Pharmaceutical Patents: Incentives for R&D or Marketing?[*]

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November 1, 2005

Abstract

We analyse how a patent-holding pharmaceutical firm may strategically use advertising of existing drugs to affect R&D investments in new (differentiated) drugs, and thereby affect the probability distribution of future market structures in the industry. Within a fairly general model framework, we derive exact conditions for advertising and R&D being substitute strategies for the incumbent firm and show that it may overinvest in advertising to reduce the incentive for an entrant to invest in R&D, thereby reducing the probability of a new product on the market. In a more specific setting of informative advertising, we show that such overinvestment incentives are always present, and that more generous patent protection implies that a larger share of the patent rent is spent on marketing, relative to R&D.

Keywords: Marketing; Research & Development; Pharmaceuticals

JEL Classification: I11; L13; O31

1 Introduction

A patent protects the patent-holder from firms copying its product. In other words, patents restrict entry of homogeneous (identical) products for a given period, and thus provide the holder with some market power. It is important to notice, though, that patents seldom lead to a complete monopolisation of a market. In most cases, a patent just implies that competing products must be sufficiently differentiated. Markets with patented products are thus typically characterised as oligopolistic markets with differentiated products.

The rationale behind patents is to stimulate firms to undertake R&D investments to discover new products by granting some degree of market power and thus returns on the investments. A generous patent system is likely to stimulate innovation strongly. However, there may be a flip-side of the coin. A generous patent system may also induce patent-holding firms to exhibit market power in a potentially detrimental way. In particular, patents may provide incentives for patent-holding firms not only to spend resources on R&D to obtain new patents, but also to spend resources on marketing to protect existing patents, thereby reducing the probability of increased future competition. This is the basic idea that we explore in the present paper. In a model framework designed to fit the pharmaceutical industry, we analyse in detail how a patent-holding pharmaceutical firm may strategically use advertising ex ante to affect the R&D investments in new drugs, and thereby affect the probability distribution of future market structures.

Some simple stylised facts suggest that the problems addressed in this paper are potentially highly relevant for the pharmaceutical industry. In this industry patents of chemical compounds play a crucial role in terms of stimulating developments of new drugs. Consequently, the pharmaceutical industry is very R&D-intensive. However, this industry is also one of the most advertising-intensive industries (Scherer and Ross, 1990). Marketing expenditures typically amount to 20-40 percent of sales revenues, often exceeding R&D expenditures. According to Schweitzer (1997) the marketing expenses for three of the largest US pharmaceutical companies – Merck, Pfizer, and Eli Lilly – ranged from 21 to

40% of annual sales revenues, while the R&D expenses varied between 11 and 15%.[1] The importance of non-price strategies in the pharmaceutical market may be explained by the fact that most countries exert some sort of price control either directly by regulating the prices or indirectly via the reimbursement system. In addition, the demand for pharmaceuticals is highly price inelastic, mainly due to health insurance and/or physicians' ignorance of price in the prescription choice.

To analyse the interaction between pharmaceutical advertising and R&D, we consider a therapeutic market with potentially two horizontally differentiated products. We assume that one of the products – the 'breakthrough' drug – has already been developed, and is advertised and sold by an incumbent monopolist. The second product may or may not be discovered, depending on the amount of R&D investments incurred. In the R&D race there are two competitors: the incumbent monopolist and a potential entrant. Thus, there are potentially three different ex post market structures: (i) single-product monopoly if neither firm discovers the second product; (ii) multi-product monopoly if the incumbent wins the R&D race; and (iii) a duopoly if the entrant wins the R&D race. In line with the specific features of pharmaceutical markets, we focus exclusively on non-price strategies, where the firms face exogenous (regulated) drug prices and use advertising to induce demand.[2] The key mechanism in the relationship between advertising and R&D incentives is the incumbent's ability to influence ex post payoffs of the potential entrant through ex ante advertising of the existing product.[3] The model is analysed both within a general framework and in a standard informative advertising application.

We focus on innovations of competing products (non-drastic innovations), and not on innovations of completely new products (drastic innovations). In the pharmaceutical industry a patent is granted for a drug's novel chemical composition rather than its

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[1] Similar figures are reported from Novartis and Aventis, the largest pharmaceutical companies in Europe. See also Zweifel and Breyer (1997) for figures for Germany and Switzerland.

[2] Although this assumption is most appropriate in pharmaceutical markets, where demand is highly price-inelastic and drug prices are subject to price regulation in most countries, there are several papers on patents with a more general applicability that abstract from pricing strategies, see, e.g., Needham (1976), Waterson (1990) and Langinier (2004).

[3] This mechanism was observed by Needham (1976), who argued that an incumbent's pre-entry advertising influences the entry decision only if there is some link between pre-entry advertising and the entrant's post-entry expected profits.

therapeutic properties. Many new pharmaceuticals receive patents despite their being functionally similar to existing drugs. As such, their introduction expands physicians' choices and can pose a competitive threat to established drugs with the same or similar indications. Lu and Comanor (1998) find that all but 13 of 148 new branded chemical entities introduced in the US between 1978-87 had at least one fairly close substitute; the average number of substitutes being 1.86. Scherer (2000) reports that the number of drugs per symptom group ranged from 1 to 50, with a median of 5 drugs and a mean of 6.04. Thus, empirical evidence clearly demonstrates the importance of non-drastic product innovations.

Within a fairly general framework, we show that advertising and R&D are *substitute strategies* for the incumbent firm – implying that more advertising will, all else equal, induce the incumbent to spend less on R&D – if the following two conditions are met, in equilibrium: (i) the second-order cross derivatives of demand with respect to advertising expenditures are negative (implying that advertising expenditures are strategic substitutes), and (ii) the second-order cross derivatives of the innovation success functions are sufficiently small in absolute terms. Under these general conditions, we show that the incumbent has an incentive to *strategically overinvest* in advertising in order to negatively affect R&D investments and thereby protect its existing patent rent. Applying the general framework within a standard informative advertising model, as introduced by Butters (1977), we show that such overinvestment incentives are always present, and we also demonstrate that a generous patent system (equivalently, generous drug prices) tends to stimulate marketing incentives, relative to R&D incentives.

Finally, we extend the informative advertising example to discuss some welfare and policy implications. In particular, we analyse welfare effects of a stricter regulation on advertising and a more generous patent system.[4] These issues are especially relevant for the pharmaceutical industry, since most countries impose regulations on both market-

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[4]Applying the informative advertising model, we take the most positive view of advertising. If we assumed advertising to be purely persuasive, a complete ban on advertising is more likely to be socially beneficial. In most cases, including pharmaceutical marketing, advertising contains elements of both persuasion and information.

ing and prices of prescription drugs. Based on the informative advertising example, we present numerical simulations suggesting that strict regulation of advertising and strict price regulation (or, equivalently, a less generous patent system) are policy substitutes.

The rest of the paper is organised as follows. In the next section we give an overview of related literature. We present the general framework in Section 3, and derive the equilibrium in terms of advertising and R&D investments in Section 4. In Section 5 we illustrate our model by analysing a standard (parameterised) informative advertising model, which is extended in Section 6 to include some discussion of welfare and policy implications. Finally, the paper is concluded in Section 7.

2   Related literature

Although there are, to our knowledge, no previous studies of the strategic link between advertising and R&D, our paper is clearly related to the literature on advertising and entry. In his seminal paper, Schmalensee (1983) considers a homogenous-product market served by an incumbent with a potential entrant. He analyses the following three-stage game: at stage 1 the incumbent sends out ads to consumers; at stage 2 the entrant decides whether or not to enter, and, if entry occurs, the entrant sends out its own ads. Finally, at stage 3 active firms play some simultaneous-move oligopoly game.[5] The main result is that the incumbent can deter entry, but does so by strategically *under-investing* in advertising.

