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Ghislandi, Simone; Kuhn, Michael

DOI:
10.57938/81da86d1-6bef-479f-9754-d9210abb2f03

Published: 01/02/2016

Document Version:
Publisher's PDF, also known as Version of record

Document License:
Unspecified

Department of Economics
Working Paper No. 219

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Simone Ghislandi
Michael Kuhn

February 2016

WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS AND BUSINESS

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Asymmetric information in the regulation of the access to markets

Simone Ghislandi,[*] Michael Kuhn[†]

February 17, 2016

Abstract

It is frequently argued that the high costs of clinical trials prior to the admission of new pharmaceuticals are stifling innovation. At the same time, regulation of the access to markets is often justified on the basis of consumers' inability to detect the true quality of a product. We examine these arguments from an information economic perspective by setting a framework where the incentives to invest in R&D are influenced by the information structure prevailing when the product is launched in the market at a later stage. In this setting, by changing the information structure, regulation (or the lack of) can thus indirectly affect R&D efforts. More formally, we construct a moral hazard – cum – adverse selection model in which a pharmaceutical firm exerts an unobservable effort towards developing an innovative (high quality) drug (moral hazard) and then announces the (unobservable) quality outcome to an uninformed regulator and/or consumers (adverse selection). We compare the outcomes in regard to innovation effort and expected welfare under two regimes: (i) regulation, where products undergo a clinical trial designed to ascertain product quality at the point of market access; and (ii) laissez-faire with free entry, where the revelation of quality is left to the market process. Results show that whether or not innovation is greater in the presence of entry regulation crucially depends on the efficacy of the trial in identifying (poor) quality, on the probability that unknown qualities are revealed in the market process, and on the preference and cost structure. The welfare ranking of the two regimes depends on the differential effort incentive and on the net welfare gain from implementing full information instantaneously. For example, in settings of vertical monopoly, vertical differentiation and horizontal differentiation with no variable cost of quality, entry regulation tends to be the preferred regime if the effort incentive under pooling is relatively low and profits do not count too much towards welfare. A complementary numerical analysis shows how the outcomes vary with the market and cost structure.

Keywords: adverse selection, (entry) regulation, moral hazard, pharmaceutical industry, R&D incentives.

JEL-classification D82: Asymmetric and Private Information, I18: Government Policy; Regulation; Public Health, L15: Information and Product Quality; Standardization and Compatibility, L51: Economics of Regulation, O31: Innovation and Invention: Processes and Incentives

1 Introduction

It is frequently argued that the high costs of the clinical trials that new pharmaceuticals have to undergo prior to their admission to the market are stifling pharmaceutical innovation.[1] We examine this argument and explore some of its consequences from an information economic perspective. In particular, the main idea driving the present model is that the incentives to invest in research and development (R&D) and develop a good quality product are significantly influenced by the information structure prevailing when the product is launched in the market at a later stage. By changing this information structure, regulation (or the lack of) can thus indirectly affect R&D efforts. More formally, we construct a moral hazard – cum – adverse selection model in which a pharmaceutical firm exerts an unobservable effort towards developing an innovative (high quality) drug (moral hazard) and then announces the (unobservable) quality outcome to an uninformed regulator and/or consumers (adverse selection). The product is then sold to the market

[*]University of Economics and Business, Vienna, Austria

[†]Wittgenstein Centre (IIASA, VID/ÖAW, WU) and Vienna Institute of Demography, Vienna, Austria.

[1]See Munos (2009) for a recent overview on this debate as well as for evidence on trends in pharmaceutical innovation in the US.

over a certain (possibly infinite) number of periods with consumers' willingness to pay depending on their expectations about product quality. True quality may be discovered at a certain probability over the course of the market period, at which point consumers readjust their expectations.

We compare the outcomes under two regimes: (i) a regulation regime in which products undergo a clinical trial designed to ascertain product quality at the point of market access. Such a trial may be manipulated at a cost by a firm having failed to develop a high quality. If fraudulent access is discovered ex-post, a fine can be levied on the firm. We establish conditions under which the trial separates the types. (ii) a laissez-faire regime with free market entry, where the discovery of the quality is left to the market process. We compare the outcomes of these two regimes in regard to (a) the effort exerted on product development; and (b) expected welfare, composed of consumer surplus and weighted profits.

The asymmetric information issues described in the present model are typical for industries in which, for reasons of technological complexity, product quality and, thus, the benefits from innovation cannot be easily evaluated, and in which the access to market is often regulated. In particular, the asymmetric information between regulators/consumers and firms can help explaining some real-world scandals in the pharma industry as well as in other "high-tech" industries. Two recent examples are particularly illustrative. First, the Vioxx case in the pharma industry, where the firm launching the product (Vioxx, brand name of Rofecoxib, a pain killer) downplayed the relevance of negative findings from an important clinical trial (VIGOR). VIGOR revealed a significant increase of cardiovascular episodes in the patients treated with the new drug. In this specific case, regulatory authorities probably knew about the problem, but somehow decided not to withdraw the product. Hence, regulators did not behave as market gate-keepers and the product accessed the market directly. Unaware consumers bought the drug, ignoring the seriousness of the cardiovascular risks associated with its consumption. Eventually, the problem emerged and the company was fined, consistent with what would happen in our model.

A second example relates to the recent Volkswagen case, where the company admitted to having manipulated emission tests after the Environmental Protection Agency (EPA) found that diesel cars were equipped with a software that could detect when the car was being tested and reduce emissions accordingly. In this case, the asymmetric information between the regulators and the firm is evident because the cheating was discovered only after entry occurred. Fines and penalties will probably follow, as they would in our model. Both cases illustrate, however, the presence of a non-trivial regulatory problem when it comes to neutralizing the incentives for firms to manipulate quality/safety testing in the run-up to market access (either in absolute terms, where access is denied to low quality products; or in relative terms, where testing leads to published quality gradings).

The present model applies also to contexts where the definition of quality is fuzzy and related to the effectiveness, rather than the safety, of a product. For example, in the pharmaceutical sector the practice of launching new products similar to the old ones in order to artificially extend patent protection (a practice known as evergreening, or product hopping) has often come under the scrutiny of legal authorities[2]. Here, although the quality of a product is defined comparatively with respect to an incumbent, the main framework and results can be straightforwardly applied (see the vertically differentiated duopoly example we report in Section 6). The main approach of the present model is then to recognize that evergreening might provide incentives to under-invest in really innovative R&D activities, implying that an optimal regulatory setting should take these backward induction effect into account.

Our results suggest that, although the up-front cost of trials stifles innovative effort, it is by no means clear that a relaxation of such regulation would mitigate the situation. First, an arbitrary relaxation of the access-regulation would lead to a configuration in which consumers remain uninformed. Second, in the absence of access regulation the returns (in terms of extra profit) to innovation are reduced, as consumers' willingness to pay for quality is dampened by the expectation that quality may be low. Whether or not this leads to lower innovative effort depends on the specific structure of profits within the market stage. Given an equal level of innovative effort across the two regimes, the welfare outcome depends on whether or not consumers prefer to be informed about quality. This is for many plausible settings ambivalent: if quality is

[2]See, for example, the Gleevec case in India, where the Supreme Court did not recognize the patent protection of a new drug that was considered too similar to the original entity; or the 2008 Walgreen vs Astrazeneca case, where the Distric Court of Columbia, USA, took the opposite decision dismissing the argument by which Astrazeneca was using a product hopping strategy to prolong the patent of Omeprazole.

low consumers benefit from being informed about this; but for many specifications the converse is true if quality is high after successful innovation. Consumers then benefit from not having market access regulation, as a seller of high quality is unable to raise the price to the full information level. We can nevertheless show that, in expected terms, consumers always benefit from access regulation within a monopoly setting with vertical preferences for quality, within a vertically differentiated duopoly, with an innovating firm taking on the role of high quality provider, and within a horizontally differentiated duopoly, with an innovating firm having a quality advantage.

Numerical simulations show that whether or not innovation is greater in the presence of entry regulation crucially depends on the efficacy of the trial in identifying (poor) quality and on the probability that unknown qualities are revealed in the market process. As expected, innovation is greater in the presence of entry regulation if clinical trials are sufficiently effective; at the same time, a greater probability of ex-post development tends to close the gap between effort levels regardless of whether or not they are higher under innovation. This illustrates that the entry regime (laissez-faire or regulation) makes a particularly strong difference for innovation effort in those environments in which the ex-post revelation of quality is unlikely. Interestingly, however, differences in innovation effort play a comparatively minor role when it comes to assessing the welfare impact of the two entry regimes. At least for the settings we are studying, the welfare impact is determined through the impact on consumer surplus and profit of providing full information right from the outset rather than leaving this to the market process. While our numerical analysis confirms that, in expected terms, consumers are better off under complete information, this may be more than offset by a reduction in expected profits, whenever the latter is counted towards welfare.

The remainder of the paper is structured as follows. In the following section, we discuss how our model contributes to the debate on the entry regulation of pharmaceuticals and relates our model to the literature. Section 3 sets out the model, Section 4 analyses the role of access regulation in separating quality types and derives the R&D incentives in the first stage of the game. Welfare is analyzed in Section 5. The following three sections consider three examples, applying the framework to the specific settings of monopoly with vertical preferences (Section 6), vertically differentiated duopoly (Section 7), and horizontally differentiated duopoly with quality (Section 8). Section 9 studies two extensions to the model, while Section 10 concludes. Proofs are relegated to Appendix A, while Appendix B describes how the numerical analysis has been set up.

2 Motivation and relation to the literature

Following the Thalomide case, the 1962 Kefauver-Harris Amendments strengthened the existing regulation for market access to pharmaceutical products (the 1938 Food, Drug and Cosmetics Act). In addition to safety, the Amendment required proof of efficacy, usually through a double blind, randomized controlled trial against a placebo. The rationale behind this approach is evident: since drugs' effectiveness cannot be evaluated by doctors' or patients' direct experience, accurate evaluation is possible only after proper information is produced. To the extent that information is asymmetrically distributed between firms and consumers, adverse selection might induce self-interested firms to underprovide information and consumers to waste resources on ineffective products. This motivation for access regulation has already been noted by the economic literature (e.g. Danzon (2000); Peltzman (1973)).

More importantly from the perspective of our study, adverse selection might affect the incentives to invest in R&D *before* products are even ready to be launched. If signaling product quality is difficult, strong R&D efforts might be a waste of resources for firms, since consumers would not be willing to pay more for high quality products. Hence, not only consumers over-spend on ineffective products, but firms under-invest in research. Katz (2007) defines this as a pharmaceutical lemons problem, whereby sellers underinvest in research, producing only low quality drugs. The argument is similar to the one motivating our model. Katz (2007), however, does not formalize it. In particular, from a theoretical point of view one main feature of the afore mentioned approach needs to be made explicit: if R&D effort could be observed, it would represent a good signal of drug quality. Unfortunately, R&D is not precisely observable in most real-world research intensive industries.[3] An additional "moral hazard" issue effectively characterizes these markets. It is this

[3]The literature on the costs of innovation in pharmaceuticals (Di Masi et al, 1991, 2003) does not apply in this context since information here requires that regulators and consumers know the expenditure in R&D for each specific product being launched

combination of hidden action (in the research stage) and hidden quality (in the consumption stage) that drives our model and represents the first attempt to analyze market access by considering the impact of asymmetric information and regulation on the different stages of a drug production and commercialisation process.

