R&D in the Pharmaceutical Industry: A World of Small Innovations*

Juan José Ganuza† Gerard Llobet‡ Beatriz Domínguez§

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Abstract

It is commonly argued that in recent years pharmaceutical companies have directed their R&D towards small improvements of existing compounds instead of more risky drastic innovations. In this paper we show that this bias towards small innovations is likely to be linked to the lack of market sensitivity of a part of the demand to changes in prices. Compared to their social contribution, small innovations are relatively more profitable than large ones because they are targeted to inelastic segments of the demand. We also study the effect over R&D incentives of marketing strategies and regulatory instruments aimed at controlling pharmaceutical expenditure. Finally, we extend the analysis to competition in research.

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†Department of Economics, Universitat Pompeu Fabra. C/ Ramon Trias Fargas 25-27 08005 Barcelona, Spain. E-mail: juanjo.ganuza@upf.edu.

‡CEMFI. C/ Casado del Alisal 5 28014 Spain. E-mail:llobet@cemfi.es.

§BBVA.

1 Introduction

The pharmaceutical industry channels an important proportion of total research in most developed countries. In Europe, for example, it represents about 13% of total R&D. In recent years, pharmaceutical companies have been accused of devoting their resources mainly to minor improvements over existing medications that require short clinical trials and have a small risk of not being approved. This widespread concern has, for example, originated a Congressional Report by the United States Government Accountability Office (2006). This report provides evidence showing that although in the period 1993-2004 the expenditure in R&D has increased by 147%, the number of drastic innovations, denoted as Priority New Molecular Entities (Priority-NME), has remained stable. These Priority-NME's now represent 12% of all new drug Applications (NDA) submitted to the FDA (Food and Drug Administration) compared to the 60% that were mere modifications of existing compounds. Lexchin (2003) and Love (2003) provide additional evidence of this bias towards small innovations. At the same time, it has been documented that pharmaceutical companies have increased substantially their investment in the advertising and marketing of their products. According to some estimates, advertising expenditures in the U.S. multiplied by a factor of three between 1997 and 2004.[1]

In this paper, we show that the bias in the pharmaceutical industry towards small innovations might be explained by the low sensitivity of the demand. Due to the technological and regulatory characteristics of this sector, the reward that innovators obtain tends to be distorted in a systematic way with respect to the social contribution they provide. In particular, small innovations get a proportionally larger reward because pharmaceutical firms target them to the inelastic segments of the demand. As a consequence, firms find relatively more profitable to invest in small innovations.

Methylphenidate, a drug used to treat children with Attention-Deficit Hyperactivity Disorder, shows that minor modifications of existing compounds might command a large price premium. Generic versions of methylphenidate compete with the brand-name product sold by Novartis, called Ritalin. In 2000, Concerta, an extended release form of Methylphenidate, was launched. Concerta improves upon Ritalin in that children must take it only once a day,

[1]See *The Economist*, March 17th 2005. The report by the The Henry J. Kaiser Family Foundation (2003) estimates a three-fold increase in the period 1996 to 2001. Moreover, the increase in direct-to-consumer advertising has been particularly important.

instead of the three daily doses scheduled for Ritalin, being otherwise as effective as the original product. In the U.S., however, Concerta entails a monthly cost of \$130, compared with \$67 for branded Ritalin and \$31 for the generic methylphenidate.[2]

This small-innovation bias is particularly visible in two contexts. They might be the response to the entry of generic products or the result of competition with products patented by competitors. In the first case, many countries grant an extension of the legal monopoly to firms that provide improvements (albeit minor) of existing products, for which a new product patent would not be granted. In the U.S., for example, the Hatch-Waxman Act (1984) grants a patent extension of three years for "incrementally modified drugs" (IMD) and five years for "new molecular entities" (NME).[3] Moreover, in some countries modifications of existing compounds are entitled to process patents that extend the innovator's protection after the expiration of the original patent. The strategy of pursuing these modifications is usually denoted as product-line extension.[4]

In the second case, pharmaceutical firms have been accused of modifying successful products commercialized by competitors in expanding markets as a way to steal profits. These follow-on products are for this reason often denoted as *me-too* drugs. The market for statins is a case in point. Statins are cholesterol-lowering drugs that appeared in the 1990s. After Lovastatin came out, several firms introduced competing varieties of the compound like simvastatin (Zocor), atorvastatin (Lipitor), pravastatin (pravachol), fluvastatin (Lescol) or rosuvastatin (Crestor). These products are claimed to be close substitutes, and arguably, they involve a lower risk and lower investment than the development of more innovative products.[5]

We aim to understand why firms in this market tend to target their research towards these small improvements. Starting with Nordhaus (1969), existing literature on the incentives (or

[2]This cost has been computed for a typical 20mg daily dosage, using data from the Consumer Reports Best Buys Drugs report for 2005, available at `http://www.crbestbuydrugs.org/PDFs/2pager_ADHD.pdf`.

[3]See Bulow (2004) for a review of the Hatch-Waxman Act, and the effects on patent holders and potential generic producers.

[4]See Hong et al. (2005) for a study of this strategy. They consider a sample of 27 prescription drugs that lost patent protection between 1987 and 1992. They show that product-line extensions were more likely to occur for successful drugs and these extensions contributed to the price rigidity of the original product after entry of generic versions.

[5]The social value of these follow-on improvements is the subject of an active controversy (See Hollis (2005), Hollis (2004) and the references therein). Contrary to the previous view, DiMassi and Paquette (2004) argue that some of these follow-on products are the result of real innovations that arrived sequentially. We do not take a stand regarding the proportion of follow-on drugs that do not constitute genuine innovations. Our model only provides insights to explain why a bias towards small innovations may exist.

their lack) to innovate has commonly argued that to the extent that firms do not internalize all the surplus of the inventions they generate, underinvestment is likely to occur. The existence of patents is seen as a way to address this inefficiency and classical papers like Gilbert and Shapiro (1990) and Klemperer (1990) have studied the trade-offs of longer versus wider patents. Recent papers, such as Scotchmer (1999), have shown that patents are also efficient tools to relate the value of the invention to the social reward it generates. In this paper, we argue that in obtaining the optimal level of innovation an additional margin is important. As the previous examples illustrate, firms typically choose the size of the innovation they pursue, and for this reason, underinvestment (or overinvestment) will be a function of how close are the profits obtained to the social contribution *for each size of innovation* they might achieve. As a result, misallocation of resources will occur in markets where the signals originating from the demand for the good are dampened in a systematic way.

In the case of the pharmaceutical industry, the difference between the social value and the private benefits that firms obtain may arise from several sources. We emphasize two. First, the prevalence of public as well as private insurance schemes that cover a substantial proportion of the costs of prescription drugs has made the demand little sensitive to the price of the product.[6] This insurance component of the decision alters the trade-offs of patients and their doctors in the decision between products with different qualities and prices towards more expensive ones. Second, part of the marketing effort of pharmaceutical firms aims at decreasing the price sensitivity of the demand.

In our benchmark model we study the first case by assuming that patients do not pay (all) the price of their medications. However, these drugs are prescribed by doctors who are heterogeneous in how much they internalize their real cost as opposed to internalizing the preferences of their patients. This assumed heterogeneity is consistent with the differentiated doctors' prescription behavior obtained in empirical studies such as Hellerstein (1998). Similarly, Coscelli (2000) shows that doctors take into account the patient's preferences in the prescription choice.

For expositional purposes our model introduces this heterogeneity in a rather simple way. We consider two extreme kinds of doctors. Some doctors completely internalize the preferences

[6] In many countries, drug prescription coverage has increased at a substantial rate. In the United States, according to The Henry J. Kaiser Family Foundation (2007), consumer out-of pocket payments accounted for 56% of total prescription drugs expenditures in 1990, while by 2006 this proportion had decreased to around 19%. The counterpart of this decline has been the sharp increase in private and public health insurance costs.

of their patients, and we denote them as *captured* doctors. The rest of the doctors take into account the benefit as well as the total cost of the several medications and are denoted as *non-captured* doctors.[7] Pharmaceutical firms might choose between setting a high price in order to sell to the captured part of the demand or to charge a rather lower price in order to also attract the rest of the patients. For firms with small innovations, a higher price compensates for the lower level of sales, while for big improvements, targeting the whole market is optimal, since the willingness to pay of price-sensitive consumers is higher.[8]

Compared to the social optimum, the lack of price-sensitivity of the demand provides an excessive reward for small innovations and consequently it distorts the incentives of pharmaceutical firms. As a result, firms underinvest in R&D. As mentioned earlier, this result does not arise from the lack of rents from innovation but rather on how these rents are distributed across different possible improvements.

It is important to point out that the demand distortions that drive the results of this model can arise from different sources. For example, the low demand elasticity can arise from the lack of incentives of some doctors to be informed about the quality of products and their price, as discussed in Caves et al. (1991) and Danzon and Chao (2000). More important, although our basic interpretation of the model is coherent with the universal public health coverage common in Europe, in countries in which health insurance is not universally provided, heterogeneous patient insurance coverage entails different demand elasticities. In fact, Duggan and Scott-Morton (2006) provides evidence consistent with our model for the case of Medicaid that, due to its importance for this paper, we discuss in detail in the conclusion.

We also study how the lack of price-sensitivity of the demand might be reinforced by the firm's behavior. The marketing effort is a leading example of this behavior. While marketing can be used to inform consumers of the existence and properties of an existing drug, it is often used to decrease the demand's price elasticity. This goal is achieved by affecting doctors'

[7]Along similar lines Frank and Salkever (1992) propose a model where the demand for a patented product is divided into two segments depending on whether they are sensitive to the price of the generic product or not. Papers such as Bhattacharya and Vogt (2003) assume instead a reduced-form continuous demand function. We later argue that similar results could be obtained under more general demand specifications.