Another seminal paper is Fudenberg and Tirole (1984). They assume products to be differentiated, and analyse the following two-period model: in the first (pre-entry) period, the incumbent chooses a fraction of consumers to inform, which becomes the incumbent's captive market. In the second period, the incumbent and the entrant compete for the non-captive market through price competition. They find that the incumbent firm will under-invest in advertising ('lean and hungry look') if it chooses to deter entry, because this establishes a credible threat to cut prices in the event of entry. Conversely, if the

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[5]Schmalensee (1983) observes that if entry occurs and firms set prices, then a pure-strategy Nash equilibrium does not exist. Accordingly, he assumes that firms compete in quantities. Ishigaki (2000) characterises the mixed-strategy pricing equilibria induced by entry, and finds that entry is either blockaded or accommodated.

established firm chooses to allow entry, it will advertise heavily and become a 'fat cat' in order to soften the entrant's pricing behaviour.

Together, these papers suggest the following striking conclusion: the incumbent firm does not deter entry by investing more in advertising than it would have done if there were no threat of entry.[6] Thus, there is no formal support for strategic over-investment in advertising by the incumbent firm. Notice that the incumbent can credibly threaten not to *decrease* its investment since such reductions are infeasible. In these models, advertising is a durable investment since buyers never forget the ads they receive. However, the incumbent can always *increase* its advertising ex post if this is profitable. This raises a concern whether the incumbent can *credibly* commit to under-invest in advertising. Schmalensee (1983) observes this problem, but avoids it by making restrictions on the incumbent's advertising choices.[7] Fudenberg and Tirole (1984) also avoids this problem simply by making second-period advertising *exogenous*.

The present paper differs from the above mentioned contributions in several respects. Our model is not an entry model as such, but entry is one possible outcome of an R&D contest. Furthermore, by focusing on non-price competition we establish incentives for *over-investment* in advertising by the incumbent firm, which contrasts with results for entry deterrence under price or quantity competition, as previously discussed. In doing so, we also enforce dynamic consistency by allowing the incumbent to re-optimise its advertising investment ex post. More precisely, if it is profitable for the incumbent to advertise more heavily if entry occurs than if not, then it is never credible for the incumbent to under-invest in advertising ex ante. The potential entrant will foresee this and base its decision on the ex post advertising level.

Our paper also relates to more specific studies of pharmaceutical markets. In this field, the issue of advertising and entry has received considerable attention for a long period, especially from empirical studies, see, e.g., Hurwitz and Caves (1988), Caves et al. (1991),

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[6]Despite several similarities, this result is contrary to the production capacity literature. For instance, Dixit (1980) shows that the incumbent strategically overinvests in capacity in order to deter entry.

[7]The assumption that the incumbent can credibly commit not to increase its advertising after entry, is justified by Schmalensee (1983) as follows: "Under some conditions, destruction of the materials necessary to print more leaflets may serve to accomplish this" (p. 647). This justification is certainly debatable.

Grabowski and Vernon (1992), and Scott Morton (2000). A common finding is that there is no evidence of entry deterring behaviour on the part of incumbents. However, all these papers are concerned about branded vs. generic competition, which means that they are considering competition between homogenous or 'artificially' vertically differentiated products.[8] To our best knowledge, there is no study that analyses advertising as a device for restricting competition between branded (or patented) products, nor the effect of advertising on R&D investments.

Finally, our paper relates to the literature on patent races, and especially, that on monopoly persistence. The issue – which has been addressed by Gilbert and Newberry (1982) and Reinganum (1983), among others – is whether a monopolist in the product market is more likely to innovate than an entrant. The basic result from this literature is two-fold: (i) if the innovation is drastic, then it is more likely with entry into the product market; (ii) if innovation is non-drastic, then it is more likely for the monopoly to persist.[9] This literature is mainly on process innovations. Since we consider non-drastic product innovations, the parallels are not straightforward. However, in a loose sense, our paper contributes to this literature by providing an alternative explanation for monopoly persistence, namely that the incumbent can use advertising to reduce the entrant's incentive to spend resources on R&D.

3 A general model

Consider a therapeutic market with potentially two horizontally differentiated patented products (prescription drugs). One of the products – the 'breakthrough' drug – has already been developed by firm 1. The second (horizontally differentiated) product may or may not be discovered, depending on the amount of R&D investments incurred. We assume

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[8]Generic drugs are chemically identical products to the original brand-name drug. However, all the mentioned empirical studies strongly suggest that generics are not *de facto* perfect substitutes to the original brand-name drug. It turns out that a vertical differentiation model, where the generics are perceived to be of lower quality than the brand-name drug, produces results that fit the empirical observations well (see, e.g., Cabrales, 2003, Königbauer, 2004, Brekke et al., 2005).

[9]A related paper is Langinier (2004) who examines the role of patents – or more precisely patent renewals – as strategic barriers to entry, depending on the information structure.

that firm 1 faces competition from a potential entrant – firm 2 – in the race to discover the new drug.

We consider a two-period model with the following sequence of events:

Stage 1a: The incumbent advertises and sells the existing drug.

Stage 1b: The incumbent and the potential entrant simultaneously invest in R&D to develop a new drug.

Stage 2: The new drug – if discovered – is advertised by the patent holder and sold in the market alongside the already existing drug.

Stages 1a and 1b constitute the first period, where the incumbent is a monopolist in the market. The breakthrough product (drug 1) is sold in both periods, whereas the new product (drug 2) – if discovered – is sold in the second period only. Thus, while the first-period is a single-product monopoly phase, the second period is characterised by one of three different market structures: (i) a single-product monopoly if neither firm discovers the second product; (ii) a multi-product monopoly if the incumbent wins the R&D race; and (iii) a duopoly if the entrant wins the R&D race.

Drug demand

Due to the extensive prevalence of third-party payment for prescription drugs in most countries, which implies that drug demand is highly price-inelastic[10], we make the assumption that demand for a particular drug depends only on the amounts of advertising for the existing drugs within the therapeutic market. More specifically, if we let A_i denote the amount of advertising for drug i, the demand for this drug in the *second period* is given by a function

$$D_i\left(A_i, A_j\right), \quad i, j = 1, 2; \quad i \neq j,$$

where

$$\frac{\partial D_i}{\partial A_i} > 0, \quad \frac{\partial^2 D_i}{\partial A_i^2} \leq 0, \quad \frac{\partial D_i}{\partial A_j} < 0 \quad \text{and} \quad \frac{\partial D_i}{\partial A_i} > \left|\frac{\partial D_j}{\partial A_i}\right|.$$

[10] See, e.g., Rizzo (1999) and Scherer (2000).

These assumptions on the demand function imply that advertising has both a *market expanding* and a *business stealing* effect. In the *first period* – the single-product monopoly phase – demand for drug 1 is given by

$$\theta D_1 \left(A_1, 0 \right),$$

where $\theta > 0$. Thus, the parameter θ reflects the importance (length) of the first period, relative to the second.

Advertising

A key assumption in our analysis is that the effects of advertising persist over time. As is common in the literature on strategic advertising, we take this assumption to the extreme by letting the effects of advertising on demand be infinitely durable.[11] The firm producing drug i can invest in an advertising stock A_i for this product at a cost

$$K \left(A_i \right),$$

where

$$K' \left(A_i \right) > 0, \quad K'' \left(A_i \right) > 0 \quad \text{and} \quad K \left(0 \right) = 0.$$

Thus, we assume that both firms possess the same advertising technology.