One additional feature of our model is that the asymmetry of information which is typically assumed to affect consumers extends to regulators. Indeed, even regulators like the US Food and Drug Administration (FDA) are facing a very high level of uncertainty and do not have access to all the information available to the company pursuing market access. In this sense, regulators find themselves in a position not so different from the one of the final consumers. The differences between a consumer and the regulator are twofold. First, regulators could better read the scientific evidence required in order to evaluate a product. Although this argument is in many ways realistic, it does not set its roots into the rational choice framework used in economic modelling. Hence, in our approach regulators and consumers are equally rational, in the sense that they can interpret the evidence with the same precision. Besides this, however, regulators can impose restrictions and costs *before* or punishments *after* the product is launched, something consumers cannot do.[4] But good regulation requires good information. Asymmetric information then represents a serious regulatory challenge.

The main literature related to safety and efficacy regulation in pharmaceuticals has been empirical, with rather mixed results regarding the optimality of introducing tough regulation. Early contributions evaluated the costs of the intervention by assessing the reduction in the number of New Chemical Entities (NCEs) following regulation (Peltzman, 1973; Grabowski et al, 1978). These studies found that the costs of regulation are higher than the benefits (i.e. avoidance of the "underprovision of information"),[5] findings that have been confirmed by more recent research (Vernon, 2005; Golec and Vernon, 2010). However, these conclusions have been based on a series of assumptions which have been contested. First, Temin (1980) points out that if consumers learn slowly and with high uncertainty, benefits from regulation increase. This is an important issue that is considered in our model as well. Indeed, the speed and the precision at which a low-quality product is identified as such represents one of the main parameters driving the optimal regulation of market access. Second, it is generally difficult to understand how much of the observed change in the number of NCEs in the pharmaceutical industry is due to regulatory changes as opposed to purely scientific/technological motivations. Attributing to regulation all of the reduction in the number of new products reaching the market is likely to artificially increases the costs associated with regulation. By considering R&D effort, unobservable to the regulator, we rely on a more precise measure of the welfare impact of regulation.[6] Finally, using the number of NCEs as an outcome measure might not represent the best way to capture the actual objectives of the regulatory process. In particular, the issue of the quality of the product is crucial (Garattini and Ghislandi, 2007), since what we are really interested in is the final welfare impact of research, not its size. For example, Olson (2008) shows that faster access is associated with an increase in adverse effects events. In our approach, we provide measures of both R&D effort and welfare, paying particular attention to the fact that post-launch market structure, by affecting prices, can change consumers' welfare independently from the quality of the product. Dranove and Meltzer (1994) show that regulation might induce both companies and authorities to develop and approve important drugs more rapidly. This idea is embraced by our assumptions that regulation might imply different costs depending on the true quality of a product, where the costs involved in verifying quality in the access stage should typically be lower for effective drugs.[7]

The three following papers are also concerned with the role of clinical trials in the regulation of the pharmaceutical industry although their focus and approach is rather different from ours. Atella et al (2008) consider the impact of minimum efficacy standards and price regulation on quality and prices within pharmaceutical markets. While minimum efficacy standards can be viewed as a form of entry regulation which have a bearing on investments in drug quality, the model in Atella et al (2008) is based on a rather different

[4]Note that although the model has been conceived for the pharmaceutical sector, many features apply to other industries in which safety concerns matter. For airlines, for instance, the regulator imposes strict safety rules that must be met by all airplanes on the fleet. As the Volkswagen scandal illustrates, the same issues apply to the imposition of emission & fuel standards in the automobile industry.

[5]A related stream of literature analyses empirically the impact of price regulation on launch delays of new products (Danzon et al, 2005).

[6]Of course, we can do this because we are in a theoretical, rather than empirical, framework.

[7]This is indeed the role of randomised clinical trials.

information structure: there it is firms who are uninformed about the consumers' willingness to pay, while consumers are perfectly informed about drug quality. This implies a very different role for entry regulation. Dahm et al (2009) deal with the problem of pharmaceutical companies selectively communicating only favourable trial results. They examine what policies, e.g. compulsory or voluntary registry of trial outcomes, best resolve the trade-off between transparency and a firm's incentive to invest in researching the effects of their drug. The crucial difference to our approach is that Dahm et al (2009) focus on postmarketing studies, i.e. on trials which are aimed at reducing the residual uncertainty in regard to the impact of a drug that has already been admitted to the market. Finally Henry and Ottaviani (2015) focus on the process of information acquisition and revelation in the course of a clinical trial. Although very much related to our analysis, their paper is more detailed on the flow of information in the market access stage, but does not provide a general theoretical framework that encompasses the innovation and the post-marketing stage. In contrast, our interest lies particularly on the post-entry market conditions (cost, preferences, mode of competition, probability of ex-post discovery) and on the design of regulation.

From a theoretical point of view, our approach is related to literature on the disclosure of quality to otherwise uninformed consumers. One strand of this literature is concerned with the question whether consumers always benefit from more complete information about quality. Matthews and Postlewaite (1985), Creane (2008), Piccolo et al. (2015) and Rhodes and Wilson (2015) all characterize circumstances under which consumers are harmed (on average) by better information. This is true in particular if the true quality of the product is high, where the move from a pooling into a full information equilibrium comes with a price increase. Our modeling confirms these considerations for three market structures: monopoly with vertical preferences, vertical product differentiation and horizontal differentiation with quality differences. Nevertheless, our analysis also shows for these settings that, in expected terms, consumers tend to benefit from complete information when facing uncertainty about the success of a quality-related innovation.

A second strand of this literature deals with regulatory policies toward the verification or falsification (by firms) of information on product quality.[8] Matthews and Postlewaite (1985), Daughety and Reinganum (2008) and Polinsky and Shavell (2012) study how different schemes of mandatory testing and disclosure as opposed to voluntary disclosure, direct or through signalling, compare in terms of their social value and their private value to firms. Polinsky and Shavell (2012) show that even if consumers benefit from information, voluntary disclosure may still be preferred if this provides a greater incentive to an ex-ante uninformed firm for gathering information on quality. While this is a moral hazard problem akin to the modeling of first stage R&D effort in our model, our analysis does, indeed, differ from Polinsky and Shavell (2012) as well as from the other literature on disclosure on the following counts:[9] (1) Quality is endogenized during a first stage of innovation. (2) The disclosure process is assumed to be open to manipulation. This implies that the cost of verification is determined endogenously from an incentive compatibility constraint for a low quality firm. While some of the other works also allow for a costly verification process, the cost of verification is assumed to be exogenous there. (3) We are considering a combination of ex-ante access regulation, leading to disclosure, and ex-post fines for the falsification of information.[10]

Corts (2014) and Rhodes and Wilson (2015) deal with optimal policies towards curbing (or eliminating) the incentive for low quality firms to engage in false advertising. Both studies identify conditions under which a limited amount of false advertising is socially optimal: in Corts (2014) this is relating again to the knock-on effect of policies on the firm's ex-ante incentive to collect information about product quality; in Rhodes and Wilson (2015) this is relating to an offsetting regulatory objective to reducing distortions due to market power. While these considerations also play a role in our model, the crucial difference is that the models on false advertising regulation only consider ex-post policies. While we also account for ex-post policies, the focus of our analysis is on entry regulation as an ex-ante policy.[11]

[8]See Dranove and Jin (2010) for a survey of the theoretical and empirical literature on disclosure.

[9]Board (2009), Levin et al (2009) and Hotz and Xiao (2013) consider the incentives for voluntary disclosure and the impact of disclosure on market outcomes in the context of vertical [Board (2009)] and horizontal product differentiation [Levin et al (2009) and Hotz and Xiao (2013)]. While their modeling parallels to some extent two of our examples (see Sections 7 and 8), the focus of analysis differs for the reasons outlined in the main text.

[10]Spence (1977) and Polinsky and Shavell (2012) consider the role of producer liability as a ex-post policy akin to the one modeled by us.

[11]Another related stream of literature refers to "credence goods", the quality of which cannot be judged by non-expert consumers neither by inspection nor by experience (Darby and Karni, 1973; Dulleck and Kerschbamer, 2006). However, the presence of market access regulation and the focus on the regulatory process distinguishes substantially our analysis from the

3 The model

A firm decides to develop a product and to launch it on the market. The product can be of low (l) or high (h) quality. There are three consecutive stages: (1) product development; (2) market access; and (3) a market phase during which the firm is selling the product to consumers, acting as a monopolist or in competition against an incumbent rival.

In the first stage the firm develops the product, deciding a level of effort (e) that increases monotonically the probability of developing a high quality good, which we will subsequently understand to be an "innovation". In the second stage the firm launches the product on the market. With regulation, this second stage is a game between the firm and the authorities. Without regulation, the product goes straight to the market. Information is asymmetric throughout both stages. In the development process, the firm knows the effort, but neither final consumers nor public authorities have access to this information. Hence, there is an issue of moral hazard, where the firm might hide its real effort level. In the second stage, market access is characterized by the inability, of both consumers and public authorities, to distinguish high from low quality products. This defines a problem of adverse selection, or hidden information, which determines the consumers' state of information during the third stage.

Denote by $i = l, h$ the *true* quality of the product and by $j = l, h$ the quality *announced* by a firm. Hence, i is determined in the first stage, while j is defined in the second stage of the game. Whenever $j \neq i$, the firm is trying to cheat by hiding the true quality of the product. Let $\pi(i, j)$ denote the profit for a firm of type i and announcing j for the case that consumers believe the firm's quality announcement, regardless for the moment whether or not this belief is rational. Although the main focus of our analysis is on R&D intensive industries, such as the pharmaceutical industry, where quality is determined through innovative designs rather than through the production process, we allow for the possibility that high quality is associated with a higher variable cost of production (e.g. because it requires better skilled labour or higher quality materials). Thus, we assume without loss of generality that constant marginal cost is given by $c(h) = c \geq 0 = c(l)$. Assuming that the willingness to pay for quality in the market is sufficiently high so as to guarantee $\pi(h, h) > \pi(l, l)$ we obtain the following ordering of relevant profits

$$\pi(l, h) \geq \pi(h, h) > \pi(l, l) \geq \pi(h, l) \geq 0.$$

Here, $\pi(h, h) > \pi(l, l)$ implies that the marginal cost of high quality, c, is sufficiently low, where the inequality always hold for $c \to 0$. At the same time, $\pi(l, j) \geq \pi(h, j)$, with $j = l, h$, holds by a revealed preference argument (with an equality for $c = 0$): Given that the consumers' willingness to pay is governed by the announced quality j regardless of whether it corresponds to the true quality, then by virtue of its cost advantage the low quality firm could already attain at least the profit of a high quality producer by charging the same price, but usually do even better.

In contrast, define by $\pi(i, \lambda)$ the profit for a type $i = l, h$ when consumers are forming rational expectations about quality, where $\lambda \in [0, 1]$ is the probability consumers assign to the firm having developed a high quality product. Defining $\theta(h)$ and $\theta(l)$, with $\theta(h) \geq \theta(l)$, as measures of high and low quality, we can then write expected quality as $E(\theta) = \lambda\theta(h) + (1 - \lambda)\theta(l)$. Given that consumers willingness to pay increases with quality and given that there is no production cost, it then follows that the profit-maximizing selling price only varies with λ, such that $p(i, 1) \geq p(i, \lambda) \geq p(i, 0)$, with a strict inequality for $\lambda \in (0, 1)$ and $p(h, \lambda) = p(l, \lambda)$. In terms of profit this implies

$$\pi(i, h) = \pi(i, 1) \geq \pi(i, \lambda) \geq \pi(i, 0) = \pi(i, l); \quad i = h, l$$

where $\pi(l, \lambda) \geq \pi(h, \lambda)$.

Based on this, we can now characterize the three stages of the game, depending on the regulatory regime.

