrt{4-4\eta+3\eta^2}\right) - 2(-2\eta+\eta^2+2)$ is:



If $\eta = 0$ then the expression is -4 and if $\eta = 1/2$ the expression is $-2.168\,4 \times 10^{-19}$

In conclusion we obtain the following: If $c \in \{\min(0, \frac{\Delta q\overline{\theta}\left(2+3\eta^2-6\eta\right)}{(1-\eta)(2+\eta^2-2\eta)}\}, c^+\}$ then $OF^{NPC} - OF^{PC} > 0$. If $c \in \{c^+, \frac{2\Delta q\overline{\theta}}{\eta+\sqrt{7\eta^2+2\eta}}\}$ then $OF^{NPC} - OF^{PC} < 0$.

Case e1 (Comparison of the outcomes with no price commitment (θ^{F*}) and price commitment (θ^{LIM}))

Profit Comparison: See the proof of lemma 10 for reference.

Agency's objective function comparison: Note that $OF^{NPC} = OF^{NL} = q\frac{\overline{\theta}^2}{2} - \frac{\underline{\theta}^2}{2} - \Delta q\frac{\theta^{F*^2}}{2}$ and $OF^{PC} = q\frac{\overline{\theta}^2}{2} - \frac{\underline{\theta}^2}{2} - \Delta q\frac{\theta^{LIM^2}}{2} - (1-\eta)\,P^{LIM}\left(\overline{\theta} - \theta^{LIM}\right)$. Recall that in case d we have proven that for $c < c^+$ then $OF^{NL} - OF^+ > 0$. Case e1 is relevant when $0 < c < \frac{\Delta q\overline{\theta}\left(2+3\eta^2-6\eta\right)}{(1-\eta)(2+\eta^2-2\eta)} (< c^+)$. Hence in this case we know that $OF^{NL} - OF^+ > 0$.We now proof that $OF^+ - OF^{LIM} > 0$ to conclude that in case d $OF^{NL} - OF^{LIM} > 0$ this is that $OF^{NPC} > OF^{PC}$

Proof that $OF^+ - OF^{LIM} > 0$. This entails proving that $\frac{\partial OF^+(P)}{\partial P} < 0$ where $OF^+ = q\frac{\overline{\theta}^2}{2} - \frac{\underline{\theta}^2}{2} - \Delta q\frac{\theta^{+^2}}{2} - (1-\eta)\,P\left(\overline{\theta} - \theta^+\right)$ and $\theta^+ = \frac{(1-\eta)P}{\Delta q}$ hence: $OF^+ = q\frac{\overline{\theta}^2}{2} - \frac{\underline{\theta}^2}{2} - \Delta q\frac{\left(\frac{(1-\eta)P}{\Delta q}\right)^2}{2} - (1-\eta)\,P\left(\overline{\theta} - \left(\frac{(1-\eta)P}{\Delta q}\right)\right)$; $\frac{\partial OF^+}{\partial P} = -\Delta q\left(\frac{1-\eta}{\Delta q}\right)^2 P - (1-\eta)\left(\overline{\theta} - \left(\frac{2(1-\eta)P}{\Delta q}\right)\right) =$

$-\Delta q\left(\frac{1-\eta}{\Delta q}\right)^2 P - (1-\eta)\,\overline{\theta} + \frac{2(1-\eta)^2 P}{\Delta q} = \frac{(1-\eta)}{\Delta q}^2 P - (1-\eta)\,\overline{\theta}$.

Hence $\frac{\partial OF^+}{\partial P} < 0$ if $\frac{(1-\eta)}{\Delta q}P - \overline{\theta} < 0$ this is $(1-\eta)P < \Delta q\overline{\theta}$. This is satisfied as $\theta^+ = \frac{(1-\eta)P}{\Delta q} < \overline{\theta}$.