R&D

During the monopoly phase, the incumbent and the potential entrant compete in terms of R&D to develop a new (horizontally differentiated) drug in the market. Game-theoretically, we assume that R&D investments are made simultaneously and non-cooperatively. If we denote the amount of R&D investment of firm i by x_i, the probability of success for

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[11] See, e.g., Schmalensee (1983), Fudenberg and Tirole (1984), Grossman and Shapiro (1984), etc. See also Brekke and Kuhn (2005) for an application to the pharmaceutical industry. As will be discussed in Section 7, our results only need some degree of advertising persistence. The assumption of infinite durability is just a simplification, making the analysis more tractable.

firm i in the R&D contest is given by a function

$$z_i\left(x_i, x_j\right), \quad i, j = 1, 2; \quad i \neq j,$$

By 'success' we mean that firm i will develop and obtain a patent for the new drug. We assume that $z_1 + z_2 \leq 1$, accommodating the possibility that the new drug will not be developed. The R&D success function is assumed to have the following general characteristics:

$$\frac{\partial z_i}{\partial x_i} > 0, \quad \frac{\partial z_i}{\partial x_j} < 0, \quad \frac{\partial^2 z_i}{\partial x_i^2} \leq 0, \quad \frac{\partial^2 z_i}{\partial x_j^2} \geq 0 \quad \text{and} \quad \frac{\partial z_i}{\partial x_i} > \left| \frac{\partial z_i}{\partial x_j} \right|.$$

The last assumption essentially means that increased R&D effort by either firm will always increase the overall probability that a new drug is developed. The cost of exerting an R&D effort of x_i is given by a function

$$C\left(x_i\right),$$

where

$$C'\left(x_i\right) > 0, \quad C''\left(x_i\right) > 0 \quad \text{and} \quad C\left(0\right) = 0.$$

Profits

As already mentioned, markets for prescription drugs are predominantly characterised by highly price inelastic demand, mainly due to extensive third-party payment and highly asymmetric information in the physician-patient relationship. As a consequence, prescription drugs are, in most countries, subject to some kind of price regulation. In the present model, we therefore make the assumption that the firms face exogenous drug prices, which seems a reasonable approximation to the above mentioned particular features. More specifically, we assume that the firms face a regulated drug price p, which – for simplicity – is assumed to be equal for both drugs.[12] Note that, since demand is insensitive to price changes, a price increase is equivalent to a demand increase. Thus, an increase in p can

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[12] Equal prices for both drugs might be a reasonable assumption in the case of horizontally differentiated drugs with equivalent therapeutic benefits. In the last section of the paper, we briefly discuss how different drug prices might affect our results.

also be interpreted as being equivalent to an increase in the patent length. Whether we use this interpretation, or explicitly acknowledge that the regulated drug price is an integral part of patent protection for pharmaceuticals, we can (loosely) think of p as the 'generosity' of the patent system.

We abstract from production costs once a new drug has been developed, implying that all costs of the pharmaceutical firms are related to marketing and R&D. In line with the specific features of the pharmaceutical industry – where marginal production costs are very low – we also disregard the possibility of capacity constraints, and assume that firms will always supply the quantity demanded, as long as the price covers marginal production costs (i.e., $p \geq 0$).

Second period profits for firm i in market structure z is denoted V_i^z, where $i = 1, 2$, and $z = S$(ingle-product monopoly), M(ulti-product monopoly), D(uopoly). Assuming dynamic consistency, i.e., that the incumbent has no incentive to increase advertising of the original product ex post, second period profits are given by[13]

$$V_1^S = pD_1\left(A_1, 0\right), \tag{1}$$

$$V_1^M = p\left[D_1\left(A_1, A_2\right) + D_2\left(A_1, A_2\right)\right] - K\left(A_2\right), \tag{2}$$

$$V_1^D = pD_1\left(A_1, A_2\right), \tag{3}$$

$$V_2^D = pD_2\left(A_1, A_2\right) - K\left(A_2\right). \tag{4}$$

Since the market structure in the second period depends on the outcome of the R&D contest, *expected second period profits* for firm i, denoted B_i, are given by

$$B_1 = \left[1 - z_1\left(x_1, x_2\right) - z_2\left(x_1, x_2\right)\right]V_1^S + z_1\left(x_1, x_2\right)V_1^M + z_2\left(x_1, x_2\right)V_1^D - C\left(x_1\right), \tag{5}$$

$$B_2 = z_2\left(x_1, x_2\right)V_2^D - C\left(x_2\right). \tag{6}$$

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[13] In general, a sufficiently high value of θ will always ensure that this is indeed the case. This will be made clearer below.

Expected present-value profits for the incumbent firm at the outset of the game, denoted Π_1, are consequently given by[14]

$$\Pi_1 = \theta V_1^S + B_1 - K(A_1).\tag{7}$$

4 Analysis

We look for the subgame-perfect Nash equilibrium of the above described game, solving the model by backwards induction. We start, then, by analysing second-period advertising of the new product: drug 2.

4.1 Second-period advertising

The introduction of a new product gives rise to one of potentially two new market structures, depending on which firm develops the new product:

Duopoly

If the entrant obtains the patent for the new product, it chooses a level of advertising, A_2^D, that maximises profits for firm 2, given by (4). The first-order condition for optimal advertising of the new product is then given by

$$p\frac{\partial D_2(A_1, A_2)}{\partial A_2} - \frac{\partial K(A_2)}{\partial A_2} = 0,\tag{8}$$

which defines a best response function $A_2^D(A_1)$. By total differentiation of (8), we can easily obtain

$$\frac{\partial A_2^D(A_1)}{\partial A_1} = \frac{-p\frac{\partial^2 D_2}{\partial A_1 \partial A_2}}{p\frac{\partial^2 D_2}{\partial A_2^2} - \frac{\partial^2 K}{\partial A_2^2}}.$$

Applying the second-order condition, we see that

$$\frac{\partial A_2^D(A_1)}{\partial A_1} < 0 \quad if \quad \frac{\partial^2 D_2}{\partial A_1 \partial A_2} < 0.$$

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[14]Discounting between periods is captured by the parameter θ.

In this case the decision variables are *strategic substitutes*[15], implying that increased first-period advertising by the incumbent will reduce the optimal second-period advertising by the entrant.

Monopoly

If the new product is developed by the incumbent, the optimal level of advertising for this product, A_2^M, maximises the incumbent's second-period profits, given by (2). The first-order condition is then given by

$$p \left(\frac{\partial D_1 \left(A_1, A_2 \right)}{\partial A_2} + \frac{\partial D_2 \left(A_1, A_2 \right)}{\partial A_2} \right) - \frac{\partial K \left(A_2 \right)}{\partial A_2} = 0, \tag{9}$$

which defines a best response function $A_2^M \left(A_1 \right)$. Comparing (8) and (9), we see that the multi-product monopolist internalises the business-stealing effect of advertising, implying that

$$A_2^M \left(A_1 \right) < A_2^D \left(A_1 \right).$$

Once more, by total differentiation of (9) we derive

$$\frac{\partial A_2^M \left(A_1 \right)}{\partial A_1} = \frac{-p \left(\frac{\partial^2 D_1}{\partial A_1 \partial A_2} + \frac{\partial^2 D_2}{\partial A_1 \partial A_2} \right)}{p \left(\frac{\partial D_1^2}{\partial A_2^2} + \frac{\partial^2 D_2}{\partial A_2^2} \right) - \frac{\partial^2 K}{\partial A_2^2}}.$$

Equivalent to the duopoly case, we see that

$$\frac{\partial A_2^M \left(A_1 \right)}{\partial A_1} < 0 \quad if \quad \frac{\partial^2 D_i}{\partial A_i \partial A_j} < 0.$$

For the remainder of the analysis, we will generally assume that advertising investments are strategic substitutes for the firms.

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[15] See Bulow et al. (1985).

4.2 The effects of first-period advertising on second-period profits

By inserting the equilibrium levels of second-period advertising in the second-period profit expressions, (1)-(4), we derive equilibrium second-period profits for firm i in market structure z as a function of first-period advertising for the incumbent product; $V_i^z(A_1)$. The properties of the demand functions – where advertising has both a market expanding and a business-stealing effect – implies the following ranking of equilibrium second-period profits:

$$V_1^M(A_1) > V_1^S(A_1) > V_1^D(A_1).$$

In words: for any level of first-period advertising, the introduction of a new drug in the therapeutic market is beneficial for the incumbent if the drug is developed by the incumbent himself, but detrimental for the incumbent if the drug is developed by a new entrant.