4 Equilibrium policy design and outcomes

4.1 Stage 3: post-entry market outcomes

In the absence of regulation firms are able to enter the market freely and announce a quality $j = l, h$ without any further regulatory consequences. For the moment, let us also assume that firms have no other way

one on credence goods.

of credibly signalling quality.[12] In this case a firm that has failed to innovate and is, therefore, turning into a low quality producer always has an incentive to cheat, since $\pi(l,h) > \pi(l,l)$. Rational consumers would anticipate that an announcement $j = h$ is uninformative about the true quality i and, therefore, pool qualities according to their prior belief $\lambda = e$, where e is the innovation effort at the first-stage of the game. The expected quality under pooling is, thus, given by $\theta^P := E(\theta) = e\theta(h) + (1-e)\theta(l)$ with price given by $p^P \in [p(l,l), p(h,h)]$ and profits given by

$$\pi(h,\lambda) = \pi^P(h) \leq \pi^P(l) = \pi(l,\lambda).$$

Since $\pi(h,h) \geq \pi^P(h)$ and $\pi^P(l) \geq \pi(l,l)$, it follows that the producer of a high quality product would always be better off under perfect information as compared to pooling, whereas the converse is true for a producer of low quality.

To keep the framework as general as possible we assume that the market in stage 3 is open for $T+1$ periods, with $T \geq 1$. Infinite T can be obtained as a subcase. The product enters the market in $t = 0$. After each period there is a probability $\rho \in [0,1]$ that the true quality of the product is revealed. The discount factor for future profits is $\delta \in [0,1]$. Using $\overline{\pi}_t$ to denote the expected flow of profits at time t, we obtain for a pooling firm

$$\overline{\pi}_0^P(i) = \pi^P(i) + \delta\left[\rho\frac{1-\delta^{T-1}}{1-\delta}\pi(i,i) + (1-\rho)\overline{\pi}_1^P(i)\right]; \quad i = h,l$$

The first term on the RHS is the pooling profit $\pi^P(i)$ obtained during the current period 0. The second term is the expected flow of profits from the continuation of the game. Here, the first term in the square brackets denotes the profit stream if the true type is revealed at the beginning of $t = 1$, which happens with probability ρ. In this case, the pooling equilibrium is broken and the two types are separated, giving rise to the perfect information profit $\pi(i,i)$. The second term in square brackets gives the expected profit stream from the continuation of pooling into period 1 if the true type is not discovered . Solving for the iteration up to T, the expected profit at $t = 0$ is a linear combination of pooling profit $\pi^P(i)$ and the separating profit $\pi(i,i)$ with the coefficients depending on the length of the game, on the discount factor and on the probability of quality being revealed. Formally, we obtain[13]

$$\overline{\pi}^P(i) = A\pi^P(i) + \frac{\rho\delta}{1-\delta}B\pi(i,i); \quad i = h,l \tag{1}$$

where

$$A = \sum_{t=0}^{T-1}(1-\rho)^t\delta^t = \frac{1-(1-\rho)^T\delta^T}{1-(1-\rho)\delta} \in \left[1; \frac{1}{1-(1-\rho)\delta}\right], \tag{2}$$

$$\begin{aligned} B &= \sum_{t=0}^{T-2}(1-\rho)^t\delta^t(1-\delta^{T-t-1}) \\ &= \frac{1-(1-\rho)^{T-1}\delta^{T-1}}{1-(1-\rho)\delta} - \frac{\delta^{T-1}\left[1-(1-\rho)^{T-1}\right]}{\rho} \in \left[0; \frac{1}{1-(1-\rho)\delta}\right]. \end{aligned} \tag{3}$$

While the presence of initial periods of pooling reduce the present value of selling a high quality product,

there continues to be a return to innovation, since consumers might sooner or later find a way to discriminate between qualities. The advantage of having a high quality product can be shown to increase with δ, implying a greater willingness to wait for the full-information profit, and with ρ, implying a greater probability of separation. These are important features of the unregulated market, which we will consider in greater detail below.

For the regulation regime, we assume the regulator to intervene at two different stages of the market: *ex-ante*, i.e. before market access, and *ex-post*, i.e. after cheating has been disclosed. An *ex-post* regulatory

[12]See section 9.1, for an extension, showing that high quality firms prefer to be pooled under plausible conditions.
[13]For notational convenience we drop the subscript "0", referring to the present period.

mechanism has the advantage of being imposed only on the cheating firm. The most intuitive form of an *ex-post* intervention is the imposition of a fine, $F \geq 0$, once a wrong claim, $j \neq i$, has been revealed. For the moment, let us assume that in the presence of regulation consumers believe the quality announcements $j = h, l$. We will verify that such beliefs are rational within a separating equilibrium further on below. For a firm that is misrepresenting quality the expected flow of profits at time $t = 0$ then becomes

$$\overline{\pi}_0(i,j) = \pi(i,j) + \rho[\delta\frac{1-\delta^{T-1}}{1-\delta}\pi(i,i) - F] + (1-\rho)\delta\overline{\pi}_1(i,j), \quad j \neq i$$

which, after solving for the iterations, can be written as

$$\overline{\pi}(i,j) = A(\pi(i,j) - \rho F) + \frac{\rho\delta}{1-\delta}B\pi(i,i). \tag{4}$$

As can be shown and as is intuitively clear, cheating is possibly profitable only for a low quality firm, such that $i = l$ and $j = h$. Such a firm would realize extra profit $\pi(l,h) > \pi(l,l)$ up to the point of discovery at rate $\rho \in [0,1]$ at which point the firm would have to pay the fine F and obtain the full information profit $\pi(l,l)$ for the remaining duration of the market.

The expected flow of profits for a truth-telling firm is regularly defined as

$$\overline{\pi}(i,i) = \sum_{t=0}^{T-1}\delta^t\pi(i,i) = \frac{1-\delta^T}{1-\delta}\pi(i,i); \quad i = h, l. \tag{5}$$

4.2 Stage 2: Market access

This stage is trivial in the absence of regulation, where firms enter, face an initial pooling equilibrium and expect a profit stream as in (1).

With *ex-ante* regulation, the regulator sets a policy $\langle F, q\rangle$, consisting of the ex-post fine F and a quality standard q, below which the product cannot be claimed to be high quality. This can be seen as a "burden of proof", where proving that the standard is met implicitly imposes a market access cost $C(i,q)$ that varies with the true quality of the product, i. More specifically, we assume (i) $\frac{\partial C(i,q)}{\partial q} \geq 0$, implying that having to meet a tougher standard raises the access cost for both types; (ii) $C(i,0) = 0$, implying that there are no access costs in the absence of ex-ante regulation; and (iii) $C(h,q) = sC(l,q)$ with $s \in [0,1]$, implying that it is less costly (or at the worst as costly) for a high quality producer to meet the standard than for a low quality producer. Or in other words, falsifying low quality is more costly than verifying high quality. Thanks to assumption (i) q and $C()$ are monotonically related, so that we can write $C(i)$ instead of $C(i,q)$. More importantly, since q implicitly defines C for a given true quality level of the product, the *ex-ante* regulation can be expressed in terms of C rather than q. We will use this property in the subsequent analysis. Assumption (iii) is imposing a linear structure on the relation between $C(h)$ and $C(l)$, maintaining the basic requirement that $C(h) \leq C(l)$. The parameter s is an implicit measure of how informative the *ex-ante* test is about real product quality. If $s = 0$, a high quality product does not require any effort to show the regulator its true type, i.e. it cannot be "fabricated". Low values of s could be interpreted, for example, as depicting a situation where the regulator is imposing clinical trials that should show the effectiveness of the product. In this case, statistically significant results can be achieved at much lower costs for a h type than for a l type. If $s = 1$, on the other hand, the true quality of the product does not change the access costs. In this case, the regulation works more like a fee to enter the market, a fee that is independent from the real quality of the product.

The regulator sets $\langle F, q\rangle$ in order to achieve a separation between h and l. Crucially, the regulator seeks to attain this goal while imposing the lowest possible cost on firms. This is what we define as "optimal" scheme. Imposing the monotonicity condition

$$\overline{\pi}(h,h) - \overline{\pi}(h,l) \geq \overline{\pi}(l,h) - \overline{\pi}(l,l)$$

with the profit flows as defined in (4) and (5), or equivalently,[14]

$$\pi(h,h) - \pi(h,l) \geq \pi(l,h) - \rho F - \pi(l,l) \tag{6}$$

[14] Here, we assume that an h type claiming to be l is not subjected to a fine. Otherwise, we would need to count $-2\rho F$ on the RHS of (6), relaxing the condition.

we obtain the following:

Proposition 4.1. *Define*

$$\widehat{F} := \frac{\pi(l,h) - \pi(l,l)}{\rho}$$

as the threshold fine for separation. Then, for a maximal feasible fine $\overline{F} \geq 0$, the optimal separating regulation $\langle F^*, q^* \rangle$ is given by:

$$\begin{array}{rll} \left\langle \widehat{F}, 0 \right\rangle & \text{if} & \overline{F} \geq \widehat{F} \\ \langle \overline{F}, C_l^{-1}\{A[\pi(l,h) - \pi(l,l) - \rho\overline{F}]\} \rangle & \text{if} & \overline{F} < \widehat{F} \end{array}$$

where C_l^{-1} is the inverse of the market entry cost function for a product of low quality.

Proof. See Appendix A. ∎

The Lemma provides insights into the way regulators should balance *ex-ante* and *ex-post* interventions. The first point of note is that it is always optimal to raise the *ex-post* fine either to the maximal feasible level or otherwise to the level at which separation occurs "naturally", i.e. without any *ex-ante* intervention. In the latter case the threat of a fine is sufficient for a firm with low quality never to claim high quality even in the absence of any *ex-ante* quality requirement. In expectation, such a fine should extract the full period value of cheating, $\pi(l,h) - \pi(l,l)$. While separation may, thus, be induced at modest levels of the fine in the case of certain discovery, $\rho = 1$, it is also evident that the separating fine, $\widehat{F}$, increases in line with a decline in the probability of discovery and may take on very high values for a low probability of discovery, i.e. for $\rho << 1$.

Noting that the separating fine $\widehat{F}$ approaches an infinite value if $\rho = 0$, it is clear that the implementation of a separating fine is feasible if and only if the probability of discovery is sufficiently high. Otherwise it is optimal to set the maximum feasible fine, $\overline{F}$, as defined by constraints on liquidity or credibility. In this latter case *ex-ante* regulation becomes necessary for the purpose of separating types. Here the regulator sets a product standard, q, at a level for which the cost for a low quality producer of meeting equals the discounted gains from mimicking a high quality. Since $C(h) = sC(l)$, however, separation implies that a market-access cost is imposed on a true h type. This is indeed the real waste associated with the *ex-ante* regulation.

In the light of calls from the industry that the costs imposed by clinical trials and other regulatory measures in the entry to market should be reduced, our results yield an important insight for policy: If the cost-minimizing regulation has been implemented, there is no scope for discretionary reductions in the market access costs for innovating firms. This is because any reduction in the cost $C(h,\overline{q}) = sC(l,\overline{q})$ by a relaxation of the quality standard to $q = \overline{q} - \varepsilon$ will undo the sorting property of the access regulation. Provided that rational consumers are anticipating the breakdown of separation, qualities are pooled. But then there is no benefit to access regulation and it should be abolished altogether, i.e. $q = 0$, in order to save the access cost.

The following is readily verified.