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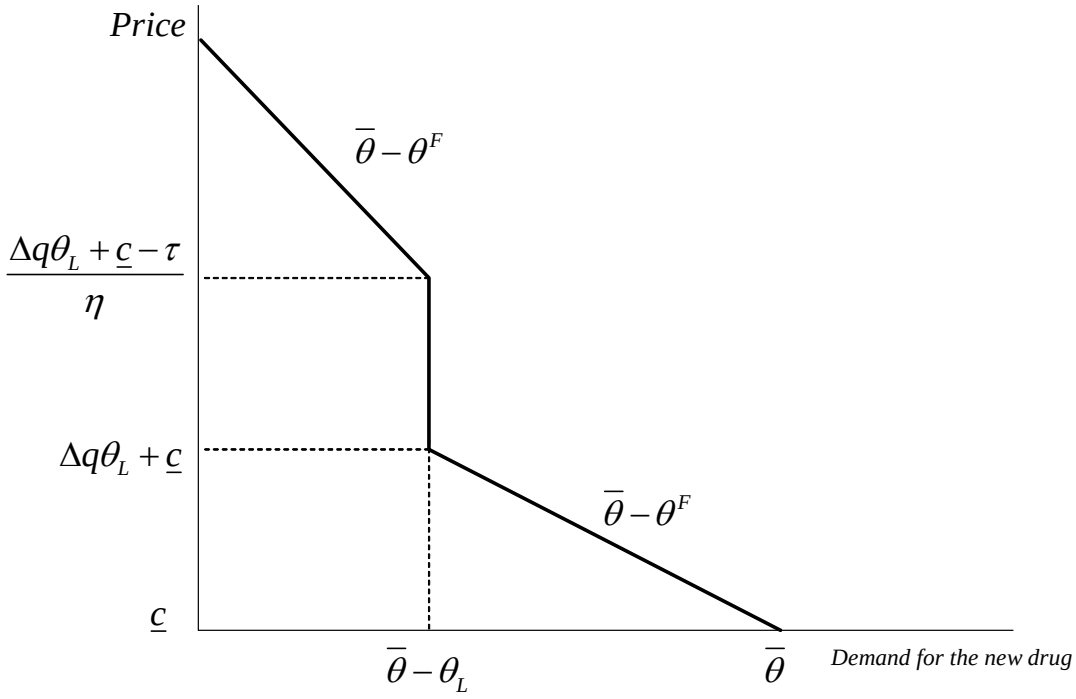

Figure 1: Demand function.

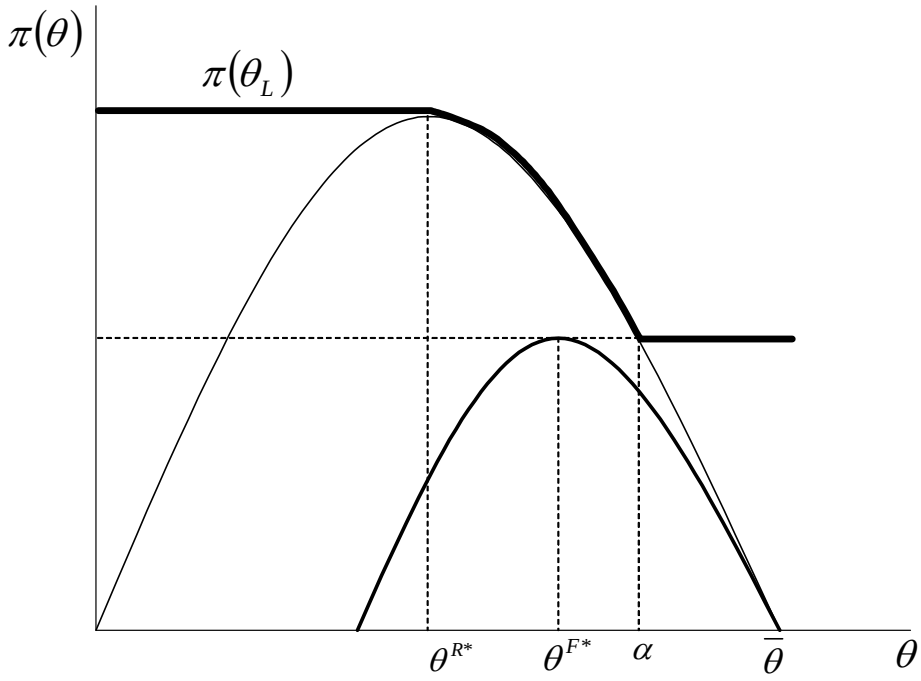

Figure 2: Profit function.