A key mechanism of the model is that first-period advertising by the incumbent affects second-period profits for both firms. Applying the Envelope Theorem, the effects of first-period advertising on second-period profits are easily derived:

$$\frac{\partial V_1^S(A_1)}{\partial A_1} = p\frac{\partial D_1(A_1, 0)}{\partial A_1} > 0, \tag{10}$$

$$\frac{\partial V_1^M(A_1)}{\partial A_1} = p[\frac{\partial D_1\left(A_1, A_2^M\right)}{\partial A_1} + \frac{\partial D_2\left(A_1, A_2^M\right)}{\partial A_1}] > 0, \tag{11}$$

$$\frac{\partial V_1^D(A_1)}{\partial A_1} = p\left[\frac{\partial D_1\left(A_1, A_2^D\right)}{\partial A_1} + \frac{\partial D_1\left(A_1, A_2^D\right)}{\partial A_2}\frac{\partial A_2^D}{\partial A_1}\right] > 0, \tag{12}$$

$$\frac{\partial V_2^D(A_1)}{\partial A_1} = p\frac{\partial D_2\left(A_1, A_2^D\right)}{\partial A_1} < 0. \tag{13}$$

As we observe from (13), first-period advertising by the incumbent directly reduces the second-period payoff of the entrant. In addition, if advertising decisions are strategic substitutes, the incumbent has a strategic first-mover advantage which enables him to shift second period duopoly rents from the possible entrant through first-period advertising. This effect is reflected in the second term of (12).

With the assumptions of $\partial D_i / \partial A_j < 0$ and $\partial^2 D_i / \partial A_i \partial A_j < 0$, it follows from (10)-(12) that

$$\frac{\partial V_1^S (A_1)}{\partial A_1} > \frac{\partial V_1^M (A_1)}{\partial A_1} \tag{14}$$

and

$$\frac{\partial V_1^D (A_1)}{\partial A_1} > \frac{\partial V_1^M (A_1)}{\partial A_1}. \tag{15}$$

The latter inequality implies that first-period advertising has a larger positive effect on the incumbent's second-period profits in duopoly than in multi-product monopoly. This follows from the internalisation of the business-stealing effect in multi-product monopoly (i.e., $\partial D_i / \partial A_j < 0$) and the first-mover advantage vis-à-vis the entrant in duopoly (i.e., $\partial A_2^D / \partial A_1 < 0$). This particular relationship between the marginal second-period effects of first-period advertising will prove crucial in the subsequent analysis.

4.3 R&D competition

During the monopoly phase, the incumbent and a potential entrant compete in terms of R&D to develop a new, horizontally differentiated, drug in the market. For a given level of advertising by the incumbent, each firm chooses the level of R&D that maximises expected second-period payoffs, anticipating the equilibrium second-period outcome. Expected second-period profits are given by (5) and (6). For illustrative purposes, it may be useful to re-arrange the expression for the incumbent's expected second-period profits in the following way:

$$B_1 = V_1^S + z_1 (x_1, x_2) \underbrace{\left[V_1^M - V_1^S \right]}_{\text{Gain of winning}} - z_2 (x_1, x_2) \underbrace{\left[V_1^S - V_1^D \right]}_{\text{Loss of losing}} - C (x_1). \tag{16}$$

Thus, the incentive for the incumbent to undertake R&D investments can be decomposed into two different forces: (i) the profit gain derived from winning the R&D competition, and (ii) the profit loss of losing the R&D competition.[16]

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[16] Beath et al. (1989) label the first effect as the 'profit incentive' and the second effect as the 'competitive threat'. These also correspond to the 'replacement effect' and the 'efficiency effect' in Gilbert and Newberry (1982) and Reinganum (1983).

From (6) and (16), equilibrium R&D efforts by the two firms are given by the solution to the following pair of first-order conditions:

$$\frac{\partial B_1}{\partial x_1} = \frac{\partial z_1}{\partial x_1}\left(V_1^M - V_1^S\right) - \frac{\partial z_2}{\partial x_1}\left(V_1^S - V_1^D\right) - \frac{\partial C}{\partial x_1} = 0, \tag{17}$$

$$\frac{\partial B_2}{\partial x_2} = \frac{\partial z_2}{\partial x_2}V_2^D - \frac{\partial C}{\partial x_2} = 0. \tag{18}$$

Our assumptions on $z_i\left(\cdot\right)$ and $C\left(\cdot\right)$ ensure that the second-order conditions are met.[17] We also assume that the determinant of the Jacobian matrix,

$$J = \begin{bmatrix} \partial^2 B_1/\partial x_1^2 & \partial^2 B_1/\partial x_1\partial x_2 \\ \partial^2 B_2/\partial x_2\partial x_1 & \partial^2 B_2/\partial x_2^2 \end{bmatrix},$$

is positive, guaranteeing uniqueness of the equilibrium.[18]

4.4 The effects of first-period advertising on R&D incentives

The first-order conditions (17)-(18) implicitly define the optimal R&D efforts of firm 1 and 2 as functions of the first-period investment level by the incumbent: $x_1^*\left(A_1\right)$ and $x_2^*\left(A_1\right)$, respectively. How do R&D incentives depend on first-period advertising? Using Cramer's Rule, we can derive expressions for $\partial x_1^*/\partial A_1$ and $\partial x_2^*/\partial A_1$ from the first-order conditions of the R&D game:

$$\frac{\partial x_1^*}{\partial A_1} = \frac{\begin{vmatrix} -\partial^2 B_1/\partial A_1\partial x_1 & \partial^2 B_1/\partial x_1\partial x_2 \\ -\partial^2 B_2/\partial A_1\partial x_2 & \partial^2 B_2/\partial x_2^2 \end{vmatrix}}{|J|}, \tag{19}$$

---

[17]The second-order conditions are given by

$$\frac{\partial^2 B_1}{\partial x_1^2} = \frac{\partial^2 z_1}{\partial x_1^2}\left(V_1^M - V_1^S\right) - \frac{\partial^2 z_2}{\partial x_1^2}\left(V_1^S - V_1^D\right) - \frac{\partial^2 C}{\partial x_1^2} < 0,$$

$$\frac{\partial^2 B_2}{\partial x_2^2} = \frac{\partial^2 z_2}{\partial x_2^2}V_2^D - \frac{\partial^2 C}{\partial x_1^2} < 0.$$

[18]See the Appendix for an explicit expression of $|J|$, with the corresponding condition for $|J| > 0$.

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$$\frac{\partial x_2^*}{\partial A_1} = \frac{\begin{vmatrix} \partial^2 B_1 / \partial x_1^2 & -\partial^2 B_1 / \partial A_1 \partial x_1 \\ \partial^2 B_2 / \partial x_2 \partial x_1 & -\partial^2 B_2 / \partial A_1 \partial x_2 \end{vmatrix}}{|J|}. \tag{20}$$

From $|J| > 0$, it follows that

$$sign\left(\frac{\partial x_1^*}{\partial A_1}\right) = sign\left\{-\Omega\left(\underbrace{\frac{\partial^2 z_2}{\partial x_2^2}V_2^D - \frac{\partial^2 C}{\partial x_2^2}}_{<0}\right) + \Phi\underbrace{\frac{\partial z_2}{\partial x_2}\frac{\partial V_2^D}{\partial A_1}}_{<0}\right\} \tag{21}$$

and

$$sign\left(\frac{\partial x_2^*}{\partial A_1}\right) = sign\left\{-\underbrace{\frac{\partial^2 B_1}{\partial x_1^2}\frac{\partial z_2}{\partial x_2}\frac{\partial V_2^D}{\partial A_1}}_{>0} + \Omega\underbrace{\frac{\partial^2 z_2}{\partial x_1 \partial x_2}V_2^D}_{\lessgtr 0}\right\}, \tag{22}$$

where

$$\Omega := \frac{\partial z_1}{\partial x_1}\left(\frac{\partial V_1^M}{\partial A_1} - \frac{\partial V_1^S}{\partial A_1}\right) - \frac{\partial z_2}{\partial x_1}\left(\frac{\partial V_1^S}{\partial A_1} - \frac{\partial V_1^D}{\partial A_1}\right) < 0,$$

$$\Phi := \frac{\partial^2 z_1}{\partial x_2 \partial x_1}\left(V_1^M - V_1^S\right) - \frac{\partial^2 z_2}{\partial x_2 \partial x_1}\left(V_1^S - V_1^D\right) \lessgtr 0.$$

An increase in first-period advertising by the incumbent has a direct and (potentially) an indirect effect on R&D efforts of both firms, and we see that the sign of the overall effect is generally ambiguous in both cases. The direct effects of increased advertising are unambiguously negative with respect to R&D efforts for both firms. Increased advertising by the incumbent directly reduces the second-period payoff of firm 2 – as can be seen from (13) – and thus reduces the incentives for the potential entrant to exert effort in the R&D contest. This effect is reflected in the first term of (22). Increased advertising for the existing product also directly reduces the incentives to invest in R&D for the incumbent, because such advertising reduces the gain of winning the contest by more than a potential increase in the loss of losing. This follows from (14)-(15), and is reflected in the first term

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of (21).[19]

If $\partial^2 z_i / \partial x_i \partial x_j = 0$, the direct effects unambiguously ensure that increased advertising of the breakthrough product will reduce the R&D incentives for both firms. However, if $\partial^2 z_i / \partial x_i \partial x_j \neq 0$ there are additional indirect effects that could work in the opposite direction. The second terms in (21) and (22) reflect that a lower amount of R&D by firm i could – ceteris paribus – spur increased R&D investments by firm j if R&D efforts are strategic substitutes; that is, if $\partial^2 z_i / \partial x_i \partial x_j < 0$.