Corollary 4.1.1. *Both $\overline{q}$ and $C(h,\overline{q})$ decrease with $\overline{F}$ and ρ, and increase with δ, T and s*

Proof. See Appendix A. ∎

The *ex-ante* cost of inducing separation thus decreases with the ex-post fine, which illustrates the substitute nature of the two instruments. As the fine itself does not come at a cost to the regulator, it is then always optimal to set it at its maximum level, implying that the *ex-ante* regulation has a residual character.[15] Note that this result resembles the maximum punishment principle in models with auditing (Baron and Besanko, 1984), according to which a regulator can always save on auditing costs by raising the fine. In our model, the cost savings do not directly accrue with the regulator but rather with the high quality firm, which saves on entry costs if the separating entry standard is reduced. As we will see in the following section, this raises the innovation incentives and, thereby, contributes towards a higher welfare. In analogy to the impact of the *ex-post* fine on the *ex-ante* regulation, the need to be tough in the *ex-ante* regulation also reduces when it is easier to detect the cheating. Conversely, a higher orientation towards the future, as captured by the discount factor, δ, and the time horizon, T, calls for tougher *ex-ante* regulation. This is because less discounting and/or a longer market horizon inflate the returns to cheating. Finally, the smaller s, i.e. the more informative the *ex-ante* regulatory process, the lower is the access cost. If $s = 0$ separation can be achieved at no cost to a h type, turning *ex-ante* and *ex-post* regulation into equivalent instruments. *Ex-ante* regulation may then turn out to be superior in the sense that it may induce separation at low levels of *ex-post* revelation,ρ, where separating *ex-post* fines turn out to be unfeasible.

4.3 Stage 1: Development

In this stage, firms exert an effort $e \in [0,1]$ towards developing an innovation, i.e. a high quality product. The outcome of the development process is stochastic, where we assume for simplicity the probability of obtaining a high quality product to be given by $\lambda(e) = e$. Effort costs are given by an increasing and convex function $D(e)$, where for simplicity we set $D(e) = \frac{e^2}{2}$. In the following, we assume that the period profit levels $\pi(i,j)$ and $\pi^P(i)$ are normalized in a way that guarantees $e \leq 1$. We can then formulate the following.

Proposition 4.2. *(i) The effort exerted in the absence of regulation (stage 2 pooling equilibrium) is*

$$e^P = \max\left\{0; \frac{1-\delta^T}{1-\delta}[\pi(h,h) - \pi(l,l)] - A\left\{\left[\pi(h,h) - \pi^P(h)\right] + \left[\pi^P(l) - \pi(l,l)\right]\right\}\right\}.$$

(ii) Assume $\overline{F} \leq \widehat{F}$. The effort under regulation (stage 2 separating equilibrium) is

$$e^S = \max\left\{0; \frac{1-\delta^T}{1-\delta}[\pi(h,h) - \pi(l,l)] - sA[\pi(l,h) - \pi(l,l) - \rho\overline{F}\right\}.$$

(iii) For $\min\left\{e^S, e^P\right\} \geq 0$ it holds that

$$\begin{aligned} \Delta_e \quad &: = e^S - e^P = A\left\{\left[\pi(h,h) - \pi^P(h)\right] + \left[\pi^P(l) - \pi(l,l)\right] - s[\pi(l,h) - \pi(l,l) - \rho\overline{F}]\right\} \geq 0 \\ &\Leftrightarrow \quad [\pi(h,h) - s\pi(l,h)] - \left[\pi^P(h) - \pi^P(l)\right] - (1-s)\,\pi(l,l) + s\rho\overline{F}] \geq 0. \end{aligned}$$

Proof. See Appendix A. ■

Parts (i) and (ii) of the proposition characterize effort levels for the two cases of stage 2 pooling and separation, respectively. In both cases, effort increases in the expected discounted stream of the excess profit from selling a high rather than a low quality product under full information. With this defining the upper bound, effort levels are reduced in both cases by the respective "cost of information", and, indeed, it is possible in either case that effort levels are reduced to zero, as a lower bound. Under separation the cost of information amounts to the entry cost imposed on an innovating firm to access the market. As we have discussed previously, this cost is the lower the more informative is the ex-ante regulation, i.e. the lower is s; the lower are the gains from cheating $\pi(l,h) - \pi(l,l) > 0$; and the higher is the expected fine, $\rho\overline{F}$. The

[15]The self-selection property of the regulation implies that, in principle, it separates types even if *ex-ante* testing does not reveal to the regulator "real" information about the product. This defines a scenario which is strongly biased **against** this type of regulation, implying our result is strong.

resulting drag on innovation is well-known from the arguments brought forward by proponents of a more lenient access regulation. What is less of a matter of debate, however, is that a cost of information also places a drag on innovation even in the absence of access regulations. This cost is implicit in the form of profit differentials. Recalling that $\pi(h,h) > \pi^P(h)$ and $\pi^P(l) > \pi(l,l)$ typically hold, it follows that the pooling of qualities in the absence of a sorting mechanism lowers innovation incentives both by lowering the profits of an innovating firm and by raising the profits of a non-innovating firm up to the point that true quality is revealed.

Consequently, it is not clear a priori which regime, separating *ex-ante* regulation or free entry (with initial pooling), will generate the greater incentives. According to part (iii) the sign of the differential effort $\Delta_e = e^S - e^P$ turns on the cost of information associated with the two regimes. Effort will always be greater in the regime that is associated with the lower cost of information.

The following corollary summarizes a number of special cases, illustrating the spectrum of possible innovation incentives.

Corollary 4.2.1. *(i) For $s = 0$ or $\overline{F} = \widehat{F}$, i.e. for perfectly discriminatory tests or separating fines, we have $e^S = \frac{1-\delta^T}{1-\delta}[\pi(h,h) - \pi(l,l)]$ and, thus, $\Delta_e \geq 0$.*

(ii) For $s = 1$ and $\overline{F} = 0$, i.e. if tests are non-discriminatory and ex-post fines cannot be raised, we have $\Delta_e \leq 0$ if $\pi(l,h) - \pi^P(l) \geq \pi(h,h) - \pi^P(h)$.

(iii) For $\rho = 0$, i.e. for the case that true quality is not discovered during the market process, we have $e^P = 0$ but $e^S > 0$ for s sufficiently small.

Part (i) of the corollary illustrates the two cases in which regulation does not jeopardize R&D effort. More generally, if the access costs imposed on innovating firms are sufficiently low, either because the sorting mechanism is very effective in discriminating types or because high fines can be levied ex-post, then a regime with access regulation will generate a greater innovation effort than pooling.

By contrast, part (ii) illustrates that ineffective ex-ante regulation reduces innovation incentives below those under free entry if the value of cheating as opposed to pooling, $\pi(l,h) - \pi^P(l)$, for a low quality firm exceeds the value of separation as opposed to pooling, $\pi(h,h) - \pi^P(h)$, for a high quality firm. Whether or not this condition holds strongly depends on the market structure. Suppose for instance, that the production of high quality is associated with an extra marginal cost $c > 0$. Given that a cheating low quality firm is able to charge the same price $p\,(h,h)$ and thereby sell the same number of units $x\,(h,h)$ as a separating high quality firm, we have $\pi(l,h) = p\,(h,h)\,x\,(h,h)$ and $\pi(h,h) = [p\,(h,h) - c]\,x\,(h,h)$ implying that $\pi(l,h) - \pi(h,h) = cx\,(h,h)$. By a similar argument we obtain $\pi^P(l) - \pi^P(h) = cx^P$. But then we have $\pi(l,h) - \pi^P(l) \geq \pi(h,h) - \pi^P(h)$ if $x\,(h,h) \geq x^P$. Thus, the sales volume for a high quality product under full information would have to exceed that under pooling. This assertion holds, for instance, for a monopoly under vertical quality preference for quality $U = v\theta - p$, with the willingness to pay v uniformly distributed on $[0,1]$. It also holds for a horizontally differentiated duopoly with preferences $U = \theta - p - tx$, where $x \in [0,1]$ is the consumer's horizontal preference location, and $t > 0$ the disutility from mis-specification [see Sections 6 and 8, respectively]. For either of these cases, demand can be shown to increase in the perceived quality. But then $\theta\,(h) \geq \theta^P$ implies that $x\,(h,h) \geq x^P$. The assertion does not hold, however, for a vertically differentiated duopoly with the firm under consideration acting as the (perceived) "high" quality producer [see Section 7]. For this case, demand is decreasing in the expected quality, so that $\theta\,(h) \geq \theta^P$ implies that $x\,(h,h) \leq x^P$. Hence, while ex-ante regulation that is poorly effective in sorting types lowers innovation incentives under monopoly and horizontal differentiation, it continues to raise them if the market outcome is vertical differentiation.

According to part (iii) innovation incentives under free entry are stifled when the probability that quality is discovered during the market process becomes sufficiently small. This is readily checked by noting that $A = \frac{1-\delta^T}{1-\delta}$ for $\rho = 0$. We then obtain $e^P\,|_{\rho=0} = \max\left\{0; \frac{1-\delta^T}{1-\delta}\left[\pi^P(h) - \pi^P(l)\right]\right\}$, where $\pi^P(h) \leq \pi^P(l)$ holds for $c \geq 0$. The situation of continued pooling that arises in the absence of market transparency stifles all incentives to innovate, as the production of a high quality product is not generating any extra revenue to offset the innovation cost and, possibly, additional marginal cost of production. At the same time, $e^S\,|_{\rho=0} = \frac{1-\delta^T}{1-\delta}[\pi(h,h) - s\pi(l,h) - (1-s)\,\pi(l,l)] > 0$ as long as, for low s, the screening effectiveness of the test is sufficiently high.

5 Welfare

We now turn to the welfare properties of the two regulatory regimes. For this purpose we define the welfare flow as

$$\overline{W} = \overline{CS} + \alpha\overline{\pi},$$

where CS stands for consumer surplus and where $\alpha \in [0,1]$ is the weight assigned to profits. For the purpose of the present analysis, we assume a monopoly situation both in the presence and absence of innovation. We will expand the analysis to a duopoly setting in Sections 7 and 8 below. The $\overline{(\cdot)}$ operator refers to the expected, present value, of the stream from 0 to T of the respective measure, as calculated in analogy to (1), (4) and (5). Since regulation affects the development stage as well, the welfare function must be determined in expected terms at the beginning of stage 1. In other words, it must be a linear combination of the outcomes "innovation" or "no innovation", where the weights are given by e and $1-e$, respectively. Taking into account the cost of effort $D(e)$, we obtain

$$W^k = e^k\overline{W}^k(h) + (1-e^k)\overline{W}^k(l) - \alpha D(e^k),$$

where h and l refer to the true quality of the product, as following from the first-stage outcome, and where $k \in (P,S)$ indicates whether a pooling equilibrium (laissez-faire) or a separating equilibrium (regulation) obtains in stage 2. Continuing to employ the quadratic form $D(e) = \frac{e^2}{2}$, we can then formulate the following result.