[8]This strategic tradeoff is not unique of our setup. It also appears, for example, in the study of the phenomenon of price dispersion, often explained using the so-called tourist-native model introduced by Salop and Stiglitz (1977). This seminal paper assumes that there are informed and uninformed consumers, giving raise to differentiated strategies. In the competitive equilibrium, some firms choose to sell at a high price only to uninformed consumers (tourists), while others sell at a lower price to both informed consumers (natives) as well as to some lucky tourists.

prescription choice through promotional gifts, sponsoring agreements or affecting directly the patients' perception through direct-to-consumer marketing.[9] In this last case, doctors might believe that the prescription of a heavily advertised branded product instead of a generic one affects the patient's perception of the quality of the treatment.

We allow firms to choose between informative or persuasive marketing as a complementary strategy to their R&D investments. Our results show that firms will endogenously choose to make the demand inelastic to the quality of the product when this quality is low by investing in persuasive marketing, whereas informative market will be optimal for high quality innovations. Once firms account for this differentiated strategy, they endogenously reduce their pursuit of large innovations and instead rely more on persuasive marketing.

Abundant regulations are in place in most countries to address the excessive market power of pharmaceutical firms and reduce the ensuing medical expenditures. Although they were not intended to modify the incentives of firms to innovate, they have clear effects. As an example, we discuss the likely consequences on innovation of three commonly used instruments: *price ceilings*, *reference prices*, and *copayments*.[10] We focus our analysis on the last one and we distinguish between proportional copayments (patients pay a fixed share of the price of the medication) and fixed ones (patients pay a fixed amount regardless of the final price of the product).

Pharmaceutical firms often argue that this kind of demand regulations, to the extent that they reduce the profits from innovation, lead to a lower level of research. The lesson from our study is that these instruments may give raise to an opposing force. By affecting the demand elasticity, their introduction may also provide more incentives to undertake research.

Finally, we generalize the benchmark model to the case of competition in innovation among pharmaceutical firms. We devise an environment in which under competition the first best can be achieved if the demand is perfectly sensitive to the price. Captured doctors have in this case an ambiguous effect on the level of innovation due to two opposing forces. On the one hand,

[9]King (2002) provides evidence of the effectiveness of marketing efforts in reducing doctors' price sensitivity and reports significant demand elasticities with respect to marketing expenditures. Manchanda and Chintagunta (2004) documents the important impact of the interaction between doctors and pharmaceutical-firms salesforce (also known as detailing) and promotional gifts on drug prescription choice.

[10]These price controls often co-exist. For example, in Germany, patients typically pay 10 % of the price with a minimum of 5 euros and a maximum of 10 euros. They also cover the excess price difference using reference pricing.

a less sensitive demand provides more incentives for each firm to obtain an improvement that outperforms the innovation that the rival achieves. On the other, contingent on outperforming the rival, the demand becomes very little sensitive to further improvements. We show by means of example that the second force is likely to dominate when the risk of the R&D process is large, leading to underinvestment.

The paper proceeds as follows. The next section introduces the benchmark model. Section 3 discusses the effects of each of the instruments. In section 4 we study the firm's marketing decision. Section 5 analyzes the scenario with competition and section 6 concludes.

2 The Model

Consider a market where a number of firms is producing an existing good. We normalize its quality to 0. One of the firms, firm i, can invest in increasing its quality by performing R&D. Firm i makes effort θ to obtain a good of random quality v in the interval $[0, 1]$. The quality of the good originates from the distribution $F(v, \theta)$ with density $f(v, \theta)$. We assume that the distribution F is ordered in the first-order stochastic sense, so that more effort increases the probability of obtaining a good of high quality; if $\theta' > \theta$ then $F(v, \theta') < F(v, \theta)$ for all v. The cost of performing effort θ is also denoted as θ.[11]

We assume that the marginal cost of production of all goods is normalized to 0. As a result of competition, the original good has an equilibrium price of 0, while firm i sets a positive price p for its improved good.

The demand side of the market corresponds to a unit mass of patients with a completely inelastic demand for a single unit of the good. Each patient derives utility $U(v) = v$. Initially, we assume that patients do not pay directly for the good, and the cost is incurred instead by an insurance company. For analytical simplicity we further assume that regulation sets a price ceiling, which is limited to 1.[12]

Patients do not choose directly the good they consume. Instead, the demand for the good is determined by the doctors' prescription choice. We assume there are two kinds of doctors. A proportion σ are denoted as *captured* doctors (C), that prescribe the good with the highest

[11] By redefining the density function f, any cost function $C(\theta)$ would lead to the same results in as long as C is increasing in θ.

[12] We refer the reader to *Appendix A* for an example in which this assumption is relaxed.

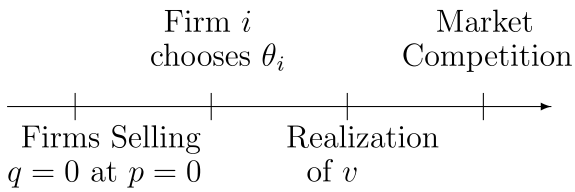

Figure 1: Timing of the Game.

quality regardless of its price. The remaining proportion $1 - \sigma$ of *non-captured* doctors (NC) assign the medication according to a cost-efficiency analysis. Captured doctors' preferences can be represented by a utility function

$$U_C(v) = U(v) = v,$$

which can be interpreted as collusion between doctors and their patients. Non-captured doctors take into account the valuation as well as the price of the good according to the utility function

$$U_{NC}(v, p) = v - p,$$

so that they choose as if patients themselves had to pay the price of the medication. In other words, they consider the total cost and benefit for the patient as well as the insurer.

The timing of the game is described in *Figure 1* and explained next. In the first stage, firm i chooses effort θ. In the second stage the quality v is realized and market competition leads to equilibrium prices and allocation of the goods.

2.1 The First Best

From a social point of view, the optimal allocation of the goods can be easily derived. Given that the marginal cost of production is 0 and all patients are alike, they ought to consume the good with quality v. Hence, the social value that an innovation of size v generates is precisely $S(v) = v$, which means that the optimal level of effort can be defined as,

$$\theta^S \in \arg\max_{\theta \geq 0} \int_0^1 v f(v, \theta) dv - \theta.$$

To avoid trivial results, we focus on the case in which the socially optimal level of investment is positive, $\theta^s > 0$.

2.2 The Market Equilibrium

In the private solution, the price p that firm i sets in the second stage and the ensuing profits affect the firm's innovative effort. In spite of the assumption that patients do not pay for the drug, the demand of firm i will still depend on the price because some doctors are price sensitive when choosing their prescriptions. These doctors only choose the drug sold by firm i when it provides net value $v - p$ larger than what the homogeneous product would provide, 0.

Hence, for a given quality v, firm i might essentially maximize profits by choosing two different prices depending on whether only the captured doctors prescribe the drug or all doctors prescribe it. For the first, the maximum price allowed, $p = 1$ is optimal, resulting in sales of σ. For the second, the optimal price is defined as $p = v$ so that all doctors prescribe the drug and sales are equal to 1. By comparing the profits from both options we can derive the following lemma.

Lemma 1 *For high quality improvements, $v \geq \sigma$ the optimal price is $p = v$ so that firm i sells to all patients. Otherwise, the optimal price is $p = 1$ and a proportion σ of patients buys the improved product.*

Interestingly, while this model naturally predicts that larger innovations are associated with higher profits, they do not necessarily lead to a higher price for the good.

In the first stage, the effort decision of firm i depends on the profits obtained from the sale of the good. In particular, because profits from a small and a large improvement correspond to σ and v respectively, the privately optimal effort decision of firm i can be characterized by the expression

$$\theta^*(\sigma) \in \arg\max_{\theta} \int_0^{\sigma} \sigma f(v,\theta)dv + \int_{\sigma}^{1} vf(v,\theta)dv - \theta.$$

Notice that for $\sigma = 0$ the private choice of effort coincides with the first best, since the innovator captures all the surplus generated from the production of the good and $\theta^* = \theta^S$. However, for larger values of σ distortions will in general arise. In particular, a higher proportion of captured doctors implies that the profits of firm i for a larger range of low realizations of v are higher than the social value they generate. This is so, because the improvement generates a social value of v, yet the firm obtains profits $\sigma > v$. As *Figure 2* shows, this distortion reduces the incentives to

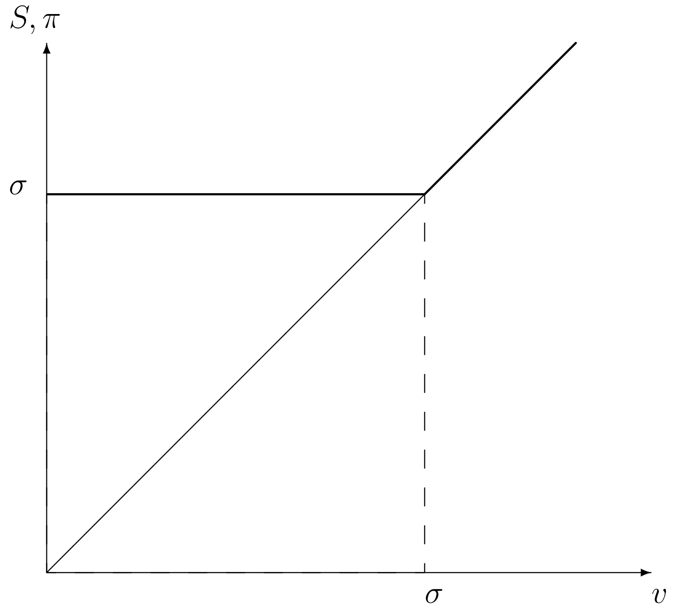

Figure 2: As in the following figures, for different realizations of v, the thin diagonal denotes social value S while profits corresponds to the thick line.

exert innovative effort because low realizations of v are to some extent *insured* by the inelastic preferences of captured doctors. We summarize these result in the next proposition.[13]

Proposition 1 *The privately optimal choice of effort is lower than the first best for all $\sigma > 0$. Moreover, the level of effort $\theta^*(\sigma)$ is decreasing in σ.*

Notice that, contrary to other models of innovation, lower values of σ are associated with lower expected profits from innovation yet they foster investment. In the next section we further study this effect and we argue that it is not specific of the two-tier demand function we assume.