From the above analysis, we can thus characterise the relationship between first-period advertising and R&D investments as follows:

Proposition 1 *Assume that advertising investments are strategic substitutes for the firms;*
$\frac{\partial^2 D_i(A_i, A_j)}{\partial A_i \partial A_j} < 0.$ *Then the following results obtain:*
(i) $\frac{\partial x_1^*}{\partial A_1} < 0$ *if* $\left| \frac{\partial^2 z_i \left(x_i^*, x_j^* \right)}{\partial x_i \partial x_j} \right|$ *is sufficiently small.*
(ii) $\frac{\partial x_2^*}{\partial A_1} < 0$ *if* $\frac{\partial^2 z_i \left(x_i^*, x_j^* \right)}{\partial x_i \partial x_j} \geq 0$ *or* $\left| \frac{\partial^2 z_i \left(x_i^*, x_j^* \right)}{\partial x_i \partial x_j} \right|$ *is sufficiently small.*

The first part of the proposition establishes the conditions for *advertising and R&D being substitute strategies* for the incumbent firm, implying that more resources spent on advertising will lead to less resources spent on R&D. This will be the case if advertising investments are strategic substitutes and the second-order cross derivatives of the innovation success functions are sufficiently small in absolute value in equilibrium.[20] Since the condition for the second part of the proposition is less restrictive, the following implication holds:

Corollary 1 *Increased first-period advertising by the incumbent reduces the probability that a new product is developed and introduced on the market if $\partial^2 D_i / \partial A_i \partial A_j < 0$ and $\left| \partial^2 z_i / \partial x_i \partial x_j \right|$ is sufficiently small.*

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[19]It follows from (14)-(15) that

$$\left| \frac{\partial \left(V_1^M - V_1^S \right)}{\partial A_1} \right| > \frac{\partial \left(V_1^S - V_1^D \right)}{\partial A_1}.$$

Note also that (14)-(15) together with $\partial z_i / \partial x_i > |\partial z_i / \partial x_j|$ ensure that $\Omega < 0$.

[20]Note that this is also the condition, in qualitative terms, for $|J| > 0$. See the Appendix for further details.

4.5   First-period advertising

At the outset of the game, the incumbent chooses the optimal level of advertising for the existing patented drug by maximising expected present-value profits over the two periods, given by (7), anticipating the outcome of the R&D game and the subsequent market equilibria in the second period. Thus, optimal first-period advertising is given by

$$
A_1^* = \arg\max \left\{ \Pi_1 \left(A_1 \right) = \theta V_1^S \left(A_1 \right) + B_1 \left(x_1^* \left(A_1 \right), x_1^* \left(A_1 \right), A_1 \right) - K \left(A_1 \right) \right\}. \qquad (23)
$$

As a benchmark for comparison, we start out by considering the case of exogenous probabilities of second-period market structures. In this case, the first-order condition for optimal advertising is given by

$$
(1 + \theta) \frac{\partial V_1^S}{\partial A_1} - z_1 \left(\frac{\partial V_1^S}{\partial A_1} - \frac{\partial V_1^M}{\partial A_1} \right) - z_2 \left(\frac{\partial V_1^S}{\partial A_1} - \frac{\partial V_1^D}{\partial A_1} \right) - \frac{\partial K}{\partial A_1} = 0. \qquad (24)
$$

When deciding the optimal level of first-period advertising, the incumbent has to consider the marginal second-period benefits of increased advertising in the different market structures, and weigh these net benefits with the relevant probabilities. We see that a sufficiently high value of θ will ensure dynamic consistency, in the sense that the incumbent has no incentives to increase advertising of drug 1 in the second-period.[21]

In the following, we define *overinvestment* in advertising as an advertising level in excess of the level given by the above benchmark. In other words, we say that an incumbent firm overinvests in advertising if it advertises more than it would have done if advertising and R&D decisions were unrelated, implying that the R&D probabilities (z_1 and z_2) were exogenous with respect to the first-period advertising decision.

Let us now turn to the case of endogenous probabilities, determined by the absolute and relative R&D efforts of the firms. From (23), the first-order condition for an optimal

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[21]In the parametric example presented in the next section, we demonstrate that dynamic consistency can be ensured by a very low value of θ. It is important to note that while θ plays a role with respect to the dynamic consistency of the model, it is otherwise irrelevant for qualitative nature of all the results derived in the paper.

level of first-period advertising can be conceptualised and expressed as follows:

$$\frac{\partial \Pi_1 (A_1)}{\partial A_1} = Direct\ rent\ effect\ +\ Strategic\ R\&D\ effect = 0,$$

where the *Direct rent effect* is equal to the left-hand side of (24), whereas the *Strategic R&D effect* is given by

$$\left(\frac{\partial z_1}{\partial x_1} \frac{\partial x_1^*}{\partial A_1} + \frac{\partial z_1}{\partial x_2} \frac{\partial x_2^*}{\partial A_1} \right) \left(V_1^M - V_1^S \right) \tag{25}$$
$$+ \left(\frac{\partial z_2}{\partial x_1} \frac{\partial x_1^*}{\partial A_1} + \frac{\partial z_2}{\partial x_2} \frac{\partial x_2^*}{\partial A_1} \right) \left(V_1^D - V_1^S \right) - \frac{\partial C}{\partial x_1} \frac{\partial x_1^*}{\partial A_1}.$$

However, by using (17), (25) can be reduced to

$$\left[\frac{\partial z_1}{\partial x_2} \left(V_1^M - V_1^S \right) - \frac{\partial z_2}{\partial x_2} \left(V_1^S - V_1^D \right) \right] \frac{\partial x_2^*}{\partial A_1}. \tag{26}$$

Since the expression in square brackets is unambiguously negative, it follows that the *Strategic R&D effect* is positive if and only if $\partial x_2^*/\partial A_1 < 0$. Since our definition of *overinvestment* is equivalent to a positive *Strategic R&D effect*, the following result follows immediately:

Proposition 2 *The incumbent firm optimally overinvests in advertising if and only if such advertising reduces the R&D effort of the potential entrant.*

As we can see from (26), the gain for the incumbent of inducing a lower R&D effort from the potential entrant – which provides the incentives for overinvestment – is constituted by two parts. A lower value of x_2^* implies that the incumbent's expected gain of winning the contest, $z_1 \left(V_1^M - V_1^S \right)$, is increased, while the expected loss of losing, $z_2 \left(V_1^S - V_1^D \right)$, is reduced. Thus, as long as first-period advertising by the incumbent reduces R&D efforts by the potential entrant, with the relevant conditions given in Proposition 1, incentives for overinvestment are present.