Proposition 5.1. *(i) Under laissez-faire (stage 2 pooling) we have:*

$$\begin{aligned} W^P &= \frac{1-\delta^T}{1-\delta}\left[\left(1-e^P\right)CS(l,l) + e^P CS(h,h) + \alpha\pi(l,l)\right] + \frac{\alpha(e^P)^2}{2} \\ &\quad -A\left\{\begin{array}{c} \left(1-e^P\right)\left[CS(l,l) - CS^P(l)\right] + e^P\left[CS(h,h) - CS^P(h)\right] \\ -\alpha\left[\pi^P(l) - \pi(l,l)\right] \end{array}\right\}. \end{aligned}$$

(ii) Under regulation (stage 2 separation) we have:

$$W^S = \frac{1-\delta^T}{1-\delta}\left[\left(1-e^S\right)CS(l,l) + e^S CS(h,h) + \alpha\pi(l,l)\right] + \frac{\alpha(e^S)^2}{2}$$

(iii) The welfare differential is given by:

$$\begin{aligned} \Delta_W &:= W^S - W^P \\ &= \underbrace{(e^S - e^P)\frac{1-\delta^T}{1-\delta}\left[CS(h,h) - CS(l,l)\right] + \frac{\alpha}{2}\left[(e^S)^2 - (e^P)^2\right]}_{\textit{Effort-related}} \\ &\quad \underbrace{+A\left\{\begin{array}{c} \left(1-e^P\right)\left[CS(l,l) - CS^P(l)\right] \\ +e^P\left[CS(h,h) - CS^P(h)\right] - \alpha\left[\pi^P(l) - \pi(l,l)\right] \end{array}\right\}}_{\textit{Information-related}}. \end{aligned} \tag{7}$$

Proof. See Appendix A. ■

Under laissez-faire, welfare can be decomposed into four components: (a) expected consumer surplus that would accrue over the interval $[0,T]$ in the presence of perfect information; (b) the weighed profit stream over the interval $[0,T]$ in the absence of an innovation, again provided there is perfect information; (c) the profit return to an innovation, as measured by $\frac{(e^P)^2}{2}$; and (d) the expected net welfare loss from imperfect information. The latter is composed of the (d.i) net loss of consumer surplus due to imperfect information less (d.ii) the net gain in profit for a producer of low quality due to imperfect information, where $\pi^P(l) \geq \pi(l,l)$.

Under regulation, welfare falls into only three components: (a) expected consumer surplus over the interval $[0, T]$ in the presence of perfect information; (b) the weighted profit stream over the interval $[0, T]$ in the absence of an innovation, again under perfect information; and (c) the profit return to an innovation. Notably, there is no direct welfare impact of the informational asymmetry. This is because the separating character of the ex-ante regulation eliminates all informational asymmetry instantaneously, leaving only an indirect impact through the reduction of the R&D effort.

The welfare differential, Δ_W is then consisting of three terms: (a) the net gain in consumer surplus under perfect information that arises from differential effort $\Delta_e = e_S - e_P$; (b) the differential profit return to innovation, the first two terms combining to an effort-related differential; and (c) the net welfare gain from eliminating the informational asymmetry from the outset, which we label the information-related differential.

In regard to the first two effort related impacts, the following finding is immediate.

Corollary 5.1.1. *If $CS(h, h) \geq CS(l, l)$ then Δ_W increases with Δ_e.*

Under the reasonable assumption that an innovative high quality product is associated with a greater level of consumer surplus under perfect information, welfare tends to be larger in the presence (absence) of regulation whenever it induces an innovative effort that is greater (lower) than the effort under free entry. Welfare gains then accrue both through greater expected consumer surplus and through a greater expected profit return to innovation. The conditions under which regulation stimulates greater effort, such that $\Delta_e > 0$, have been developed and discussed surrounding Proposition 4.2 and Corollary 4.2.1.

However, any welfare impact relating to differential effort is modified by the net welfare gain from eliminating the informational asymmetry. Notably, this impact is ambiguous for two reasons: First, provided it does not innovate, a firm would prefer pooling, $\pi^P(l) \geq \pi(l, l)$, which depresses Δ_W according to the magnitude of α.

Second, in many settings we have $CS(l, l) \geq CS^P(l)$ but $CS(h, h) \leq CS^P(h)$: Consumers benefit from perfect innovation if and only if quality is low after the firm's failure to innovate. Writing the expected quality under pooling as $E(\theta) = e^P\theta(h) + (1 - e^P)\theta(l) \in [\theta(l); \theta(h)]$, with $\theta(l) < \theta(h)$ denoting measures of quality,it follows that consumers tend to have anticipated too high a quality level, if quality turns out to be low. This implies that for any given price some consumers purchase the product under pooling who would not have done so under perfect information. In addition, we typically have $p(l, l) < p^P < p(h, h)$, implying that all consumers are worse off due to the (unwarranted) price increase under pooling. In contrast, if quality is high after a successful innovation, consumers may prefer to remain uninformed (Matthews and Postlewaite, 1985; Creane, 2008; Piccolo et al., 2015; Rhodes and Wilson, 2015). In this case, two offsetting effects are at work: For a given price the anticipation of a lower than the true level of quality induces some consumers to forego a purchase under pooling that they would have realized under perfect information. But this effect is offset by the price under pooling falling short of the full information price.

If $CS(l, l) \geq CS^P(l)$ and $CS(h, h) \leq CS^P(h)$ the overall impact of restoring full information on consumer surplus is ambiguous and obviously depends on the probability of innovation, e^P. It would be wrong, however, to conclude that the impact is positive as long as e^P is sufficiently low. This is because the expected quality under pooling, $E(\theta)$, itself is a function of e^P, which therefore also has a bearing on the associated levels of consumer surplus $CS^P(l)$ and $CS^P(h)$.

A general assessment is difficult without placing specific assumptions on the underlying utility function, deriving the demand function, and explicitly solving for the profit maximizing allocation. We devote the next section to the analysis of three specific examples.

6 Example 1: Monopoly under vertical preferences

The general model can be applied to a series of interesting cases. One natural setting relates to a situation in which consumers have vertical preferences, i.e. in which they are heterogeneous in their willingness to pay for quality. In this section, we assume that the innovating firm becomes a monopolist upon entry. Monopoly represents a particularly realistic scenario in pharmaceuticals given patent protection of new drugs.

Assume a consumer's net surplus from purchasing one unit of the product of quality $\theta \geq 0$ is given by

$$U = v\theta - p$$

with $v \in [0,1]$ the willingness to pay, following a uniform distribution with unit density; and p the price of the product. We assume that the firm that is considering entry to the market produces a high quality $\theta(h) = \overline{\theta}$ if it innovates and a low quality $\theta(l) = \underline{\theta}$ if it fails to do so. Naturally, $\overline{\theta} > \underline{\theta} \geq 0$, where $\underline{\theta} = 0$ represents the case where a product of revealed low quality is not purchased at all or where such a product is not admitted to the market. Finally, we assume

$$c \leq \underline{\theta} < \overline{\theta} - \sqrt{\overline{\theta}\underline{\theta}}, \tag{8}$$

which guarantees that $\pi(h,h) > \pi(l,l) \geq 0$ and $\pi^P(l) > \pi^P(h) \geq 0$.

Given that consumers condition their purchasing decision on the perceived quality, $\widehat{\theta}$, we obtain the marginal consumer $\widehat{v} = \frac{p}{\widehat{\theta}}$ and from this the demand function $d\left(\widehat{\theta}, p\right) = 1 - \frac{p}{\widehat{\theta}}$ and profit function $\pi\left(\theta, \widehat{\theta}, p\right) = [p - c(\theta)]\, d\left(\widehat{\theta}, p\right)$. Under perfect information, the firm's problem $\max_p \pi(\theta, \theta, p)$ then yields the following solution: $p^*(\theta,\theta) = \frac{\theta + c(\theta)}{2}$; $d^*(\theta,\theta) = d(\theta, p^*(\theta,\theta)) = \frac{\theta - c(\theta)}{2\widehat{\theta}}$ and $\pi^*(\theta,\theta) = \pi(\theta,\theta,p^*(\theta,\theta)) = \frac{[\theta - c(\theta)]^2}{4\widehat{\theta}}$. In the case of pooling we assume that the price needs to satisfy the intuitive criterion, implying in particular, that the high quality producer must not have an incentive to deviate to a different price. Thus, we obtain $p^P = p^*\left(\overline{\theta}, \theta^P\right) = \frac{\theta^P + c}{2}$; $d^P = d\left(\theta^P, p^P\right) = \frac{\theta^P - c}{2\widehat{\theta}}$ and $\pi^*\left(\theta, \theta^P\right) = \pi\left(\theta, \theta^P, p^P\right) = \frac{\left[p^P - c(\theta)\right]\left(\theta^P - c\right)}{2\theta^P}$. By a similar argument, we have $\pi^*\left(\underline{\theta}, \overline{\theta}\right) = \pi\left(\underline{\theta}, \overline{\theta}, p^*\left(\overline{\theta}, \overline{\theta}\right)\right)$.

Assuming that

$$\overline{F} < \widehat{F} = \frac{\pi(l,h) - \pi(l,l)}{\rho} = \frac{\overline{\theta} - \underline{\theta}}{4\rho} - \frac{c^2}{4\rho\overline{\theta}}, \tag{9}$$

separation will always have to rely on *ex-ante* regulation. We then find the separating cost to be

$$C(l, \overline{q}) = A\left[\pi(l,h) - \pi(l,l) - \rho\overline{F}\right] = A\left(\frac{\overline{\theta} - \underline{\theta}}{4} - \frac{c^2}{4\overline{\theta}} - \rho\overline{F}\right).$$

6.1 Innovation incentives

As is readily checked we then obtain

$$\begin{aligned}
e^S &= \max\left\{\frac{1-\delta^T}{1-\delta}\left[\frac{\left(\overline{\theta}-c\right)^2}{4\overline{\theta}} - \frac{\underline{\theta}}{4}\right] - sA\left(\frac{\overline{\theta}-\underline{\theta}}{4} - \frac{c^2}{4\overline{\theta}} - \rho\overline{F}\right); 0\right\}, \\
e^P &= \max\left\{\frac{1-\delta^T}{1-\delta}\left[\frac{\left(\overline{\theta}-c\right)^2}{4\overline{\theta}} - \frac{\underline{\theta}}{4}\right] - A\left[\frac{\left(\overline{\theta}-c\right)^2}{4\overline{\theta}} - \frac{\left(\theta^P-c\right)^2}{4\theta^P} + \frac{\theta^P - \underline{\theta}}{4} - \frac{c^2}{4\theta^P}\right]; 0\right\},
\end{aligned}$$

and, thus,

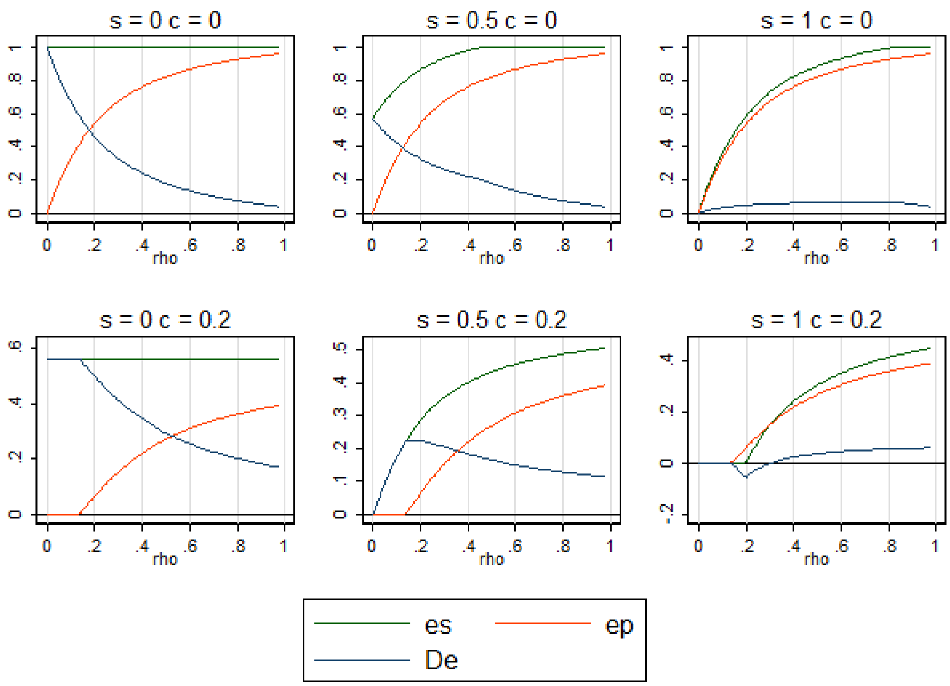
$$\Delta_e \geq 0 \Leftrightarrow \frac{(1-s)\left(\overline{\theta}-\underline{\theta}\right)}{4} - \frac{c^2\left[2\overline{\theta} - (1+s)\,\theta^P\right]}{4\overline{\theta}\theta^P} + s\rho\overline{F} \geq 0. \tag{10}$$

Hence, the wedge between innovation effort is driven by three factors: (a) a pure quality gap, favouring greater innovation effort under the separating regime; this gap vanishes, however, to the extent that ex-ante sorting is inefficient, as measured by a high s. (b) the quality cost, favouring lower innovation effort under the separating regime; this impact vanishes to the extent that pooling quality is approaching the high quality level, which in turn is true if innovation efforts are high in both regimes. (c) the expected fine, which favours greater innovation under the separating regime. The following is then readily established.