2.3 The Reason for Underinvestment

The study of the incentives to innovate that market institutions generate have been a preeminent question in the literature, where the underinvestment result is rather typical. Firms do not internalize all the social return that their innovation generates, and hence some worthwhile investments are passed up. This idea leads to the common belief that regulations aimed

[13]Throughout this paper when we will refer to functions that are weakly increasing (weakly decreasing) simply as increasing (decreasing). In this sense, all comparative statics results in the paper are stated in the weak form. Given the regularity of the problem, imposing additional differentiability assumptions are enough to make the underinvesment results strong using the results in Edlin and Shannon (1998).

to increase competition and reduce firm rents may have a negative impact over incentives to undertake research.[14]

The simplest model that exhibits this last feature can be described as follows. Firms invest in a fixed-sized project that has a social value v, yet they only appropriate a proportion $\gamma < 1$, so that their profits are $\pi = \gamma v$. In that case, underinvestment can occur if the cost of innovation, K, is such that $v \geq K > \gamma v$.

The underinvestment in our model arises from a completely different source. In the previous section, we showed that incentives to invest are not as much related to the size of the reward but to the wedge in the rewards that firms obtain from innovations of different sizes. We illustrated this intuition in a very stylized model. For example, it had a two-tier demand structure and a price ceiling. The next proposition establishes a sufficient condition for underinvestment for a more generic market competition stage in which a firm with innovation of size v obtains profits $\pi(v)$.

Proposition 2 *If the profit function $\pi(v)$ is continuous and $\pi'(v) \leq 1$, then $\theta^* \leq \theta^S$.*

In our model $\pi(v) = \max\{\sigma, v\}$, satisfying these requirements. This proposition makes transparent the idea that the driving force of our results is not the magnitude of the rents but how these rents depend on the social contribution of the innovation. In fact, in our model firms appropriate a higher surplus than the social contribution their innovation generates. In the terminology of the previous simple example, our setup implicitly assumes $\gamma > 1$.[15] Of course, for the reasons stated earlier, the underinvestment result would be reinforced if firms could not extract all the surplus from their innovation. In this sense, we can interpret our model as the least favorable situation for underinvesment to occur.

The requirements in the previous proposition could be consistent with a variety of models. In fact, in section 4 we depart from the two-tier demand structure to show that marketing expenditures may result in a profit function that meets these requirements. More generally, these conditions on profits are likely to be satisfied whenever the tradeoff between the size of the innovation and the willingness to pay is more distorted for modest innovations, in spite of

[14] Another strand of the literature, related to patent races, shows that when firms compete to become the monopolist producer of an innovation, overinvesment can occur as firms do not internalize the decrease in profits that their own investment generates on competitors.

[15] Only in the case with $\sigma = 0$ (no captured doctors), we obtain both an optimal level of investment and private profits as large as the social benefit generated.

the source of this distortion. Hence, this proposition shows that our intuitions may carry out to more comprehensive demand descriptions, for which the multiple sources of heterogeneity, such as the ones outlined in the introduction, could be factored in.

3 How Market Regulation affects R&D

In the previous section we have studied the R&D decision of firms under a distorted demand resulting from the captured doctors' decisions. Insurance companies and public health agencies react to the resulting inelasticity of the demand by introducing complex regulatory schemes aimed at aligning their own goals and the doctors' and patient incentives in order to limit the expenditure on pharmaceutical products. Some regulation schemes alter patients' choices by, for example, setting reference prices for branded products when generic ones exist or by establishing copayment mechanisms. Other schemes are aimed at changing directly the doctors' behavior. For example, doctors' prescriptions might be subject to a limited budget. Finally, some other mechanisms operate directly in the supply side by, for example, setting price ceilings, often as the result of negotiation with pharmaceutical companies.[16]

In this section we provide an overview of the likely effects of the main regulatory instruments over the firms' incentives to engage in R&D. To the extent that regulation is local but firms innovate for a global market the analysis we present does not have normative content. It does not intent to characterize the optimal policy but rather to outline the impact of these instruments. We show that their purpose of reducing pharmaceutical expenditure might also be consistent with the goal of aligning the social contribution that the innovation generates and the private profits that firms appropriate. Hence, contrary to what it is commonly claimed, regulations that reduce firm rents might, at the same time, induce more research.

The three classical instruments we analyze are price ceilings, copayments and reference prices. Although each instrument has different consequences, our analysis conveys the message that regulations that increase the elasticity of the demand have in general a positive effect on innovation. Hence, contrary to what it is commonly claimed, regulations that reduce their rents might still induce more research.

[16]See Danzon and Keuffel (2004) and Hassett (2004) for an extensive discussion of these and other instruments.

3.1 The Price Ceiling

In the benchmark case, we have normalized the maximum price that the firm can charge (the price ceiling) to 1. Part of the distortions we have identified originate from the excessive rents that this price ceiling provides to the firm. An obvious remark, therefore, is that if the regulator has full information about the value of the innovation, a price ceiling of v trivially implements the first best. However, under imperfect information one may wonder whether decreases in the price ceiling have positive effects on the investment of firm i. As we now show the results are in general ambiguous.

Given a price ceiling $\tilde{p}$, the characterization of the optimal price of firm i is similar to the benchmark case. Only two prices might maximize profits for the firm. If the firm targets only captured doctors, it chooses a price $\tilde{p}$ that yields profits $\pi = \sigma\tilde{p}$. When the firm targets all patients/doctors, a price of v is chosen as long as $v < \tilde{p}$ and $p = \tilde{p}$ otherwise. Profits correspond to $\pi = p$. The next lemma summarizes these results.

Lemma 2 *The profit maximizing price corresponds to*

$$p = \begin{cases} \tilde{p} & \textit{if } v \geq \tilde{p}, \\ v & \textit{if } \sigma\tilde{p} < v < \tilde{p}, \\ \tilde{p} & \textit{if } v \leq \sigma\tilde{p}. \end{cases}$$

Figure 3 shows that the price ceiling does not only apply to small innovations but also has effects on large innovations, the price of which is bounded by $\tilde{p}$. This additional distortion has important effects on the investment choice of firm i, θ^*_{PC}. In particular, the optimal investment level corresponds to

$$\theta^*_{PC} \in \arg\max_{\theta} \int_0^{\sigma\tilde{p}} \sigma\tilde{p} f(v,\theta)dv + \int_{\sigma\tilde{p}}^{\tilde{p}} v f(v,\theta)dv + \int_{\tilde{p}}^{1} \tilde{p} f(v,\theta)dv - \theta. \tag{1}$$

As opposed to the other instruments we consider next, the effect of a reduction in the price ceiling is in general ambiguous. A lower price ceiling reduces the excessive rents of the firm when low realizations of v occur, enticing it to increase the investment level. But to the extent that a lower price ceiling also reduces the reward when a large innovation is achieved, an opposing force arises. Hence, the direction of the results in general depends on the functional assumptions on the distribution of innovations F.

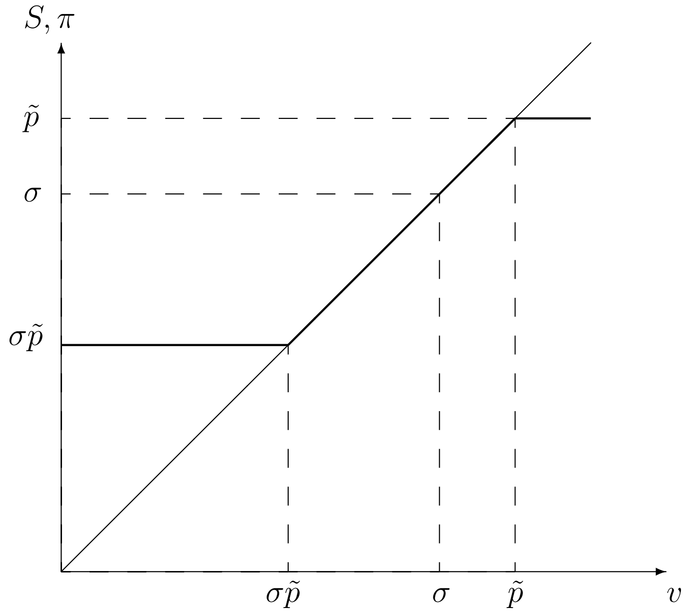

Figure 3: Profits given a reference price $\tilde{p}$.

An important implication of the previous remarks is that the first best cannot in general be achieved. A crucial difference between this instrument and copayments or reference prices is that with a price ceiling the patient is still completely subsidized. The other mechanisms operate, instead, by changing the demand elasticity. Given that the reward of the firm can only be aligned with its social contribution through the price sensitiveness of the demand, the message in this section is that efficiency is difficult to attain under full subsidization.

3.2 Copayments

Copayments are a common instrument to regulate the expenses of public health agencies and private insurance companies. These copayments assign to the patient a share of the price of the medication. However, they take different forms in Europe and in the U.S. Whereas in Europe they often correspond to a fixed percentage of the final price of the drug, private insurance companies in the U.S. usually implement copayments that consist of a fixed amount regardless of the final price.[17] In this section, we analyze both kinds of copayments. We show that, although they operate in slightly different ways, by reducing excessive rents from small

[17] Typically, insurance companies divide medications in three tiers: Generic, Preferred Branded and Non-preferred Branded drugs. Their average copayment for 2006 was, according to The Henry J. Kaiser Family Foundation (2007), \$11, \$24, and \$38 respectively. These copayments may have significant effects. Ridley (2004) estimates a demand elasticity to changes in copayment of around 0.9.

improvements they both entice larger innovations.