5 An example: Informative advertising

In this section we illustrate our model by analysing a standard specific advertising model that fits the assumptions of the general model. We consider an informative advertising model with an information technology that follows Butters (1977).[22] There is a unit mass of potential consumers that are ex ante uninformed about the existence of the products in the market, and rely on advertising to become informed. If a consumer receives one or more ads for a particular product, she knows about the existence and attributes of this product. We assume that, in the first period, informed consumers buy θ units of the existing product, whereas, in the second period, informed consumers buy 1 unit of one of the products in the market. With two products in the market, consumers who are informed about both products buy either product with probability $\frac{1}{2}$.[23] If a fraction A_i (A_j) of consumers are informed about drug i (j), second-period demand for drug i is given by

$$D_i (A_i, A_j) = A_i (1 - A_j) + \frac{A_i A_j}{2}, \qquad i, j = 1, 2; \quad i \neq j. \tag{27}$$

Note that $\partial^2 D_i / \partial A_i \partial A_j = -\frac{1}{2}$, implying that advertising choices are strategic substitutes for the firms. We assume that a firm can inform a fraction A_i of the consumers about the existence and attributes of drug i by incurring a cost of $K(A_i) = \frac{k}{2} A_i^2$, $A_i \in [0, 1]$.

We can now use the parameterised demand and cost functions to calculate second-period payoffs in the different market structures. Straightforward calculations yield

$$V_1^S (A_1) = pA_1, \tag{28}$$

$$V_1^M (A_1) = p \left[A_1 + \frac{p}{2k} (1 - A_1)^2 \right], \tag{29}$$

$$V_1^D (A_1) = pA_1 \left[1 - \frac{p}{4k} (2 - A_1) \right], \tag{30}$$

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[22] This approach has been widely used in the advertising literature. See, e.g., Schmalensee (1983), Fudenberg and Tirole (1984), Grossman and Shapiro (1984), Ishigaki (2000), Brekke and Kuhn (2005).

[23] We can interpret this as a Hotelling model with uniform distribution of consumers, symmetric location of products and ads reaching consumers randomly.

$$V_2^D (A_1) = \frac{p^2}{8k} (2 - A_1)^2. \tag{31}$$

In order to obtain analytical solutions in the R&D contest, we construct the success functions in the following way. Let $x_i \in [0, 1]$ denote the probability that firm i discovers the new product. If the product is only discovered by firm i, this firm will be granted a patent for the product. However, if both firms discover the product, the patent will be granted to either firm with probability $\frac{1}{2}$. This yields the following success functions:[24]

$$z_i (x_i, x_j) = x_i (1 - x_j) + \frac{x_i x_j}{2}, \qquad i, j = 1, 2; \quad i \neq j.$$

We assume that firm i can obtain a probability x_i of discovery by undertaking an R&D investment of $C(x_i) = \frac{c}{2} x_i^2$, $x_i \in [0, 1]$.

We can now insert these functional expressions into (6) and (16), and solve for the optimal values of x_i in the R&D competition:

$$x_1^* (A_1) = \frac{2p^2 \left[32ck (1 - A_1)^2 - p^2 [2 - 3A_1 (2 - A_1)] (2 - A_1)^2 \right]}{128c^2 k^2 - p^4 [2 - 3A_1 (2 - A_1)] (2 - A_1)^2}, \tag{32}$$

$$x_2^* (A_1) = \frac{4p^2 (2 - A_1)^2 \left[4ck - p^2 (1 - A_1)^2 \right]}{128c^2 k^2 - p^4 [2 - 3A_1 (2 - A_1)] (2 - A_1)^2}. \tag{33}$$

An interior solution requires a lower bound on the cost parameter c. It is relatively straightforward to verify that $c > \underline{c} := p^2/4k$ is a sufficient condition for $x_1^* (A_1), x_2^* (A_1) \in (0, 1)$ for $A_1 \in [0, 1]$. From (32)-(33) we derive:

Proposition 3 *In the informative advertising model, given that $c > \underline{c}$, then*

(i) $x_1^* = x_2^*$ *if $A_1 = 0$,*

(ii) $x_1^* < x_2^*$ *if $A_1 > 0$, and*

(iii) $\frac{\partial x_i^*}{\partial A_1} < 0$ *for any $A_1 \in [0, 1]$ and $i = 1, 2$.*

A proof is given in the Appendix.

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[24] This particular success function has the following properties: $\partial z_i/\partial x_i > 0$, $\partial z_i/\partial x_j < 0$, $\partial^2 z_i/\partial x_i^2 = \partial^2 z_i/\partial x_j^2 = 0$ and $\partial^2 z_i/\partial x_i \partial x_j < 0$.

Proposition 3 shows that the incumbent will invest less aggressively in R&D than the potential entrant. While the entrant's R&D incentives are determined by the possibility of duopoly profit only, the incumbent balances the profit gain of winning the R&D competition against the profit loss of losing the R&D competition. Since the incumbent has already secured some profits, due to being a single-product monopolist in the first period, the net gain of winning the R&D competition is lower than for the entrant. However, in the extreme case of no first-period advertising, both firms will invest equally much in R&D. The reason is simply that for $A_1 = 0$, single-product monopoly profits are also zero, implying that the incumbent and the entrant face identical expected profit gains from winning from the R&D competition.

The proposition also confirms that the general conditions given in Proposition 1 are always satisfied in the informative advertising model, implying that marketing and R&D are substitute strategies for the incumbent, and a lower level of first-period advertising will increase overall R&D expenditures. By combining Propositions 2 and 3, we also see that the informative advertising model yields strategic overinvestment in advertising by the incumbent.

Turning now to the first-period advertising decision and the equilibrium outcome of the full game, the complexity of the model makes analytical solutions infeasible. Instead, we present the results in the form of numerical examples where we set $\theta = \frac{1}{10}$.[25] Tables 1–3 report equilibrium values of first-period advertising and R&D investments for different values of the key parameters k, c and p. In Table 4, we present measures of the incumbent's incentives to use advertising strategically in order to affect R&D expenditures. We do so by evaluating the *Strategic R&D effect*, defined by (26), in equilibrium, which measures the degree of overinvestment in first-period advertising. Table 4 reveals that the incentives for overinvestment are increasing in p and decreasing in k and c.

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[25]It is straightforward to verify that the model is dynamically consistent even for this low level of θ. In the informative advertising model, the incumbent has no incentives to increase advertising of drug 1 in the second period if $A_1^* \geq \frac{p}{k}$. From Table 1 we see that this condition is always satisfied. The effect of a higher value of θ is essentially to increase first-period advertising and reduce R&D incentives.

Table 1: A_1^*.

	c = 1		c = 3	
p	$k = 5$	$k = 8$	$k = 5$	$k = 8$
1	0.217	0.137	0.219	0.137
2	0.426	0.267	0.435	0.272
3	0.656	0.393	0.662	0.406
4	0.977	0.522	0.918	0.543

Table 2: x_1^*.

	c = 1		c = 3	
p	$k = 5$	$k = 8$	$k = 5$	$k = 8$
1	0.060	0.046	0.020	0.015
2	0.132	0.128	0.043	0.043
3	0.161	0.203	0.041	0.066
4	0.155	0.266	0.024	0.075

Table 3: x_2^*.

	c = 1		c = 3	
p	$k = 5$	$k = 8$	$k = 5$	$k = 8$
1	0.077	0.053	0.026	0.018
2	0.231	0.176	0.080	0.061
3	0.374	0.327	0.132	0.115
4	0.386	0.473	0.154	0.170

Table 4: *Strategic R&D effect*.

	c = 1		c = 3	
p	$k = 5$	$k = 8$	$k = 5$	$k = 8$
1	0.002	0	0.001	0
2	0.033	0.011	0.013	0.004
3	0.169	0.057	0.072	0.024
4	0.506	0.169	0.217	0.081

Although we restrict ourselves to a relatively small set of numerical examples, several regularities can be identified that shed some light on the mechanisms of the model.[26] We concentrate here on the effects of prices and costs on first-period advertising and R&D expenditures. Consider first the effects of an increase in *marketing costs* (k). This always leads to a reduction of first-period advertising, through the direct cost effect. R&D efforts are ambiguously affected, though, due to an interaction of two opposing effects. On the one hand, reduced first-period advertising – ceteris paribus – increases R&D incentives, as we have analysed in great detail in Section 4.4. On the other hand, higher advertising costs also reduce second-period profits, since the new product has to be advertised. This will – all else equal – reduce R&D incentives. From our numerical examples, we observe

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[26] Other simulations with different parameter values yield a qualitatively similar picture.

that the first effect dominates only for relatively high values of p.