Proposition 6.1. *Under monopoly with vertical preferences ex-ante regulation (i) always induces (weakly) greater innovation effort if $c = 0$; (ii) induces lower innovation effort if $c > 0$, $s \to 1$ and $\rho\overline{F} \to 0$.*

In order to assess the magnitude of the impact of s, ρ and c on innovation effort we resort to a numerical analysis. The following Figure 1 plots the effort levels e^S (green) and e^P (red) as well as the difference Δ_e (blue) depending on ρ for six combinations of $s \in \{0, 0.5, 1\}$ and $c \in \{0, 0.2\}$. The remaining parameters are set to $\delta = 0.9$, $T = 10$, $\overline{\theta} = 0.9$ and $\underline{\theta} = 0.2$. The fine is set to $\overline{F} = 0.05\left(\overline{\theta} - \underline{\theta}\right) = 0.035$.

Figure 1: Effort under pooling and separation



From the figure it is clear that, all else equal, "market transparency", ρ, significantly affects innovation in free market: the higher the probability of being discovered, the stronger the incentive for innovation, e^P, when access to market is not regulated. Since firms expect to enjoy shorter periods of "'cheating"', there will be lower benefits from this strategy. While a higher probability of revelation, ρ, also enhances the innovation incentive under ex-ante regulation, e^S, the extent to which it does varies with the effectiveness of the screening process, s. Indeed, if a perfect screening technology imposes no cost on the high quality producer ($s = 0$), then innovation effort is at a constant (maximal) level regardless of the ex-post probability of discovery. For intermediate levels of screening effectiveness, the "transparency" of the market plays an increasing role in stimulating effort, e^S. This is because by lowering the returns to cheating, it relaxes the incentive compatibility constraint and, thus, the cost imposed on an innovating firm. For ineffective screening ($s = 1$) it turns out that increasing ρ is generating a stronger effort incentive than under laissez-faire. Here, the expectation of an ex-post fine is generating additional leverage. Thus, while the effort-gap $\Delta_e > 0$ is decreasing with market transparency for effective screening, it is increasing for ineffective screening.

As we would expect, for $c = 0$ both effort levels are strictly positive for $\rho > 0$, with $\Delta_e > 0$. This changes for the case where $c = 0.2$, where both effort levels are strictly lower than in the absence of marginal cost, with $e^P = 0$ and $e^S = 0$ for low levels of ρ. Notably, the less effective the screening mechanism (higher s), the higher the level of e^P relative to e^S. For an entirely ineffective mechanism ($s = 1$), laissez-faire now generates a greater level of effort for a range of intermediate values of ρ, for which we then find $\Delta_e < 0$. Only at the highest levels of ρ would the leverage related to the fine restore again the positive differential $\Delta_e > 0$.

6.2 Welfare

Generally, consumer surplus can be written as

$$CS\left(\theta,\widehat{\theta},p\right)=\int_{\widehat{v}}^{1}\left(v\theta-p\right)dv=\left(1-\widehat{v}\right)\left[\frac{\left(1+\widehat{v}\right)\theta}{2}-p\right]=\frac{\widehat{\theta}-p}{\widehat{\theta}}\left(\frac{\left(\widehat{\theta}+p\right)\theta}{2\widehat{\theta}}-p\right), \tag{11}$$

with $p=p^{*}\left(\theta,\theta\right)$ in the case of separation and $p=p^{P}=p^{*}\left(\overline{\theta},\theta^{P}\right)$ in the case of pooling. Defining,

$$\Delta_{CS}^{i}\left(\theta^{P},c\right):=CS\left(i,i\right)-CS^{P}\left(i\right);\quad i=h,l$$

as the conditional (on $i=h,l$) net gain in consumer surplus from perfect information and

$$\Delta_{CS}^{Info}:=\left(1-e^{P}\right)\Delta_{CS}^{l}\left(\theta^{P},c\right)+e^{P}\Delta_{CS}^{h}\left(\theta^{P},c\right).$$

as the information-related difference in expected consumer surplus, we obtain

Proposition 6.2. *Under monopoly with vertical preferences ex-ante regulation (i) always raises consumer surplus in the absence of innovation, i.e.* $\Delta_{CS}^{l}\left(\theta^{P},c\right)\geq 0$; *(ii) raises consumer surplus in the presence of regulation, i.e.* $\Delta_{CS}^{h}\left(\theta^{P},c\right)\geq 0$, *if and only if* $c\in[\underline{c},\underline{\theta}]$ *and* $e^{P}\in[0,\overline{e}]$, *with* $\underline{c}\in[0,\underline{\theta}]$ *and* $\overline{e}\in[0,1]$; *and (iii) always raises expected consumer surplus,* $\Delta_{CS}^{Info}\geq 0$, *for all* $e^{P}\in[0,1]$, *with a strict equality for* $c=0$.

Proof. See Appendix A. ■

For the reasons discussed earlier consumers are always better off when information about low product quality is made available instantaneously [part (i)]. Interestingly, the converse is not necessarily true when quality is high. Indeed, if the innovation effort is relatively low, implying that under pooling consumers are expecting a relatively low quality, and if the production cost associated with high quality is sufficiently high, then consumers are better off with the ex-ante revelation of high quality [part (ii)]. If $c>0$, the pooling of a high quality product generates a demand distortion which offsets the consumers' benefit from the lower pooling price. To see this, consider the marginal consumer under a profit maximizing allocation when true quality is high, $\widehat{v}^{*}\left(\overline{\theta},\widehat{\theta}\right)=\frac{p^{*}}{\widehat{\theta}}=\frac{\widehat{\theta}+c}{2\widehat{\theta}}=\frac{1}{2}+\frac{c}{2\widehat{\theta}}$. For $c=0$ we have $\widehat{v}^{*}\left(\overline{\theta},\overline{\theta}\right)=\widehat{v}^{*}\left(\overline{\theta},\theta^{P}\right)$, implying that the wrong expectation about quality is not generating a distortion in demand. But for $c>0$ we have $\widehat{v}^{*}\left(\overline{\theta},\overline{\theta}\right)<\widehat{v}^{*}\left(\overline{\theta},\theta^{P}\right)$, implying that too few consumers are purchasing under pooling. This effect is the stronger the higher c and the lower θ^{P} or e^{P}, respectively. According to part (iii) of the proposition, expected consumer surplus is always higher if quality information is revealed even if consumers prefer pooling after an innovation has occurred. This holds for any $c\in(0,\underline{\theta}]$. Consumers are indifferent about the mode of regulation if and only if $c=0$. In this case, the expected gains to consumers of ex-ante regulation in the absence of innovation are exactly offset by the expected losses in the presence of information.

For the special case where $c=0$, we then obtain

$$\Delta_{W}=\underbrace{\overbrace{\Delta_{e}}^{\geq 0}\left[\frac{1-\delta^{T}}{1-\delta}\frac{\overline{\theta}-\underline{\theta}}{8}+\frac{\alpha}{2}(e^{S}+e^{P})\right]}_{\textit{Effort-related}}-\underbrace{A\alpha e^{P}\frac{\overline{\theta}-\underline{\theta}}{4}}_{\textit{Information-related}},$$

where $\Delta_{e}:=e^{S}-e^{P}\geq 0$ follows from (10) when setting $c=0$. Based on this we find

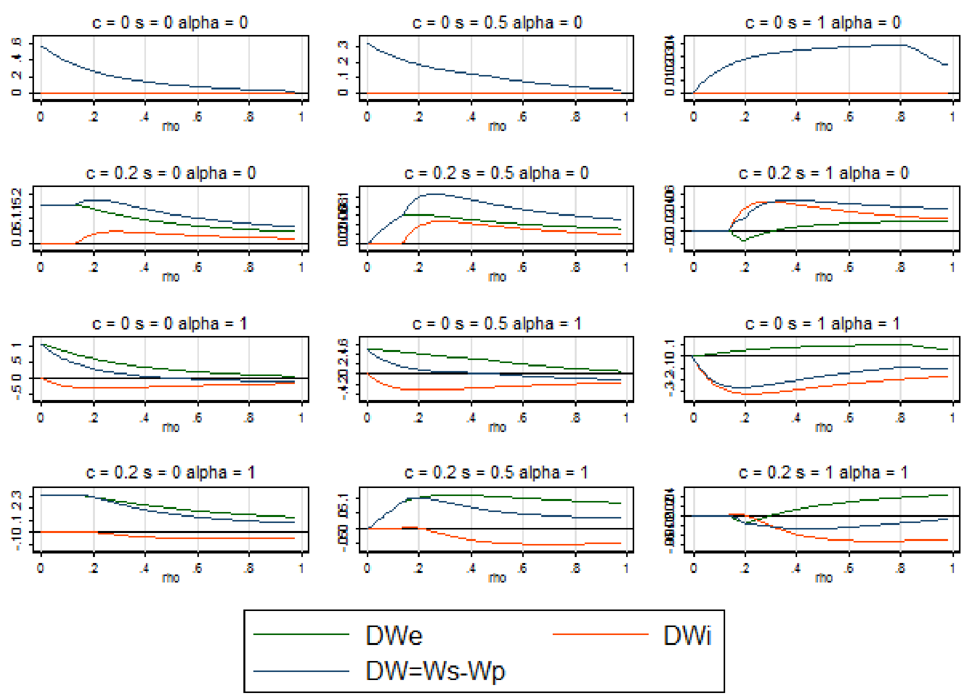
Proposition 6.3. *Under monopoly with vertical preferences and* $c=0$, *ex-ante regulation (i) (weakly) raises welfare if* $\alpha=0$; *(ii) lowers welfare if* $\alpha e^{P}>0$ *as well as* $s\rightarrow 1$ *and* $\rho\overline{F}\rightarrow 0$ *such that* $\Delta_{e}\rightarrow 0$.

A clear-cut welfare ranking between the two regulatory regimes is possible in two cases: (i) If profit does not count toward welfare, then ex-ante regulation is always the preferred option as for $c = 0$ it generates the greater R&D incentive. While consumers value an innovative product at $\frac{1-\delta^T}{1-\delta}\frac{\overline{\theta}-\underline{\theta}}{8}$, they are indifferent (in expected terms) about whether or not they are informed about product quality. Thus, (ii) if profit counts toward welfare and if a relative ineffective regulatory mechanism only leads to a weak leverage of effort, then the laissez-faire regime leads to the greater welfare.

An analysis for the case with $c > 0$ generally gives rise to ambiguity. While giving rise to an indeterminate effort differential, $\Delta_e \gtreqless 0$, the presence of quality-related production costs also lowers the return to innovation to both consumers and producers. In contrast, it tends to raise the information-related welfare gain from innovation.