We start with a copayment corresponding to a fixed percentage $\alpha < 1$ of the cost of the prescriptions. The remaining part of the payment is assumed to be paid by the insurer. Thus, patients' preferences are now price-sensitive and can be described according to

$$U(v, \alpha, p) = v - \alpha p.$$

We model doctors' preferences in the same spirit as in the previous section. In particular, we still assume that non-captured doctors, concerned with the cost-efficiency of each medication, do not change their utility function. Captured doctors, interested only in the utility of their patients, have their same preferences $U_C(v, \alpha, p) = U(v, \alpha, p)$.

The equilibrium outcome results in prices similar to the ones studied in the previous section. Firm i can focus on either the proportion σ of captured doctors that are now price-sensitive and will pay a maximum price of $\min\{\frac{v}{\alpha}, 1\}$ or cover the whole market and let the elastic part of the demand function determine the price. In this latter case, the price cannot exceed the value of the improvement, v, that the product generates. Hence, firm i targets the inelastic segment of the demand, whenever $\sigma \min\{\frac{v}{\alpha}, 1\}$ is larger than v, or in other words, when the ratio between the proportion of captured doctors and the copayment is large enough. The next lemma characterizes the prices and profits for firm i.

Lemma 3 *We can distinguish two cases: (i) If $\alpha \leq \sigma$, the equilibrium price is*

$$p = \begin{cases} v & \text{if } v \geq \sigma, \\ 1 & \text{if } \alpha < v < \sigma, \\ \frac{v}{\alpha} & \text{if } v \leq \alpha. \end{cases}$$

(ii) If $\alpha > \sigma$ then $p = v$.

Profits are $\pi = v$ when $p = v$ and the whole market is covered, and $\pi = \sigma p$ otherwise.

We now turn to the R&D decision of firm i. Denote as $\theta^*_{CO}(\sigma, \alpha)$ the investment of the firm when the copayment is set to α. In case (ii) of the previous lemma it is clear that since the firm equates the price with the value of the innovation, the incentives of the firm are correctly aligned with the social benefit generated. Hence, no distortion arises and the first-best investment level is achieved, $\theta^*_{CO}(\sigma, \alpha) = \theta^S$.

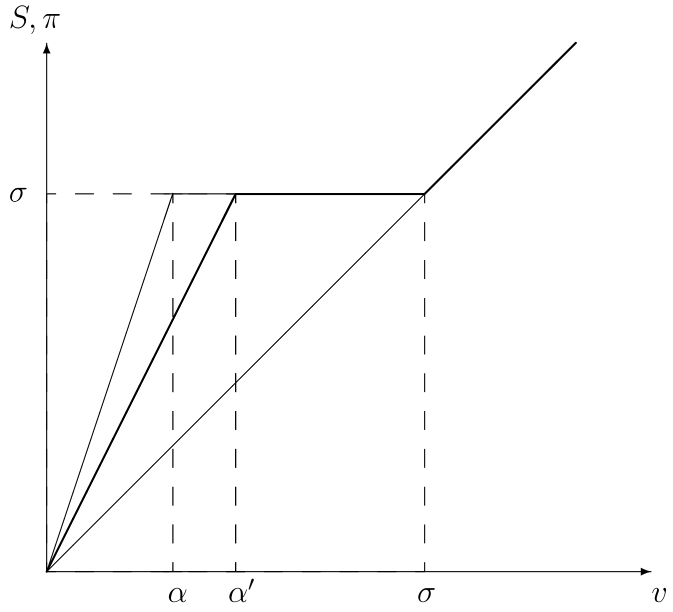

Figure 4: Profits for two levels of proportional copayment $\alpha < \alpha' < \sigma$.

In case (i) the level of innovation corresponds to the solution to

$$\theta^*_{CO}(\sigma, \alpha) \in \arg\max_{\theta} \int_0^{\alpha} \sigma \frac{v}{\alpha} f(v, \theta) dv + \int_{\alpha}^{\sigma} \sigma f(v, \theta) dv + \int_{\sigma}^{1} v f(v, \theta) dv - \theta.$$

As *Figure 4* illustrates, for low values of v the private profits from the innovation still exceed the social value they generate. However, because patients internalize part of the cost, a positive α means a more elastic demand and a reduction of the rents from small innovations. This intuition gives rise to the following proposition:

Proposition 3 *For $\alpha \geq \sigma$, $\theta_{CO}(\sigma, \alpha) = \theta^S$. Otherwise, $\theta^*(\sigma) \leq \theta^*_{CO}(\sigma, \alpha)$.*

The previous result does not imply that a higher copayment necessarily generates more incentives to invest in R&D. In fact, the comparative statics are in general ambiguous. To see it, consider an increase in the copayment from α to α' as depicted in *Figure 4*. Such an increase has two differentiated effects. It decreases the marginal return to innovations with $v < \alpha$ but it increases the marginal return of innovations with quality between α and α'. If a realization of v in the first range is relatively more likely than in the second, a higher copayment might reduce the incentives to invest.

Notice, also, that we can provide a different interpretation to the parameter α introduced in this section. As we have already mentioned, another common mechanism used to limit drug expenditure is the establishment of budgets on doctor prescriptions. It is easy to see that the existence of such a budget implies a shadow price that a doctor needs to consider when willing to increase the expenditure on a particular patient. If we interpret this shadow price as α, the results obtained in this section can be applied. In particular, we could conclude that the existence of binding budgets might imply a welfare improvement but tighter ones might not necessarily induce more innovation.

We finally consider the case of fixed-amount copayments where the insurer, instead of fixing a proportional copayment $\alpha \in [0,1]$, leaves uncovered a fixed-amount $\delta > 0$. We assume that the patient pays this copayment as long as the price exceeds δ, and otherwise he will pay the total price of the drug. Hence, a patient derives utility from consumption according to

$$U(v, c, p) = v - \min\{\delta, p\}.$$

As before, captured doctors internalize their patients' preferences, so that $U_c(v, \delta, p) = U(v, \delta, p)$. The next lemma points out an important difference between the case of fixed-amount copayments and proportional ones. With fixed-amount copayments, selling to the inelastic part of the demand function is only feasible to the extent that v is sufficiently high. No consumer will incur in a copayment δ larger than the value of the product he purchases. For intermediate size improvements, however, selling to the inelastic part of the demand function is still optimal, while for sufficiently large v the efficient solution is also profit maximizing. The shape of the profit function is pictured in *Figure 5.*

Lemma 4 *We can distinguish two cases: (i) If $\delta \leq \sigma$, the equilibrium price is*

$$p = \begin{cases} v & \text{if } v \geq \sigma, \\ 1 & \text{if } \delta < v < \sigma, \\ v & \text{if } v \leq \delta. \end{cases}$$

(ii) If $\delta > \sigma$ then $p = v$.

Profits are $\pi = v$ when $p = v$ and the whole market is covered, and $\pi = \sigma$ otherwise.

In case (i) the level of innovation results from the following expression

$$\theta^*_{FCO}(\sigma, \delta) \in \arg\max_{\theta} \int_0^{\delta} v f(v, \theta) dv + \int_{\delta}^{\sigma} \sigma f(v, \theta) dv + \int_{\sigma}^{1} v f(v, \theta) dv - \theta.$$

The level of investment is higher than in the benchmark case with no copayment.

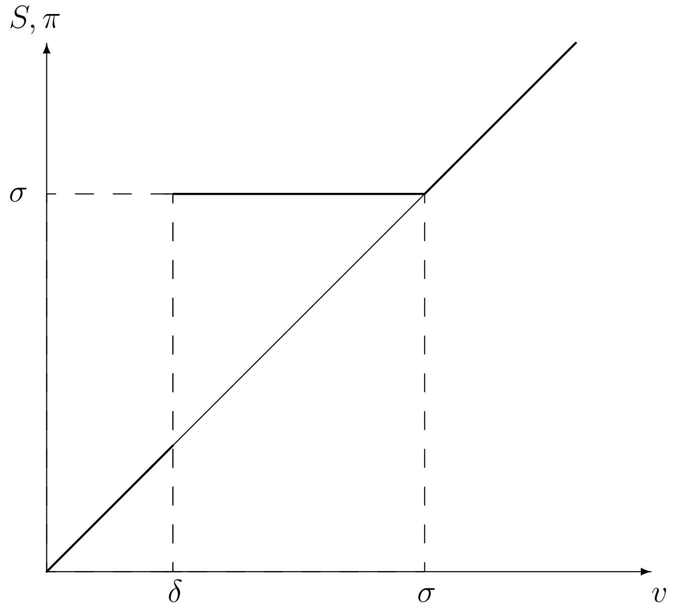

Figure 5: Profits for a fixed-amount copayment $c < \sigma$.

Proposition 4 *For $\delta \geq \sigma$, $\theta_{FCO}(\sigma, \delta) = \theta^S$. Otherwise, $\theta^*(\sigma) \leq \theta^*_{FCO}(\sigma, \delta)$.*

A conclusion of this section is that the introduction of any of the two kinds of copayments, in spite of their different structure, results in more incentives to innovate, by affecting the resulting elasticity of the demand. This intuition carries through to the next subsection.

3.3 Reference Prices

A reference price is another instrument to regulate pharmaceutical expenditures. It corresponds to a maximum price that the insurer refunds the patient for the prescription. If the price exceeds this reference price, the difference between the actual price and the reference price is borne by the patient. Let $\bar{p}$ be the reference price. Given a price p, the utility of the patient can be written as

$$U(v, p, \bar{p}) = \begin{cases} v & \text{if } p \leq \bar{p}, \\ v - (p - \bar{p}) & \text{if } p > \bar{p}. \end{cases}$$

Similarly to the previous cases, preferences of non-captured doctors are unchanged, while captured doctors adopt again the preferences of their patients.