The effect of increased *R&D costs* (c) reduces R&D efforts directly, but the effect on first-period advertising is ambiguous. We see that, for most of the reported parameter values, advertising investments will increase (although by quite small amounts). In our examples, the exception is for the combination of high price and low advertising costs. In this case the incumbent has very strong incentives to advertise in order to protect his monopoly position (which is very profitable due to the high price), and these incentives are particularly strong for low R&D costs, which (all else equal) increases the probability that a competitor will enter the market.

More interesting, perhaps, are the effects of a higher *drug price* (p). A price increase will increase first-period advertising simply because it makes the monopoly position more valuable for the incumbent patent holder. Consequently, the incumbent will have stronger incentives to use advertising strategically in order to protect his monopoly rent. Nevertheless, the potential entrant will react to a higher price by increasing his R&D efforts. This is due to the fact that a higher price not only increases the value of the existent patent, it also increases the value of obtaining the second patent in the market. Thus, the increased advertising efforts by the incumbent have only a *dampening* effect on the competitor's R&D expenditures. The effect of a higher price on the *incumbent's* R&D efforts is ambiguous, though. Ceteris paribus, more advertising of the existing product will reduce the incumbent's incentives for R&D. However, a higher p also increases the value of the contested prize, which – all else equal – leads to increased R&D efforts by both firms. From Table 2 we see that the second effect dominates when advertising costs are high, implying that it is more costly to use advertising as a means to reduce R&D investments. For lower advertising costs, on the other hand, there appears to be a hump-shaped relationship between p and x_1^*. For a sufficiently high price, a further price increase will trigger an increase in advertising that is sufficiently strong to reduce the incumbent's R&D investments.

In our numerical examples, although the incumbent's R&D efforts may decrease, *ag-*

gregate R&D expenditures always increase as a result of a higher price. This is confirmed by comparing Tables 2 and 3. However, a higher price – or, generally, a more generous patent protection – implies that a larger share of the patent rent is spent on marketing, relative to R&D. This is a key result. Indeed, we see from Tables 2 and 3 that raising p above a certain level hardly stimulates aggregate R&D expenditures at all, while incentives for advertising increase considerably.

6 Some welfare and policy implications

In most countries there exist a wide set of restrictions on drug marketing. For instance, direct-to-consumer advertising of prescription drugs is prohibited in almost every western country, except for the US and New Zealand. Moreover, there exist ethical guidelines regulating the interaction between medical doctors and sales representatives from the pharmaceutical companies. Health authorities also usually require that a disclaimer stating the effectiveness, side-effects, contraindications, etc., is printed along with an advertisement of a drug. In this section of the paper, we extend the numerical example of the previous section in order to make a contribution – albeit a tentative one – to the discussion of if and when strict regulation of drug advertising is justified from a viewpoint of social welfare.

Advertising and welfare is often a methodologically complicated issue, in particular if advertising contains elements of persuasion, which may potentially change individuals' preferences. In most cases, advertising contains elements of both information and persuasion. In the pharmaceutical market, for instance, sales representatives may inform the physician about the existence and the characteristics of a new drug, but at the same time sponsor conference trips, offer gifts, free samples, etc., which may be of a more persuasive nature. From a viewpoint of social welfare, *informational* advertising brings an obvious social benefit in the sense that a larger fraction of consumers becomes aware of a product that may yield a positive net utility if consumed. On the other hand, the potential for socially beneficial *persuasive* advertising is far less obvious. In the subsequent analysis, we assume, in line with the specific example of the previous section, that advertising is

purely informational, and ask whether restrictions on advertising can be beneficial for social welfare even in this case.

When evaluating welfare effects, we make use of the standard welfare measure, which is an (unweighted) sum of consumers' and producers' surplus net of third party payments. Assuming that third-party funds can be raised in a non-distortionary manner, the social welfare function simplifies to (gross) aggregate consumer utility net of R&D and marketing costs. Since the outcome of the R&D competition is uncertain, the relevant measure of social welfare is in expected terms. Denoting aggregate consumer utility in market structure z by U_z, expected welfare, on general form, is given by

$$
\begin{aligned}
W \;=\;& \theta U_S + (1 - z_1 - z_2) U_S + z_1 \left(U_M - K \left(A_2^M \right) \right) \\
& + z_2 \left(U_D - K \left(A_2^D \right) \right) - C \left(x_1 \right) - C \left(x_2 \right) - K \left(A_1 \right).
\end{aligned}
\tag{34}
$$

In the following, we apply the informative advertising model introduced in the previous section. We use the Hotelling interpretation of the model, with linear transportation costs, where the two drugs are located at the endpoints of the Hotelling line. Let v denote the gross utility of consuming a drug, while t is the cost per unit distance between the actually consumed drug and the consumer's 'ideal' drug. Whereas v can be interpreted as the effectiveness of the drug treatment, t can be interpreted as a measure of potential side-effects and contraindications. We also assume full market coverage, i.e., no consumers refrain from buying the existing product(s).

It is now straightforward to derive the expressions for ex post consumer utility in the different potential market structures. For simplicity, we assume full third-party payment of drugs.[27,28] In the single-product case, where neither firm succeed in developing the new

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[27] Since social welfare does not depend on prices, the assumption of full third-party payment makes the exposition easier without affecting the result.

[28] With full third-party payment, the assumption of full market coverage is equivalent to imposing a restriction $v - t \geq 0$.

drug, aggregate consumer utility is given by

$$U_S = A_1 \int_0^1 (v - ty) \, dy = A_1 \left(v - \frac{t}{2} \right). \tag{35}$$

In the multi-product case, where either the incumbent or the entrant discovers the new product, aggregate consumer utility is given by

$$U_M = U_D = A_1 (1 - A_2) \int_0^1 (v - ty) \, dy + A_2 (1 - A_1) \int_0^1 (v - t (1 - y)) \, dy \tag{36}$$

$$+ A_1 A_2 \left(\int_0^{\frac{1}{2}} (v - ty) \, dy + \int_{\frac{1}{2}}^1 (v - t (1 - y)) \, dy \right)$$

$$= [A_1 + A_2 - 2A_1 A_2] \left(v - \frac{t}{2} \right) + A_1 A_2 \left(v - \frac{t}{4} \right).$$

Observe that aggregate utility is constituted by two qualitatively different segments; the fraction of partially informed consumers, i.e., $A_i (1 - A_j)$, and the fraction of fully informed consumers, i.e., $A_1 A_2$. Partially informed consumers buy the only drug that they are aware of, with the corresponding aggregate mismatch costs $t/2$, while fully informed consumers choose the most 'suitable' drug treatment, generating aggregate mismatch costs equal to $t/4$. It clearly follows that the social benefit of developing a second drug in the market is monotonically increasing in t.

Using the same cost and success functions as in the previous section, an explicit expression for expected social welfare can now be found by inserting these, along with (35) and (36), into (34). In order to evaluate the welfare effect of a strict governmental policy towards pharmaceutical marketing, our strategy is to evaluate social welfare, as given by (34), for the numerically derived equilibrium levels of R&D and marketing in the previous section. In doing so, we interpret the advertising cost parameter k as a measure of the extent of marketing regulation. This parameter measures the cost of reaching a certain fraction of the consumer population through advertising. It seems reasonable, then, to interpret a high (low) value of k as reflecting extensive (few) restrictions on advertising. All else equal (i.e., for given levels of marketing and R&D), a higher value of k will of

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course reduce welfare, since informing a given fraction of consumers becomes more costly. The question, though, is whether the firms' marketing and R&D decisions might be influenced in a way that leads to an overall increase in social welfare. A numerical example is provided in Table 5.