In order to gain an understanding of the magnitudes of the trade-offs involved we resort to a numerical simulation. Results are shown in Figure 2 below. The analysis contained in Figure 2 is based on the same parameter values, $\delta = 0.9$, $\overline{\theta} = 0.9$, $\underline{\theta} = 0.2$, $\overline{F} = 0.035$ that have been chosen for the analysis depicted in Figure 1.[16] Here, the blue plot "DW" corresponds to the full welfare differential Δ_W, while the green plot "DWe" and the red plot "DWi" refer to the effort-related and information-related parts of the welfare differential, respectively. In addition to the six cases, referring to the combinations of $s \in \{0, 0.5, 1\}$ and $c \in \{0, 0.2\}$, we consider in addition the two polar cases $\alpha = \{0, 1\}$.

Figure 2: Welfare in monopoly



As one would expect the effort-related welfare differential DWe is generally positive, reflecting the greater effort exerted under ex-ante regulation, $\Delta_e > 0$. The one exception is the case where for $c = 0.2$, $s = 1$, and ρ sufficiently low, we have $\Delta_e \leq 0$ (see Figure 1). In this case, the effort-related welfare differential also turns negative.

As it turns out, the sign of the information-related welfare differential DWi crucially depends on whether or not profits are counted toward welfare. Consider first a setting where for $\alpha = 0$ the welfare measure is based on consumer surplus alone. As we would expect, DWi is zero for $c = 0$ and strictly positive for

[16]Simulations for different values of δ have been performed, but results are not qualitatively different from the cases shown here.

$c = 0.2$, implying that the total welfare differential DW is also positive throughout. In contrast, DWi turns negative once profit is taken into account, i.e. for $\alpha = 1$.[17] The total welfare impact of regulation now very much depends on the screening effectiveness, s, and on the transparency of the market, ρ. Indeed, for $c = 0$, regulation generates a higher welfare level only if both s and ρ are sufficiently low. Indeed, for an ineffective test ($s = 1$) laissez-faire is now strictly preferred on information grounds even if for $c = 0$ regulation is generating a greater R&D effort. Strikingly, for $c = 0.2$, the total welfare differential DW remains positive, both for $s = 0$ and $s = 0.5$ and only turns negative for $s = 1$.

In summary, it turns out that regulation tends to be conducive to welfare whenever (a) profit does not count toward welfare, e.g. because the producer is foreign; and otherwise when (b) the transparency of the market is low and (c) the screening effectiveness is sufficiently high. (d) Surprisingly perhaps, the welfare case for regulation is stronger if innovative products come with a greater production cost.

7 Example 2: Vertically differentiated duopoly

In many cases the launch of a new product can be described by a situation in which an incumbent is already in the market and a potential entrant must decide on an entry strategy. Being perceived as the seller of a high quality product should give an advantage in terms of market power, but the development of truly high quality is costly[18]. In our model, this cost is represented by the effort spent in trying to develop an innovative product, while we assume, for simplicity, that $c = 0$. Consumers condition their purchasing decision on the perceived quality, $\widehat{\theta}$, of the new product as opposed to the quality $\theta_0 \leq \widehat{\theta}$ of the incumbent's product, as well as on the selling prices p and p_0.[19] For the preference specification described in the previous section, we then obtain $\widehat{v}_1 = \frac{p-p_0}{\widehat{\theta}-\theta_0}$ as the marginal consumer who is indifferent between the new and the incumbent's product and $\widehat{v}_0 = \frac{p_0}{\theta_0}$ as the marginal consumer who is indifferent between the incumbent's product and no purchase at all. From this we can readily derive the demand functions $d\left(\widehat{\theta}, p, \theta_0, p_0\right) = 1 - \frac{p-p_0}{\widehat{\theta}-\theta_0}$ and $d_0\left(\widehat{\theta}, p, \theta_0, p_0\right) = \frac{p-p_0}{\widehat{\theta}-\theta_0} - \frac{p_0}{\theta_0}$. Solving for the Bertrand-Nash equilibrium in the ensuing simultaneous moves vertical duopoly game, in which the firms maximize profit $\pi = pd\left(\widehat{\theta}, p, \theta_0, p_0\right)$ and $\pi_0 = p_0 d_0\left(\widehat{\theta}, p, \theta_0, p_0\right)$, respectively, we obtain[20]

$$
\begin{aligned}
p^*\left(\widehat{\theta}, \theta_0\right) &= \frac{2\widehat{\theta}\left(\widehat{\theta}-\theta_0\right)}{4\widehat{\theta}-\theta_0}; \quad p_0^*\left(\widehat{\theta}, \theta_0\right) = \frac{\theta_0\left(\widehat{\theta}-\theta_0\right)}{4\widehat{\theta}-\theta_0}; \\
d^*\left(\widehat{\theta}, \theta_0\right) &= \frac{2\widehat{\theta}}{4\widehat{\theta}-\theta_0}; \quad d_0^*\left(\widehat{\theta}, \theta_0\right) = \frac{\widehat{\theta}}{4\widehat{\theta}-\theta_0}; \\
\pi^*\left(\widehat{\theta}, \theta_0\right) &= \frac{4\widehat{\theta}^2\left(\widehat{\theta}-\theta_0\right)}{\left(4\widehat{\theta}-\theta_0\right)^2}; \quad \pi_0^*\left(\widehat{\theta}, \theta_0\right) = \frac{\widehat{\theta}\theta_0\left(\widehat{\theta}-\theta_0\right)}{\left(4\widehat{\theta}-\theta_0\right)^2}.
\end{aligned} \tag{12}
$$

Noting that $\frac{\partial \pi^*\left(\widehat{\theta}, \theta_0\right)}{\partial \widehat{\theta}} = \frac{4\widehat{\theta}\left(4\widehat{\theta}^2 - 3\widehat{\theta}\theta_0 + 2\theta_0^2\right)}{\left(4\widehat{\theta}-\theta_0\right)^3} > 0$ it follows that

$$
\begin{aligned}
\pi(h, h) &= \pi(l, h) = \pi^*\left(\overline{\theta}, \theta_0\right) \\
&\geq \pi^P(h) = \pi^P(l) = \pi^*\left(\theta^P, \theta_0\right) \\
&\geq \pi(l, l) = \pi^*\left(\underline{\theta}, \theta_0\right) \geq 0.
\end{aligned}
$$

[17] For $c = 0.2$ this is strictly true only for high enough values of ρ, DWi being zero or close to zero for low values of ρ.

[18] In pharmaceuticals, it is quite common to launch "me-too" drugs, i.e. chemically and therapeutically similar to the incumbent products. Despite the similarities, however, these products can be percieved as qualitatively different. In many cases, patients beliefs can affect even the effectiveness of the drug. Although this seems to suggest that there is a link between true and percieved quality, here we assume perfect orthogonality between the two.

[19] Here, we assume that the incumbent's quality θ_0 can be replicated at zero cost, e.g. because the patent on the design θ_0 has expired.

[20] For $c = 0$, the pooling price is independent of a firm's own type, θ.

where $\pi^*(\underline{\theta}, \theta_0) = 0$ holds for $\underline{\theta} = \theta_0$. We continue to assume $\overline{F} < \widehat{F} = \frac{\pi(l,h)-\pi(l,l)}{\rho}$, implying that separation will always have to rely on *ex-ante* regulation. We then find the separating cost to be $C(l, \overline{q}) = A\left[\pi(l,h) - \pi(l,l) - \rho\overline{F}\right]$.

7.1 Innovation incentives

As is readily checked we obtain

$$\begin{aligned} e^S &= \left(\frac{1-\delta^T}{1-\delta} - sA\right)[\pi(h,h) - \pi(l,l)] + sA\rho\overline{F}, \\ e^P &= \left(\frac{1-\delta^T}{1-\delta} - A\right)[\pi(h,h) - \pi(l,l)], \end{aligned}$$

and therefore

$$\Delta_e \geq 0 \Leftrightarrow (1-s)[\pi(h,h) - \pi(l,l)] + s\rho\overline{F} \geq 0.$$

Similar to the monopoly case with $c = 0$,[21] innovation effort is always greater under regulation if the ex-ante screening is effective in sorting types, $s < 1$, or if there is scope for ex-post punishment, $s\rho\overline{F} > 0$.

7.2 Welfare

Consumer surplus can be written as

$$\begin{aligned} CS\left(\theta, \widehat{\theta}\right) &= \int_{\widehat{v}_1}^{1} (v\theta - p^*)\, dv + \int_{\widehat{v}_0}^{\widehat{v}_1} (v\theta - p_0^*)\, dv \\ &= \frac{2\widehat{\theta}\left[\left(3\widehat{\theta} - \theta_0\right)\theta - 2\left(\widehat{\theta} - \theta_0\right)\widehat{\theta}\right]}{\left(4\widehat{\theta} - \theta_0\right)^2} + \frac{\widehat{\theta}^2\theta_0}{2\left(4\widehat{\theta} - \theta_0\right)^2}, \end{aligned} \tag{13}$$

where the first and second terms give the consumer surplus for those consuming the new product (true quality θ, perceived as $\widehat{\theta}$) and incumbent's product (quality θ_0), respectively. Differentiation gives

$$\begin{aligned} \frac{\partial CS\left(\theta, \widehat{\theta}\right)}{\partial \theta} &= \frac{2\widehat{\theta}\left(3\widehat{\theta} - \theta_0\right)}{\left(4\widehat{\theta} - \theta_0\right)^2} > 0 \\ \frac{\partial CS\left(\theta, \widehat{\theta}\right)}{\partial \widehat{\theta}} &= \frac{-2\left[\left(2\widehat{\theta} - \theta_0\right)\theta_0\theta + 2\left(4\widehat{\theta}^2 - 3\widehat{\theta}\theta_0 + 2\theta_0^2\right)\widehat{\theta}\right]}{\left(4\widehat{\theta} - \theta_0\right)^3} - \frac{\widehat{\theta}\theta_0^2}{\left(4\widehat{\theta} - \theta_0\right)^3} < 0, \end{aligned}$$

implying that for a given perceived quality a higher true quality raises the surplus of consumers of the new product while leaving the surplus of consumers of the incumbent's product unaffected; and that an increase in the perceived quality lowers the surplus of all consumers. This is because higher perceived quality implies a greater perceived degree of product differentiation, which allows both firms to raise their price.