As usual, firm i needs to choose whether to only sell to the captured part of the demand or to all patients. In the first situation, the price is set according to the minimum of the price ceiling 1 and the maximum willingness to pay of the patients (of captured doctors), $v + \bar{p}$. In order to

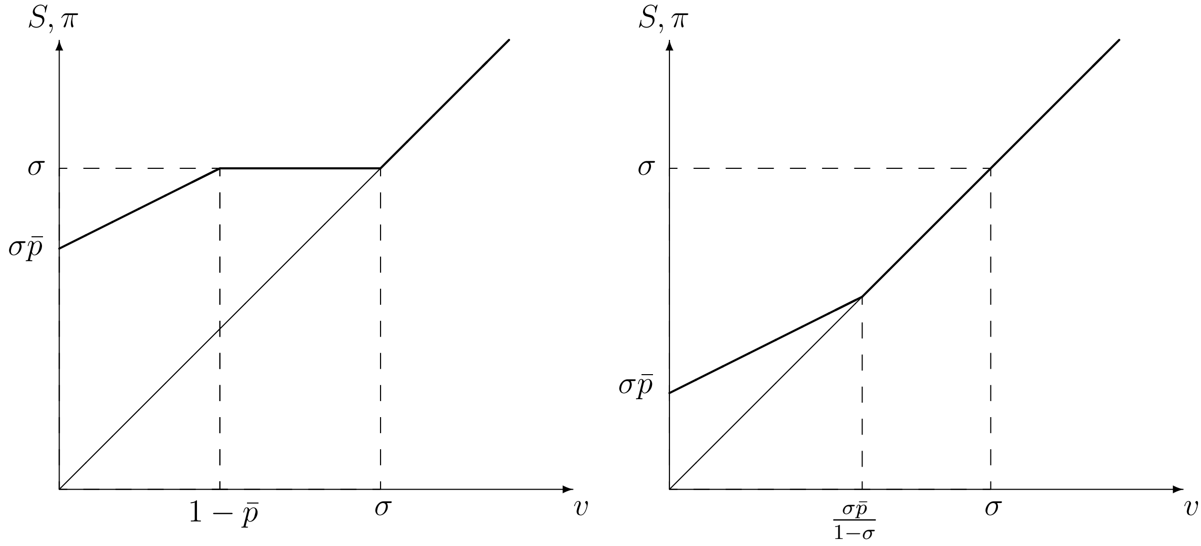

Figure 6: Profits with a reference price when (i) $\bar{p} \geq 1-\sigma$ and (ii) $\bar{p} < 1-\sigma$.

sell to all patients, firm i optimally sets $p = v$. Profits in the first case are $\sigma \min\{v+\bar{p}, 1\}$ while in the second, profits are equal to v. Hence, larger σ and $\bar{p}$ make the equilibrium where the firm serves only a part of the market more likely. The next lemma characterizes the equilibrium prices and profits.

Lemma 5 *We can distinguish two cases: (i) If $\bar{p} \geq 1-\sigma$, the equilibrium price is*

$$p = \begin{cases} v & \textit{if } v \geq \sigma, \\ 1 & \textit{if } 1-\bar{p} \leq v < \sigma, \\ v+\bar{p} & v < 1-\bar{p}. \end{cases}$$

(ii) If $\bar{p} < 1-\sigma$ the price is

$$p = \begin{cases} v & \textit{if } v \geq \frac{\sigma\bar{p}}{1-\sigma}, \\ v+\bar{p} & \textit{if } v < \frac{\sigma\bar{p}}{1-\sigma}. \end{cases}$$

Profits are $\pi = v$ when $p = v$ and the whole market is covered, and otherwise $\pi = \sigma p$.

Regarding the R&D decision of firm i, we denote as $\theta^*_{RP}(\sigma, \bar{p})$ the level of investment. *Figure 6(i)* and *6(ii)* illustrate the profits of the firm for different realizations of v in each of the two scenarios mentioned in the lemma. For case (i), the optimal investment of the firm corresponds to the solution to

$$\theta^*_{RP}(\sigma, \bar{p}) \in \arg\max_{\theta} \int_0^{1-\bar{p}} \sigma\left(v+\bar{p}\right) f(v,\theta)dv + \int_{1-\bar{p}}^{\sigma} \sigma f(v,\theta)dv + \int_{\sigma}^{1} v f(v,\theta)dv - \theta. \qquad (2)$$

In case (ii) the optimal investment is obtained as

$$\theta^*_{RP}(\sigma, \bar{p}) \in \arg\max_{\theta} \int_0^{\frac{\sigma\bar{p}}{(1-\sigma)}} \sigma\left(v + \bar{p}\right) f(v, \theta) dv + \int_{\frac{\sigma\bar{p}}{(1-\sigma)}}^{1} v f(v, \theta) dv - \theta. \quad (3)$$

From *Lemma 5*, a higher reference price leads to higher optimal prices (and profits) for low realizations of v, since $\bar{p}$ is only relevant for the captured doctors. In fact, the comparison of both cases shows that in case (i) profits for firm i are larger for low realizations of v. These excessive returns for low values of v reduce more the incentives to invest in case (i) in comparison with case (ii). Furthermore, this intuition can be generalized to any value of the reference price, so that the higher is $\bar{p}$ the lower is θ^*_{RP}.

Proposition 5 $\theta^*_{RP}(\sigma, \bar{p}) \leq \theta^S$ *is decreasing in* $\bar{p}$.

As expected, when $\bar{p}$ goes to 0, equation (3) converges to the planner's problem and the first best is thus achieved. Similarly, when $\bar{p}$ converges to 1, equation (2) converges to our benchmark case.

We have therefore shown that the reference price is an effective tool to align the incentives of the firm and the society. However, because the optimal investment level is only achieved when $\bar{p} = 0$, no inefficiency is linked to the lack of insurance to patients. This extreme result is opposed to the characterization of the copayment scheme, for which efficiency can be obtained even with a modest level of subsidization $1 - \alpha$. These two different results arise from the way each mechanism affects the demand elasticity of the captured doctors. While in the case of the reference price, decreases in $\bar{p}$ represent a constant shift in the price of the firm for low realizations of v, increases in the copayment decrease the slope of the profit profile.

4 R&D and Marketing

In the previous sections we have argued that the demand function for pharmaceutical products is inefficiently inelastic. We have related this distortion in preferences to underinvestment in R&D by pharmaceutical companies. We have shown that this lack of elasticity might be exogenous to the firm's behaviour and arise from sources related, for example, to doctors' preferences or the proportion of the population covered by insurance schemes. However, pharmaceutical companies might also affect the demand elasticity with their choice of marketing (or advertising) strategies. In fact, nowadays, marketing expenditures and R&D constitute a similar proportion of a firm's expenditures. Moreover, and particularly in the U.S., direct-to-consumer marketing (even of products that require medical prescription) represents now more than one fourth of these expenditures.

In this section, we extend our benchmark model to show that marketing expenditures might give raise to the distorted demand that we have postulated. In particular, by using different marketing strategies, pharmaceutical firms might either choose to capture a segment or target a wider demand. For illustration purposes, in the following analysis we abstract from the existence of captured doctors due to exogenous preferences, and we only allow for the possibility that differences in doctor behavior are due to the firm's marketing efforts.

Suppose that initially doctors are unaware of the quality or even the existence of the product. The firm has access to two kinds of marketing messages: *informative* and *persuasive.* Informative messages elicit the real value of the product v to a doctor. Utility becomes

$$U_I = v - p.$$

Persuasive messages transmit a noisy estimation of the value of this product. This estimation may be biased upwards in response, for example, to branding efforts, consumer pressure from direct-marketing campaigns targeted to them, sponsoring agreements or promotional gifts. We model this utility using the following reduced form

$$U_P(s) = v + s - p,$$

where the term s is heterogeneous among doctors and it is drawn from a distribution $H(s)$ with density $h(s)$.

In order to further simplify the analysis we make the complementary assumptions that informative messages have a cost normalized to 0 and all doctors receive one of the two messages. Hence, the marketing strategy of the firm can be summarized by the proportion of doctors that receive persuasive messages and that with some abuse of notation we denote as σ. We refer to the cost of sending persuasive messages to a proportion of doctors σ as $C(\sigma)$ with $C(0) = 0$ and $C' > 0$.

To accommodate the marketing choice, the benchmark model is enhanced with an intermediate stage. After v is known the firm chooses σ, consumers discover their valuation for the new product and market competition takes place. The timeline is described in Figure 7.

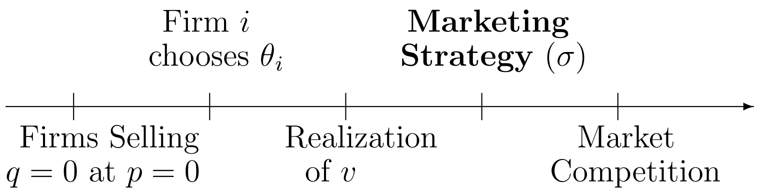

Figure 7: Timing of the model with marketing.

For a given v, the firm decides jointly his marketing and pricing strategy. We can characterize these decisions along two possibilities: they can target only some persuaded doctors and choose a price $p > v$ or appeal also to informed doctors that required a price $p \leq v$.

Regarding the first possibility, the firm's expected profits can be obtained from the following expression

$$\Pi_P(v) = \max_{p>v,\sigma} \; p\sigma(1 - H(p - v)) - C(\sigma). \tag{4}$$

If instead the chosen price is $p \leq v$ profits are

$$\Pi_I(v) = \max_{p\leq v,\sigma} \; p\left[\sigma(1 - H(p - v)) + (1 - \sigma)\right] - C(\sigma). \tag{5}$$

The next lemma characterizes the payoff of the firm under the optimal strategy in each of the scenarios.

Lemma 6 *(i) When the firm sells only to persuaded consumers, under the optimal policy* $(\sigma^*(v), p^*(v))$, $\Pi_P'(v) \in [0, 1)$. *(ii) When the firm also targets informed consumers the optimal policy involves* $\sigma^*(v) = 0$, $p^*(v) = v$ *and* $\Pi_I(v) = v$.