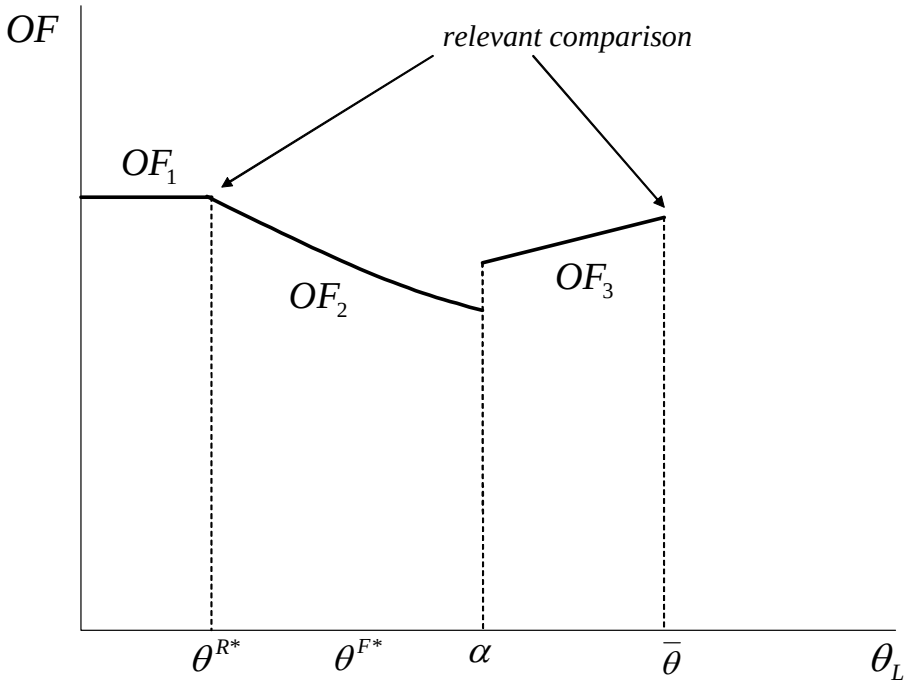

Figure 3: The OF function: low subsidies case.

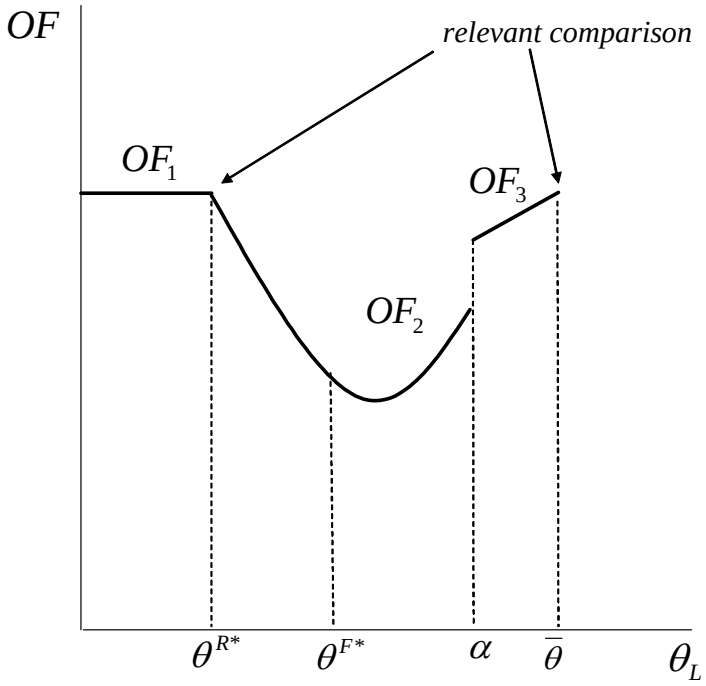

Figure 4: The OF function: high subsidies case.

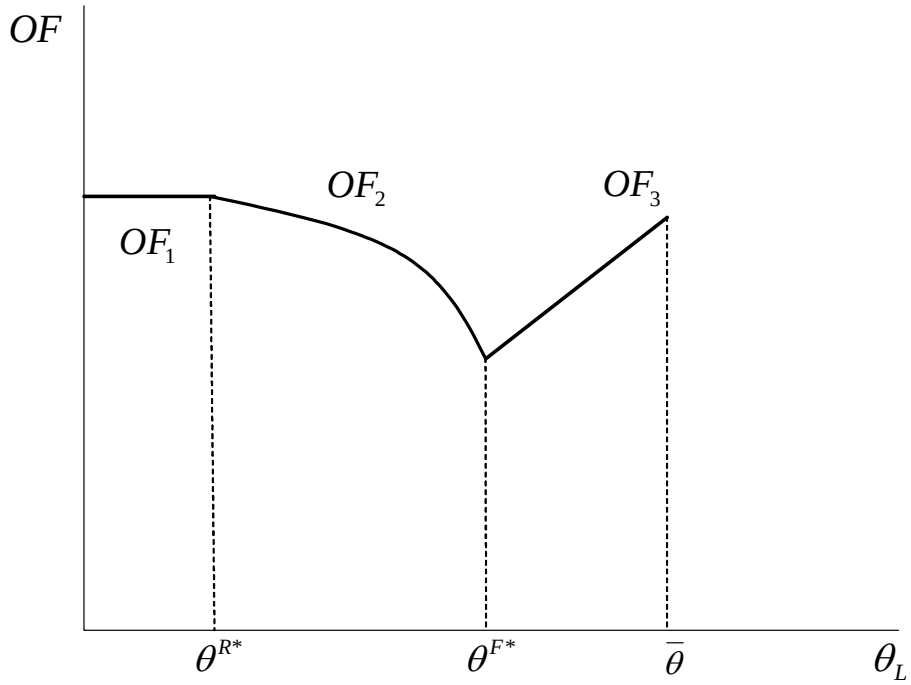

Figure 5: The OF function with price commitment: low subsidies case.