Table 5: Social welfare.

p	$c = 1$		$c = 3$	
	$k = 5$	$k = 8$	$k = 5$	$k = 8$
1	0.254	0.158	0.246	0.153
2	0.237	0.152	0.240	0.152
3	-0.117	-0.057	-0.048	-0.021
4	-0.969	-0.477	-0.676	-0.375

Assumptions: $\theta = 1/10$, $v = 3$, $t = 1$

One should of course be careful about drawing any strong conclusions based on a specific numeric example. Nevertheless, a clear pattern emerges from this example. The social loss of imposing more restrictions on drug marketing (i.e., increasing k from 5 to 8 in this example) is larger when drug prices are low. However, if p becomes sufficiently high, increased marketing restrictions is actually beneficial for social welfare, even if advertising is purely informational. In other words, strict restrictions on advertising are desirable only in health care systems with very generous price regulation (or patent protection).

Intuitively, this tallies well with our previously derived results. Generous price regulation (high p) strongly increases advertising incentives, relative to R&D incentives. Increasing the restrictions on advertising will directly reduce the incumbent's incentives to advertise, and thereby indirectly spur R&D incentives, which might improve welfare through lower expected mismatch costs in equilibrium. This is clearly observed for the cases of $p = 3, 4$ in Table 5. Several numerical simulations with different parameter values produce similar results.

In terms of (tentative) policy recommendations, our exercise suggests that a generous

price regulation (or patent) system should be matched with strict regulation on advertising, and vice versa.

7   Concluding remarks

In this paper we have analysed how a patent-holding pharmaceutical firm may strategically use advertising ex ante to affect R&D investments in new drugs, and thereby change the probability distribution of future market structures. In doing so, we have explored the basic idea that a generous patent system may provide incentives for patent-holding firms not only to spend resources on R&D to obtain new patents, but also to spend resources on marketing to protect existing patents. In this final section of the paper, we will not recapitulate our results in detail, but instead provide some discussion of a couple of key assumptions.

While the assumption of drug demand being insensitive to prices is appropriate for most pharmaceutical markets, the additional simplifying assumption that the price is equal for the old and new drug in the therapeutic market is not so obvious. However, while a relaxation of this assumption is likely to affect the relative strength of R&D and marketing incentives, it does not affect the main mechanisms of the model. A higher expected price for the new drug will – all else equal – stimulate R&D incentives for both firms. This suggests that it might be relatively less important for the incumbent to spend resources on marketing in order to protect the existing patent rent. However, a higher price for the new product also means that a potential entrant – if successful in obtaining the new patent – will advertise this drug more heavily in the second-period duopoly, which, in turn, increases the incumbent's loss in case of entry. Consequently, this gives the incumbent a stronger incentive – all else equal – to use first-period advertising as a strategic instrument in order to reduce the probability of incurring such a loss. The relative strength of these effects is a priori uncertain.

The analysis rests on the crucial assumption that the effect of advertising persists over time. If this was not the case, there would be no demand-side link between marketing

and R&D, and the two decision variables would be strategically independent. While the standard assumption in the strategic advertising literature – that the effect of advertising is infinitely durable – is obviously unrealistically strong when taken literally, it may nevertheless be a useful simplification that captures an important aspect of advertising. In reality, the effects of advertising are neither completely instantaneous nor infinitely durable, but somewhere in between. The question is rather how strong the persistence effect is. The basic idea explored in our analysis only requires that there is, to a certain degree, a persistence effect. Obviously, the weaker this persistence effect is, the more costly it is for the incumbent firm to use first-period advertising strategically in order to affect R&D expenditures and thereby the probabilities of second-period market structures.

Finally, it should be mentioned that we have focused on non-drastic innovations. A natural extension of the model would be to allow the firms also to choose drastic innovations (i.e., discovery of completely new products) and analyse the choice between drastic and non-drastic innovations. This is a topic for further research.

Appendix

The Jacobian from the R&D game.

From (17) and (18), we can derive

$$|J| = \left(\underbrace{\frac{\partial^2 z_1}{\partial x_1^2} \frac{\partial^2 z_2}{\partial x_2^2} - \frac{\partial^2 z_1}{\partial x_2 \partial x_1} \frac{\partial^2 z_2}{\partial x_1 \partial x_2}}_{\lessgtr 0} \right) \left(\underbrace{V_1^M - V_1^S}_{>0} \right) V_2^D$$

$$- \left(\underbrace{\frac{\partial^2 z_2}{\partial x_1^2} \frac{\partial^2 z_2}{\partial x_2^2} - \left(\frac{\partial^2 z_2}{\partial x_1 \partial x_2} \right)^2}_{<0} \right) \left(\underbrace{V_1^S - V_1^D}_{>0} \right) V_2^D - \underbrace{\frac{\partial^2 C}{\partial x_1^2} \frac{\partial^2 z_2}{\partial x_2^2} V_2^D}_{<0} - \underbrace{\frac{\partial^2 C}{\partial x_2^2} \frac{\partial^2 B_1}{\partial x_1^2}}_{<0}.$$

We see that $|J| > 0$ provided that the first term is either non-negative or sufficiently small in absolute value.

Proof of Proposition 3.

Part (i) and (ii): Since the denominators of (32) and (33) are equal, it is sufficient to compare the numerators to decide the ranking of $x_1^*(A_1)$ and $x_2^*(A_1)$.

$$x_2^*(A_1) - x_1^*(A_1) \geq 0$$

$$\Updownarrow$$

$$\Delta := 8 A_1 kc (4 - 3A_1) - p^2 A_1 (2 - A_1)^3 \geq 0. \tag{A.1}$$

By inspection of (A.1), it is easily verified that $\lim_{A_1 \to 0} \Delta = 0$. This establishes part (i) of the proposition.

To prove part (ii) of the proposition, we evaluate Δ at the lower bound of c, i.e., $\underline{c} := p^2/4k$, yielding the following:

$$\lim_{c \to \underline{c}} \Delta = A_1^2 p^2 \left[6 (1 - A_1) + A_1^2 \right] > 0 \text{ for any } A_1 > 0.$$

Since Δ is increasing in c, it must hold that $x_2^*(A_1) > x_1^*(A_1)$ for any $c > \underline{c}$ and $A_1 > 0$.

Part (iii): From (32) and (33) we derive:

$$\frac{\partial x_1^*(A_1)}{\partial A_1} = -\frac{128p^2ck\,(4kc\mu - \sigma)}{\left(128c^2k^2 - p^4\,(2 - 3A_1\,(2 - A_1))\,(2 - A_1)^2\right)^2} \tag{A.2}$$

and

$$\frac{\partial x_2^*(A_1)}{\partial A_1} = -\frac{8p^2\,(2 - A_1)\,(128c^2k^2\psi + \phi)}{\left(128c^2k^2 - p^4\,(2 - 3A_1\,(2 - A_1))\,(2 - A_1)^2\right)^2}, \tag{A.3}$$

where

$$\mu := 32ck\,(1 - A_1) - p^2\,(2 - A_1)\,(8 - 3A_1\,(5 - 2A_1)),$$

$$\sigma := p^4\,(1 - A_1)\,(2 - A_1)\,(3A_1\,(3 + A_1\,(A_1 - 3)) - 4),$$

$$\psi := 4ck - p^2\,(1 - A_1)\,(3 - 2A_1),$$

$$\phi := p^4\,(1 - A_1)\,(2 - A_1)^3\,(12ck - p^2).$$

We observe that $\partial x_1^*(A_1)/\partial A_1 < 0$ and $\partial x_2^*(A_1)/\partial A_1 < 0$ if the numerators are positive in (A.2) and (A.3), respectively. Since the values of both numerators are increasing in c, it suffices to make an evaluation at the limit $c \to \underline{c}$. Straightforward computation yields

$$\lim_{c \to \underline{c}} (4kc\mu - \sigma) = p^4 A_1^2 \left(22 - 36A_1 + 18A_1^2 - 3A_1^3\right) > 0 \text{ for } A_1 \in [0, 1]$$

and

$$\lim_{c \to \underline{c}} (128c^2k^2\psi + \phi) = 2p^6 A_1^2 \,(2 - A_1)\,(5 - A_1) > 0 \text{ for } A_1 \in [0, 1].$$

It follows that $\partial x_1^*(A_1)/\partial A_1 < 0$ and $\partial x_2^*(A_1)/\partial A_1 < 0$ for $c > \underline{c}$ and $A_1 \in [0, 1]$. *Q.E.D.*

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