The intuition for this lemma is straightforward. In the first case, profits grow with v at a rate less than 1 for two reasons. First, because firms sell only to a proportion of persuaded doctors (as opposed to the whole market) and, second, because the value of the product for the doctor is only partially related to the value of the good. In the second case, when selling to the informed doctors, the firm does not benefit from the additional valuation of the persuaded doctors with $s > 0$ while it gives up the possibility of selling to those doctors with $s < 0$. As a result, persuasive marketing will not pay off.

Depending on the assumptions on H three possibilities may arise. If $\Pi_P(0) = 0$ persuasive marketing is always dominated by informative marketing. If $\Pi_P(1) > 1$ persuasive marketing

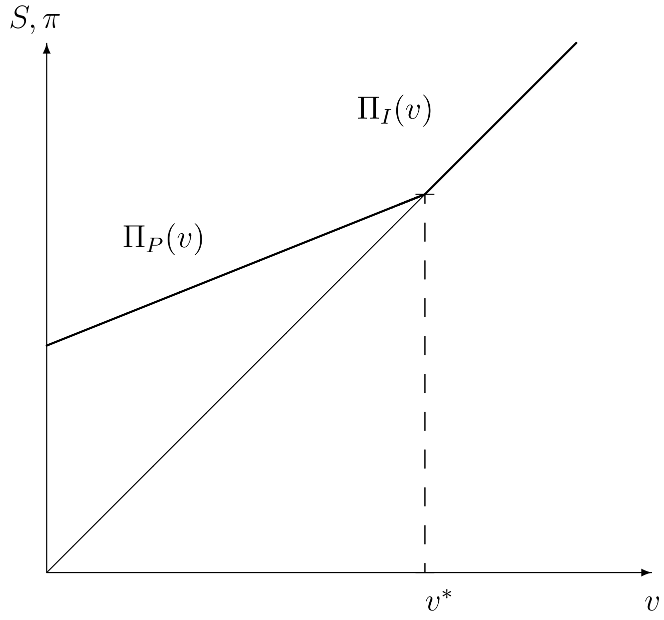

Figure 8: The effect of persuasive marketing.

is always superior. Finally, there exists and interior case characterized by $v^* = \Pi_P(v^*)$ where persuasive marketing is only used for innovations $v < v^*$. Hence,

$$\pi_M(v) = \begin{cases} \Pi_P(v) & \text{if } v < v^*, \\ \Pi_I(v) & \text{if } v \geq v^*. \end{cases}$$

This last case is pictured in *Figure 8.* Notice however that the linearity of $\Pi_P(v)$ is only used for illustration purposes and it is not a general feature of the solution.

An immediate application of Proposition 2 implies that underinvestment occurs whenever persuasive marketing is optimal for the firm for some values of v.[18]

Proposition 6 *If* $\Pi_P(0) > 0$*, the R&D effort chosen by the firm, that solves*

$$\theta^M \in \arg\max \int_0^1 \pi_M(v) f(v, \theta) d\theta - \theta,$$

is lower than θ^S.

This result allows us to conclude that from the point of view of the firm R&D and marketing may be, to some extent, substitutive strategies. Moreover, this result suggests that imposing some constraints over the marketing strategies of pharmaceutical firms such as the introduction of Codes of Best Practices may foster innovation.

[18]The comparison with the First Best obtained in the previous sections, relies on the assumption that persuasive advertising does not generate additional social value. This is a natural assumption when the difference in behavior between informed and persuaded doctors is due to the imperfect information of persuaded doctors or if their additional rents originate from transfers by pharmaceutical companies.

5 Competition in R&D

We now return to the benchmark model of section 2 and study the effects of captured doctors in the context of competition. As we have shown, in the case of a single monopolist, the existence of captured doctors decreases the demand elasticity, especially for small innovations, and results in a reduction in the innovative effort of the firm. Under oligopoly, we will show that the result is in general unclear, since firms will also try to be the one with the leading improvement. It is also important to emphasize that in the environment we consider next, the typical distortions associated to patent races characterized for example in Loury (1979) do not arise and, absent the captured doctors, the first best would be achieved with the decentralized choice of firms' effort.

In particular, suppose that starting from the situation where a good of quality 0 is produced competitively, two firms $i = 1, 2$ can obtain an improvement. Both firms share the same technology, which implies that the quality of their improvements originates from the same distribution $f(v, \theta)$, and incur the same cost of investment θ. Furthermore, we assume that the outcome of their innovations is independent.

The first best is easy to characterize. Given that all patients are identical and that the marginal cost of production is identical for all goods, if firm 1 and 2 obtain an improvement v_1 and v_2 respectively, the social optimum implies that only the good with the highest quality is produced and consumed by all agents. Therefore, the social welfare problem can be written as follows,

$$\max_{\theta_1, \theta_2} \int_0^1 \left\{ \int_0^{v_2} v_2 f(v_1, \theta_1) dv_1 + \int_{v_2}^1 v_1 f(v_1, \theta_1) dv_1 \right\} f(v_2, \theta_2) dv_2 - \theta_1 - \theta_2. \tag{6}$$

The particular form of the function $f(v, \theta)$ will determine whether the solution is symmetric or not. In particular, if $f(v, \theta)$ exhibits increasing returns to scale the solution is likely to involve different investment intensities by both firms, or even result in the corner case where only one firm invests. If, instead, $f(v, \theta)$ exhibits decreasing returns to scale and this property leads to a globally concave problem, the solution will imply equal symmetric investments.[19] Our analysis is carried out under the assumption that equal investments are optimal, and hence,

[19]The characteristics of the solution also depend on the assumption regarding the correlation between realizations of v. We have assumed that these realizations were independent, and so there is no duplication of effort. Had we assumed that their were positively correlated, the solution would most likely call for different investments.

social welfare is maximized by choosing $\theta_1^s = \theta_2^s = \theta^s$.

In the competitive solution, absent the captured doctors, if firm 1 and 2 charge prices p_1 and p_2 respectively, doctors prefer good 1 to good 2 only if

$$v_1 - p_1 \geq v_2 - p_2.$$

Again, since all firms have a marginal cost of production of 0, standard arguments related to Bertrand competition lead to the outcome that if, for example, $v_1 > v_2$, then $p_1 = v_1 - v_2$ and $p_2 = 0$. Profits would result in $\pi_1 = v_1 - v_2$ and $\pi_2 = 0$.

In the first stage, firm 1 and 2 choose their investment simultaneously. Firm 1, given θ_2, chooses the level of investment that maximizes,

$$\max_{\theta_1} \int_0^1 \left\{ \int_{v_2}^1 (v_1 - v_2) f(v_1, \theta_1) dv_1 \right\} f(v_2, \theta_2) dv_2 - \theta_1, \tag{7}$$

which results in a reaction function $\theta_1(\theta_2)$. The equilibria of the game are denoted as (θ_1^*, θ_2^*). The next lemma, shows that the investment chosen privately by firms coincides with the first best.

Lemma 7 *When $\sigma = 0$, in the symmetric equilibrium of the game $\theta_1^* = \theta_2^* = \theta^s$.*

As this lemma shows, when there are no demand distortions, i.e. $\sigma = 0$, competition between both firms does not generate any inefficiency in this environment. This result is due to the fact that each firm appropriates only of the surplus it generates. In other words, each firm implicitly internalizes in its research effort the negative marginal effect it has on the profits accrued by the competitor. *Figure 9(i)* makes this argument clear by comparing the social contribution of a firm with its private profits. This is the reason why, compared to the usual case of patent races where the winner-takes-all prevails, we do not obtain overinvestment. Hence, as in the monopoly case, the first best is achieved when there are no captured doctors.

This equivalence result does not hold, in general, for other values of σ. To see it, consider the other extreme case, characterized by $\sigma = 1$. There, in the competitive solution it would still be the case that the firm with the highest quality sells the good prescribed by the captured doctors. The price is limited by the regulated ceiling, $p_i = 1$. The other firm does not sell. Hence, the effort choice of firm 1 solves

$$\max_{\theta_1} \int_0^1 \int_{v_2}^1 f(v_1, \theta_1) dv_1 f(v_2, \theta_2) dv_2 - \theta_1 = \max_{\theta_1} \int_0^1 (1 - F(v_2, \theta_1)) f(v_2, \theta_2) dv_2 - \theta_1. \tag{8}$$

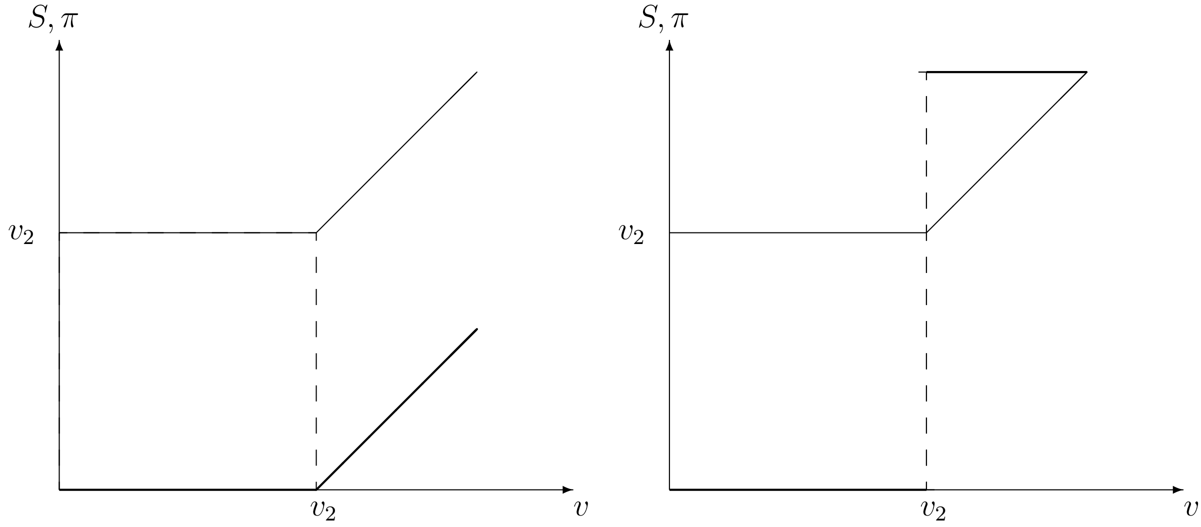

Figure 9: Profits of firm 1 and social welfare generated as a function of v_1 for a given value of v_2 when (i) $\sigma = 0$ and when (ii) $\sigma = 1$.