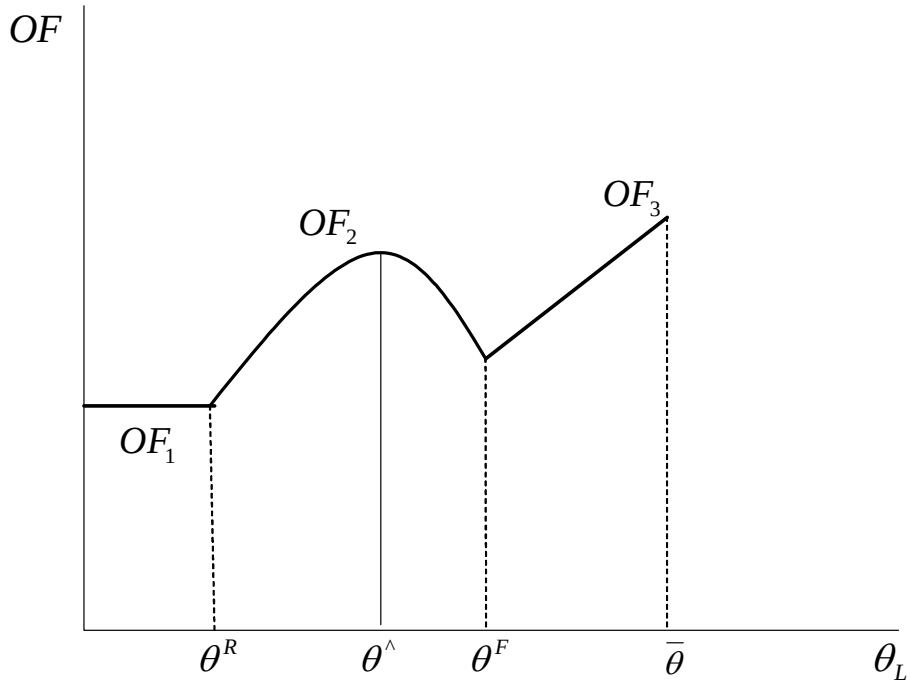

Figure 6: OF function with price commitment: high subsidies case.

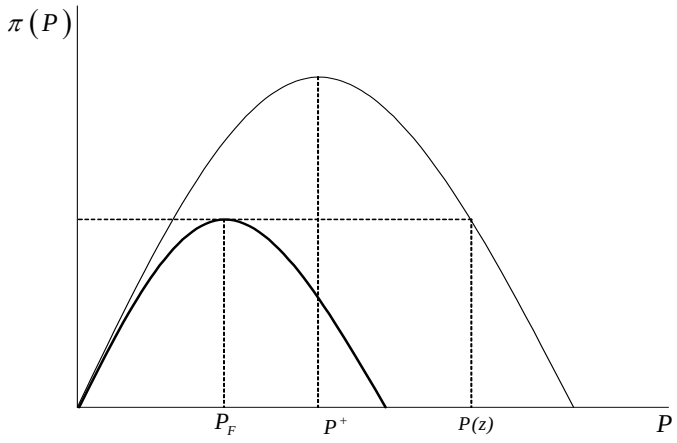

Figure 7: Listing with price commitment.

Subsidy level	Cost level	Commitment	Non commitment	Comparison
η>1/2	(a) $c > \frac{2\Delta q\bar{\theta}}{\eta+\sqrt{7\eta^2+2\eta}}$	List, θ^{R*}	List, θ^{R*}	$\pi^{PC}=\pi^{NPC}$ $OF^{PC}=OF^{NPC}$
	(b) $c < \frac{2\Delta q\bar{\theta}}{\eta+\sqrt{7\eta^2+2\eta}}$	List, θ^{R*}	Not list, θ^{F*}	$\pi^{PC}>\pi^{NPC}$ $OF^{NPC}>OF^{PC}$
η<1/2	(c) $c > \frac{2\Delta q\bar{\theta}}{\eta+\sqrt{7\eta^2+2\eta}}$	List, θ^{+}	List, θ^{R*}	$\pi^{NPC}>\pi^{PC}$ $OF^{PC}>OF^{NPC}$
	(d) $c^* < c < \frac{2\Delta q\bar{\theta}}{\eta+\sqrt{7\eta^2+2\eta}}$	List, θ^{+}	Not list, θ^{F*}	$\pi^{PC}>\pi^{NPC}$ *for* large c $OF^{PC}>OF^{NPC}$ *for* small c $OF^{NPC}>OF^{PC}$
	(e1) c<c*	List, θ^{LIM}	Not list, θ^{F*}	$\pi^{PC}>\pi^{NPC}$ $OF^{NPC}>OF^{PC}$
	(e2) c<c*	Not list, θ^{F*}	Not list, θ^{F*}	$\pi^{PC}=\pi^{NPC}$ $OF^{PC}=OF^{NPC}$

Figure 8: Table 1: Impact of price commitment on listing decision.