The comparison with the first-best case (and the situation with $\sigma = 0$) is in general unclear. As *Figure 9(ii)* illustrates, with a larger σ each firm has more incentives to reach an innovation larger than the competitor's one. However, provided that a firm achieves an innovation larger than the competitor's, the marginal return from a larger improvement is lower than its social contribution. To illustrate these two forces we now discuss a simple example.

5.1 An Example

Let's assume that $f(v, \theta)$ is such that there are two possible realizations of v, denoted $\underline{v}$ and $\bar{v}$. We parameterize these realizations as $\underline{v} = \frac{1}{2} - x$ and $\bar{v} = \frac{1}{2} + x$, where $0 \leq x \leq \frac{1}{2}$ is a measure of the risk of the innovative process. Given an investment level θ_i, the probability of obtaining the high realization is $\theta_i^{\frac{1}{2}}$.

We start by solving the first best using the discrete analog of equation (6) as

$$\max_{\theta_1, \theta_2} \theta_1^{\frac{1}{2}} \theta_2^{\frac{1}{2}} \bar{v} + \theta_1^{\frac{1}{2}} (1 - \theta_2^{\frac{1}{2}}) \bar{v} + (1 - \theta_1^{\frac{1}{2}}) \theta_2^{\frac{1}{2}} \bar{v} + (1 - \theta_1^{\frac{1}{2}})(1 - \theta_2^{\frac{1}{2}}) \underline{v} - \theta_1 - \theta_2.$$

Hence, only when both firms obtain a low realization of v, the good with value $\underline{v}$ is consumed. The unique solution to this problem implies

$$\theta_1^s = \theta_2^s = \theta^s = \left(\frac{\bar{v} - \underline{v}}{2 + \bar{v} - \underline{v}} \right)^2 = \left(\frac{x}{1 + x} \right)^2.$$

For $\sigma = 0$ the maximization problem of firm 1 can be written as

$$\max_{\theta_1} \; \theta_1^{\frac{1}{2}}(1-\theta_2^{\frac{1}{2}})(\bar{v}-\underline{v}) - \theta_1.$$

As stated in *Lemma 7*, the Nash Equilibrium of the game also implements the first best.

However, when $\sigma = 1$, the payoffs of each of the firms are as follows. When both firms obtain the same improvement, both charge a price equal to 1 and share profits equally, so that each obtains $\frac{1}{2}$.[20] When a firm obtains an improvement $\bar{v}$ and the competitor $\underline{v}$ profits are 1. Hence, the problem of the firm can be written as

$$\max_{\theta_1} \; \theta_1^{\frac{1}{2}}\theta_2^{\frac{1}{2}}\frac{1}{2} + \theta_1^{\frac{1}{2}}(1-\theta_2^{\frac{1}{2}}) + (1-\theta_1^{\frac{1}{2}})(1-\theta_2^{\frac{1}{2}})\frac{1}{2} - \theta_1,$$

and in equilibrium $\theta_1^* = \theta_2^* = \frac{1}{16}$.

Comparing the market equilibrium with the first best we observe that when $x < \frac{1}{3}$ the competitive equilibrium yields excessive innovation while the opposite is true for $x > \frac{1}{3}$. The intuition for the result is as follows. When x is very small, the productivity of effort is small. However, the profits from obtaining the large innovation exceed the social welfare generated, leading to overinvestment. An opposing force arises from the lack of sensitivity of profits to increases in the social value of the high realization. For this reason, when x is large the first best would require more investment, yet the equilibrium investment is unchanged because the private return from innovation is independent of x.

This example summarizes how the results described in the previous section change once competition is introduced. We have designed the model to avoid distortions in R&D related to effects other than the presence of captured doctors, as *Lemma 7* clearly states. However, once captured doctors are considered, innovators' profits do not only depend on their contribution beyond what the competitor has achieved, which is related to the social contribution, but there is a premium for outperforming the competitor. In our example, if $\sigma = 1$ and x is close to 0, only the second effect matters and the model becomes a winner-takes-all game. This structure yields effects similar to those of a patent race.

[20] Given that doctors are not sensitive to price reductions, other equilibria can arise. However, for the purposes of this example other symmetric equilibria have identical implications.

6 Concluding Remarks

This paper presents a stylized model of innovation that emphasizes the distortions induced by the different layers of incentives in the relationship between patients, doctors and pharmaceutical companies. We have exemplified these distortions in the differentiated behavior of some doctors depending on whether they perform an efficient cost-benefit analysis of each product or if, instead, they internalize the preferences of their patients. The ensuing lack of elasticity could also arise in other contexts such as in the presence of only a proportion of insured patients, or it can be related to the behavior of pharmaceutical companies, most notably through their marketing choice.

Regardless of whether this low elasticity originates from the doctor capture by patients or pharmaceutical firms, public or private insurance schemes or it is just due to the lack of information of some doctors, the general message of this paper remain unchanged. The level of research that firms undertake depends not only on the total rents from innovation, but also – once we take into account that the level of innovation is endogenous – on the rewards that the firm obtains for any size of innovation it might achieve. In this sector, a low demand elasticity entails a price premium that generates a bias towards small innovations. As result, regulations aimed at reducing the agency problem between doctors and insurers might, to the extent that they do not affect their decision to invest in the first place, move firms away from the pursue of small innovations.

Finally, this paper provides interesting testable implications. We outline two. First, the model predicts that higher prices and smaller innovations will be more prevalent in markets in which the inelastic segments of the demand are more significant. Second, the use of persuasive marketing (by means of, for example, direct-to-consumer advertising) should be more prevalent for small innovations and it might crowd out R&D investment.

A recent paper, Duggan and Scott-Morton (2006), provides evidence supporting the first of these empirical implications. Using data from the top 200 prescription drugs in the U.S. for 1997 and 2002, the paper studies the effect that the Medicaid market share – which covers around 50 million people, and includes among other things the cost of prescriptions – had on the final price of the product. The results show that drugs that apply to diseases that are more prevalent in patients covered by Medicaid have higher prices. Moreover, the regulation generates distortions in the product development decisions. The reason is that the initial price that Medicaid pays is based on the average price of this product in the market but, over time, the price increases only according to inflation. As a result, firms that sell successful products and are willing to increase the price to Medicaid, respond by releasing minor variations of their products (for example, changes in dosage) that are regarded as new drugs.

A Heterogeneity in the Doctors' Capture

We now extend the benchmark model to allow for heterogeneity in the degree of doctor's capture. As we will see, this heterogeneity allows us to dispense with the assumption that the price is constrained to be below 1, yet the results will remain essentially unchanged.[21] We still assume that the proportion $1-\sigma$ of non-captured doctors that perform the cost-benefit analysis is homogeneous. However, captured doctors are heterogeneous in a parameter s that is distributed uniformly between 0 and 1, and their utility corresponds to

$$U_C(v) = v + s - p.$$

Hence, doctors do not share the same preferences than their patients, and instead they overestimate the effect that the new product has on them. This additional value s can be rationalized, for example, as the increase in the quality perception derived from advertising. The resulting demand function for firm i can be described as

$$D(p) = \begin{cases} 1 & \text{if } p \leq v \\ \sigma(v+1-p) & \text{if } v < p \leq 1+v, \\ 0 & \text{otherwise} \end{cases}$$

As before, firm i might choose between selling to all consumers or only to the non-sensitive part of the demand. While for the earlier, the optimal price still corresponds to $p = v$, for the latter, the optimal price maximizes

$$\max_p \sigma(1+v-p)p$$

which results in $p^* = \frac{1+v}{2}$. Compared to the benchmark model, the relevant price and the quantity sold when firm i targets the inelastic part of the demand are strictly increasing in v. Comparing profits in both cases, we obtain the following result.

Lemma 8 *The optimal price for firm i corresponds to*

$$p^* = \begin{cases} v & \text{if } v \geq v^*(\sigma), \\ \frac{1+v}{2} & \text{otherwise,} \end{cases}$$

where $v^*(\sigma) = \frac{2}{\sigma}\left(1-\sqrt{1-\sigma}\right) - 1$ is increasing in σ. Profits can be written as

$$\pi(v) = \begin{cases} v & \text{if } v \geq v^*(\sigma), \\ \sigma\left(\frac{1+v}{2}\right)^2 & \text{otherwise,} \end{cases}$$

with $\pi'(v) < 1$ when $v < v^*(\sigma)$.

[21] Since the need for this price limit is due to the fact that captured doctors induce a completely inelastic demand, we could alternatively assume that doctors have a positive yet lower than optimal price elasticity.

Proof. Immediate from the arguments in the text and Proposition 2. ■

Notice that similarly to the benchmark model, for low values of v, profits for firm i are higher than the surplus generated. Moreover, profits in this range rise with increases in v less than the social welfare generated. Proposition 2 guarantees that underinvesment will occur in this case.

B Proofs

B.1 Preliminary Result and Notation

We will make repeated use of the following very well-known result, which we state as a lemma: if $X \geq_{st} Y$ then for all increasing functions ψ, $E[\psi(X)] \geq E[\psi(Y)]$.

Lemma 9 *Let X and Y be real-valued random variables with cumulative distribution functions F and G respectively, such that $F(z) \leq G(z)$ for all $z \in \mathbf{R}$. For all bounded real-valued increasing functions $\psi : \mathbf{R} \to \mathbf{R}$,*

$$\int_{\mathbf{R}} \psi(z)\mathrm{d}F(z) \geq \int_{\mathbf{R}} \psi(z)\mathrm{d}G(z).$$

B.2 Proofs of the Results

Proof of Lemma 1: Immediate from the arguments in the main text.

Proof of Proposition 1: The firm's profit function is

$$\pi(\sigma, \theta) = \int_0^\sigma \sigma f(v, \theta) dv + \int_\sigma^1 v f(v, \theta) dv - \theta.$$

Using the results of Milgron and Shannon (1994) it is enough to show, that $\pi(\sigma, \theta)$ has decreasing differences. Since

$$\frac{\partial \pi(\sigma, \theta)}{\partial \sigma} = \int_0^\sigma f(v, \theta) dv = F(\sigma, \theta)$$

and from our assumptions on F, $\frac{\partial \pi(\sigma,\theta)}{\partial \sigma}$ is decreasing in θ, which concludes the proof.

Proof of Proposition 2:

The optimal investment of firm i satisfies in this case

$$\theta^* \in \arg\max_\theta \int_0^1 \pi(v) f(v, \theta) dv - \theta.$$

So, let's consider the following problem. Given a parameter $\gamma \in [0,1]$, denote as H the following function

$$H(\theta,\gamma) \equiv \int_0^1 \left(\gamma\pi(v) + (1-\gamma)v\right) f(v,\theta)dv - \theta,$$

and define $\theta(\gamma)$ as

$$\theta(\gamma) \in \arg\max_{\theta} H(\theta,\gamma).$$

Notice that $\theta(\gamma)$ is decreasing in γ if $H(\theta,\gamma)$ has decreasing differences in θ and γ. Taking the derivative of H with respect to γ and integrating by parts, we obtain

$$\frac{\partial H}{\partial \gamma} = \pi(1) - 1 - \int_0^1 \left(\pi'(v) - 1\right) F(v,\theta)dv,$$

and differentiating with respect to θ,

$$\frac{\partial H}{\partial \gamma \partial \theta} = -\int_0^1 \left(\pi'(v) - 1\right) \frac{\partial F}{\partial \theta}(v,\theta)dv$$

which is negative if $\pi'(v) < 1$.

Proof of Lemma 2: Immediate from the arguments in the main text.

Proof of Lemma 3: Immediate from the arguments in the main text.

Proof of Proposition 3: Part (i) is immediate because the problem of the firm coincides with the social-planer problem when $\alpha > \sigma$. For part (ii), we compute

$$\pi(\sigma,\alpha,\theta) - \pi(\sigma,0,\theta) = \int_0^{\alpha} \sigma\left[\frac{v}{\alpha} - 1\right] f(v,\theta)dv = \int_0^1 H_{\alpha}(v) f(v,\theta)dv,$$

with

$$H_{\alpha}(v) = \begin{cases} 0 & \text{if } v \geq \alpha, \\ \sigma\left[\frac{v}{\alpha} - 1\right] & \text{if } v < \alpha, \end{cases}$$

weakly increasing in v. Hence, using Lemma 9 we obtain that $\pi(\sigma,\alpha,\theta) - \pi(\sigma,0,\theta)$ is increasing in θ. Finally, the results of Milgron and Shannon (1994) and the fact that $\pi(\sigma,\alpha,\theta) - \pi(\sigma,0,\theta)$ has increasing differences imply $\theta^*(\sigma) \leq \theta^*_{CO}(\sigma,\alpha)$.

Proof of Lemma 4: We need to distinguish two cases, depending on whether δ is greater or smaller than σ. Suppose $\delta \leq \sigma$. If $v \leq \delta$, captured doctors only buy the product if $p \leq v$, and hence the optimal strategy is to choose $p = v$ and sell to all patients. If $v \in (\delta,\sigma)$, selling to captured doctors entails utility $v - \delta > 0$ regardless of $p > \delta$, and so, the optimal price to that segment is $p = 1$, with profits $\pi = \sigma$. This is strategy is optimal as long as $v < \sigma$, because selling to all the market leads to profits $\pi = v$.

If $\delta > \sigma$ the intermediate range in the previous argument is empty and $p = v$ for all v, with profits $\pi = v$.

PROOF OF PROPOSITION 4: Similary to Proposition 3, part (i) is immediate because the problem of the firm coincides with the social planer problem when $\delta > \sigma$. For part (ii), we compute

$$\pi(\sigma,\delta,\theta) - \pi(\sigma,0,\theta) = \int_0^\delta [v-\sigma] f(v,\theta)dv = \int_0^1 H_\delta(v) f(v,\theta)dv,$$

with

$$H_\delta(v) = \begin{cases} 0 & \text{if } v \geq \delta, \\ v-\sigma & \text{if } v < \delta, \end{cases}$$

weakly increasing in v. Hence, using Lemma 9 we obtain that $\pi(\sigma,\delta,\theta) - \pi(\sigma,0,\theta)$ is increasing in θ. Finally, the results of Milgron and Shannon (1994) and the fact that $\pi(\sigma,\delta,\theta) - \pi(\sigma,0,\theta)$ has increasing differences imply $\theta^*(\sigma) \leq \theta^*_{FCO}(\sigma,\alpha)$.

PROOF OF LEMMA 5: Immediate from the arguments in the main text.

PROOF OF PROPOSITION 5: Two cases need to be analyzed. When (i) $\bar{p}' > \bar{p} \geq 1-\sigma$, then

$$\pi(\sigma,\bar{p},\theta) - \pi(\sigma,\bar{p}',\theta) = \int_0^{1-\bar{p}'} \sigma\left(\bar{p}-\bar{p}'\right) f(v,\theta)dv + \int_{1-\bar{p}'}^{1-\bar{p}} \sigma\left(v+\bar{p}-1\right) f(v,\theta)dv \tag{9}$$

Notice that, by Lemma 9, $\pi(\sigma,\bar{p},\theta) - \pi(\sigma,\bar{p}',\theta)$ is increasing in θ given that the function

$$H(v) = \begin{cases} 0 & v > 1-\bar{p}, \\ \sigma\left(v+\bar{p}-1\right) & \text{if } 1-\bar{p}' \leq v < 1-\bar{p}, \\ \sigma\left(\bar{p}-\bar{p}\right) & \text{if } v < 1-\bar{p}', \end{cases}$$

is weakly increasing in v.

Similarly, if $\bar{p}' < \bar{p} < 1-\sigma$.

$$\pi(\sigma,\bar{p},\theta) - \pi(\sigma,\bar{p}',\theta) = \int_0^{\frac{\sigma\bar{p}}{1-\sigma}} \sigma\left(\bar{p}-\bar{p}'\right) f(v,\theta)dv + \int_{\frac{\sigma\bar{p}}{1-\sigma}}^{\frac{\sigma\bar{p}'}{1-\sigma}} \left(v-\sigma\left(v+\bar{p}'\right)\right) f(v,\theta)dv \tag{10}$$

Where again, by Lemma 9 $\pi(\sigma,\bar{p},\theta) - \pi(\sigma,\bar{p}',\theta)$ is increasing in θ due to the fact that the function

$$H(v) = \begin{cases} 0 & v > \frac{\sigma\bar{p}'}{1-\sigma}, \\ v-\sigma\left(v+\bar{p}'\right) & \text{if } \frac{\sigma\bar{p}}{1-\sigma} \leq v < \frac{\sigma\bar{p}'}{1-\sigma}, \\ \sigma\left(\bar{p}-\bar{p}'\right) & \text{if } v < \frac{\sigma\bar{p}}{1-\sigma}. \end{cases}$$

is weakly increasing. The results of Milgron and Shannon (1994) and the fact that $\pi(\sigma, \bar{p}, \theta) - \pi(\sigma, \bar{p}', \theta)$ is increasing in θ imply that $\theta^*_{RP}(\sigma, \bar{p})$ is decreasing in $\bar{p}$. Finally, given that $\theta^*_{RP}(\sigma, 1) = \theta^S$ since when $\bar{p} = 1$ the firm's and social planner's problem coincide, we can conclude that $\theta^*_{RP}(\sigma, \bar{p}) \leq \theta^S$ for all $\bar{p}$.

Proof of Lemma 6: Regarding (i), from equation (4) the first order condition for p corresponds to

$$(1 - H(p^* - v)) - p^* h(p^* - v) = 0,$$

and using the Envelope theorem it is immediate that

$$\Pi'_P(v) = \sigma^*(v) p^* h(p^* - v) = \sigma^*(v)(1 - H(p^* - v)) < 1$$

which is also positive. With respect to (ii) notice that for all v the expression in (5) is decreasing in σ, resulting in an optimal $\sigma^* = 0$. Evaluated at the optimal σ profits are increasing in p resulting in $p^*(v) = v$ and hence $\Pi_I(v) = v$.

Proof of Proposition 6: Immediate from Proposition 2.

Proof of Lemma 7: The social planer problem

$$\max_{\theta_1, \theta_2} \int_0^1 \left\{ \int_0^{v_2} v_2 f(v_1, \theta_1) dv_1 + \int_{v_2}^1 v_1 f(v_1, \theta_1) dv_1 \right\} f(v_2, \theta_2) dv_2 - \theta_1 - \theta_2 \tag{11}$$

By adding and subtracting $\int_{v_2}^1 v_2 f(v_1, \theta_1) dv_1$, we obtain

$$\max_{\theta_1, \theta_2} \int_0^1 \left\{ v_2 + \int_{v_2}^1 (v_1 - v_2) f(v_1, \theta_1) dv_1 \right\} f(v_2, \theta_2) dv_2 - \theta_1 - \theta_2 \tag{12}$$

If we compare this problem with the problem of the firm,

$$\max_{\theta_1} \int_0^1 \left\{ \int_{v_2}^1 (v_1 - v_2) f(v_1, \theta_1) dv_1 \right\} f(v_2, \theta_2) dv_2 - \theta_1, \tag{13}$$

we observe that the first order conditions over θ_1 must coincide in both problems for a given θ_2. We can do the same with respect to θ_2, obtaining the same conclusion. This concludes the proof.

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