On the basis of these results we find that

$$\begin{aligned} CS^P(h) &= CS\left(\overline{\theta}, \theta^P\right) > CS\left(\underline{\theta}, \theta^P\right) = CS^P(l) \\ CS(l,l) &= CS\left(\underline{\theta}, \underline{\theta}\right) \geq CS\left(\underline{\theta}, \theta^P\right) = CS^P(l) \\ CS(h,h) &= CS\left(\overline{\theta}, \overline{\theta}\right) \leq CS\left(\overline{\theta}, \theta^P\right) = CS^P(h) \end{aligned}$$

implying that similar to the monopoly case (i) consumers are unambiguously better off if the true quality of a pooled product is high (rather than low); (ii) consumers are worse off under pooling as compared to

[21] In fact, the monopoly case corresponds to the limiting case where $\theta_0 = 0$.

separation if the true quality of the new product is low; and (iii) consumers are better off under pooling if the true quality of the new product is high. In contrast to the monopoly setting, $CS(h,h) \geq CS(l,l)$ is not always guaranteed. This is because the provision of an innovative product not only generates additional surplus for the consumers of the high quality product, but it also expands product differentiation and, thereby, induces a price increase affecting the consumers of both variants. In the following, we assume θ_0 to be sufficiently low, which guarantees that $CS(h,h) \geq CS(l,l)$.[22]

When determining the welfare impacts of regulation, we now need to take into additional account the profit $\pi_0^*(\widehat{\theta},\theta_0)$ of the incumbent firm. Amending (7) accordingly, we can write

$$\begin{aligned}\Delta_W \quad = \quad & \underbrace{\Delta_e \left\{ \frac{1-\delta^T}{1-\delta}\left[CS(h,h) - CS(l,l)\right] + \frac{\alpha}{2}(e^S + e^P) + \frac{1-\delta^T}{1-\delta}\alpha\left[\pi_0^*(\overline{\theta},\theta_0) - \pi_0^*(\underline{\theta},\theta_0)\right]\right\}}_{\textit{Effort-related}} \\ & \underbrace{+A\left\{\begin{array}{c} \left(1-e^P\right)\left[CS(l,l) - CS^P(l)\right] + e^P\left[CS(h,h) - CS^P(h)\right] \\ -\alpha\left[\pi^P(l) - \pi(l,l) - \Delta_{\pi_0}\right]\end{array}\right\}}_{\textit{Information-related}}, . \end{aligned} \tag{14}$$

where $\pi_0^*(\overline{\theta},\theta_0) - \pi_0^*(\underline{\theta},\theta_0) \geq 0$ measures the incumbent's gain from greater product differentiation in the case of innovation,[23] and where $\Delta_{\pi_0} := \left(1-e^P\right)\pi_0^*(\underline{\theta},\theta_0) + e^P\pi_0^*(\overline{\theta},\theta_0) - \pi_0^*(\theta^P,\theta_0)$ is the incumbent's expected net return to facing a rival for whom the product quality is known rather than pooled. Thus, the effort-related differential increases, as the incumbent benefits from facing a rival with a more differentiated innovative product. In contrast, it can be shown that $\Delta_{\pi_0} \leq 0$, implying that the incumbent prefers pooling in expected terms.[24] To the extent that profits count towards welfare, this lowers the information-related welfare return to separation. We are able to establish the following finding.

Proposition 7.1. *Under vertically differentiated duopoly with $c = 0$, ex-ante regulation (i) (weakly) raises welfare for $\alpha = 0$ if $CS(h,h) \geq CS(l,l)$; (ii) raises welfare for $\Delta_e \to 0$ and $\alpha \in (0,\overline{\alpha})$, with $\overline{\alpha} \in (0,1)$ if and only if $e^P \in (0,\overline{e})$, with $\overline{e} \in (0,1)$.*

Proof. See Appendix A. ■

Similar to the case of monopoly under vertical preferences and zero variable cost of quality $c = 0$, ex-ante regulation leads to an increase in consumer surplus and, thus, to a greater welfare level if $\alpha = 0$. As the proof shows, however, consumer surplus now increases not only due to a differential effort $\Delta_e \geq 0$ but also due to an information-related differential $\left(1-e^P\right)\left[CS(l,l) - CS^P(l)\right] + e^P\left[CS(h,h) - CS^P(h)\right] > 0$ for $e^P \in (0,1)$. Consumers now strictly prefer to be informed about quality whenever there is uncertainty about product quality, i.e. whenever $e^P \notin \{0,1\}$. This is because, in contrast to the monopoly case, the state of information also affects the extent of perceived product differentiation and, thus, the extent of competition. Again there is ambiguity in as far as pooling is stifling competition in the absence of innovation while it is enhancing competition in the presence of innovation. As it turns out, however, the expected returns to consumers from having greater competition at the "low end", i.e. in the absence of innovation, outweigh the expected loss from a stifling of competition at the "high end".

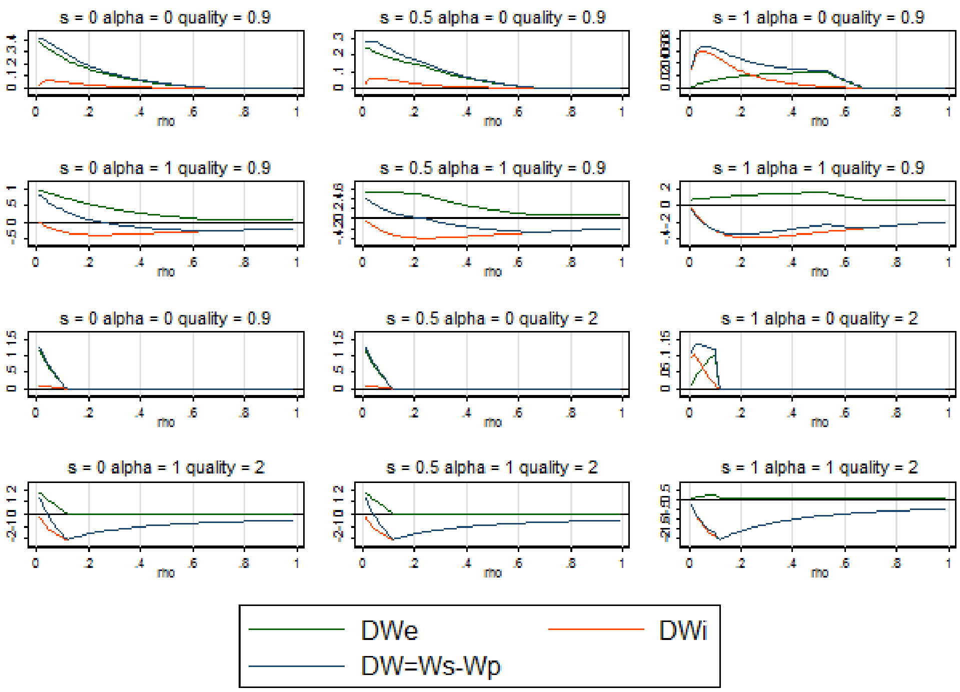
Even with profit counting toward welfare to some extent, i.e. for $\alpha \in (0,\overline{\alpha})$, regulation tends to be the welfare-superior arrangement on informational grounds alone (i.e. for $\Delta_e = 0$) as long as the overall effort-incentive is not too large. Only if innovation is very likely will the loss in profit under regulation, $\pi^P(l) - \pi(l,l) - \Delta_{\pi_0} < 0$, overcompensate the information-related gain in consumer surplus.

[22] To see this note that
$$\frac{dCS\,(\theta,\theta)}{d\theta} = \frac{\partial CS\,(\theta,\theta)}{\partial\theta} + \frac{\partial CS\,(\theta,\theta)}{\partial\widehat{\theta}} = \frac{8\theta^3 - 6\theta^2\theta_0 - 5\theta\theta_0^2}{(4\theta-\theta_0)^3},$$
which is positive if $\theta_0 \to 0$.

[23] The sign is readily verified when noting that $\frac{\partial\pi_0^*(\widehat{\theta},\theta_0)}{\partial\widehat{\theta}} = \frac{\theta_0\left(6\widehat{\theta}^2 - 4\widehat{\theta}\theta_0 + \theta_0^2\right)}{\left(4\widehat{\theta}-\theta_0\right)^3} > 0$.

[24] It can be shown that Δ_{π_0} is a strictly convex function in e^P, where $\Delta_{\pi_0}|_{e^P=0} = \Delta_{\pi_0}|_{e^P=1} = 0$. But then, $\Delta_{\pi_0} < 0$ must hold for all $e^P \in (0,1)$.

Figure 3: Welfare in a duopoly



Again, a numerical exercise confirms the theoretical insights. Figure 3 plots the welfare differentials for the vertically differentiated duopoly in analogy to Figure 1, based on the same parameter values with the additional assumptions $c = 0$ and $\theta_0 = \underline{\theta} = 0.2$. Again, the blue plot "DW" corresponds to the full welfare differential Δ_W, while the green plot "DWe" and the red plot "DWi" refer to the effort-related and information-related parts of the welfare differential, respectively. As expected, for $\alpha = 0$, the total welfare differential is positive throughout, based on both, a positive effort-related differential and a positive information-related differential. For effective screening, i.e. for $s = 0$, the welfare gains from regulation diminish with increasing levels of transparency, ρ, with laissez-faire generating the same maximal innovation incentive $e^P = e^S = 1$ for high levels of ρ. In this case, the information-related differential also turns to zero, as under both regimes any uncertainty about product quality is eliminated. For less effective screening, a peak in DW develops for less effective screening, where both the effort-related and the information-related welfare differential in favour of regulation increase with transparency when starting from low levels $\rho \to 0$.

If profits count toward welfare, i.e. for $\alpha = 1$, the effort-related welfare differential tends to be larger in favour of regulation, but the information-related welfare differential is now reversed. Indeed, information-related impacts tend to dominate for high levels of transparency and for low levels of screening effectiveness, then implying a negative welfare impact of regulation. This is true in particular for poorly effective screening, i.e. for $s = 1$, where DW is negative throughout.

In conclusion, it is worth pointing out that in the case of vertically differentiated duopoly in particular, consumer and producer interests are at odds. While in expected terms, consumers tend to prefer regulation, in particular on information-grounds, the converse is true for firms. But the same divergence of interest arises conditionally: If innovation has occurred, consumers would benefit from pooling, whereas firms would prefer to be separated. If innovation has failed, it is the firms who would benefit from pooling, whereas consumers benefit from the revelation of quality.

8 Example 3: Horizontal differentiation with quality

Finally, we will study a setting of horizontal product differentiation to illustrate the robustness of our results. Specifically, we consider a setting where consumers are distributed uniformly along the $[0,1]$ Hotelling line, with one firm placed at each of the end points. A priori, both firms, 0 and 1, can produce the same baseline quality $\underline{\theta}$ but firm 1 has the opportunity to innovate. If innovation is successful (with probability e) then firm 1 has access to a superior quality $\overline{\theta} = \underline{\theta} + \Delta$ otherwise it will continue to produce $\underline{\theta}$. A consumer located at $x \in [0,1]$ on the Hotelling line attains a net surplus $U(x,0) = \underline{\theta} - p_0 - tx$ when purchasing a unit of product 0. Here, $t > 0$ denotes the consumer's "transport cost", i.e. the degree to which she suffers a disutility from product mismatch. Similarly, the consumer expects to attain a surplus of $U(x,1) = \widehat{\theta} - p_1 - t(1-x)$ when purchasing a unit of product 1, where $\widehat{\theta} \in \left\{\overline{\theta}, \theta^P, \underline{\theta}\right\}$ denotes the perceived quality. Again, we assume the absence of a quality related production cost, i.e. $c = 0$.

Given that the market is covered, the marginal consumer is located at $\widehat{x} = \frac{1}{2} + \frac{p_1 - p_0 - \widehat{\Delta}}{2t}$, with $\widehat{\Delta} := \widehat{\theta} - \underline{\theta}$. From this, we obtain the demand functions $d_1\left(p_1, p_0, \widehat{\Delta}\right) = 1 - \widehat{x} = \frac{1}{2} - \frac{p_1 - p_0 - \widehat{\Delta}}{2t}$ and $d_0\left(p_1, p_0, \widehat{\Delta}\right) = \widehat{x} = \frac{1}{2} + \frac{p_1 - p_0 - \widehat{\Delta}}{2t}$, respectively. Solving for the Bertrand-Nash equilibrium in the ensuing simultaneous moves horizontal duopoly game (Economides, 1989; Levin et al, 2009; Hotz and Xiao, 2013), in which the firms maximize profits $\pi_1 = p_1 d_1\left(p_1, p_0, \widehat{\Delta}\right)$ and $\pi_0 = p_0 d_0\left(p_1, p_0, \widehat{\Delta}\right)$, respectively, we obtain the following equilibrium prices, demand levels and profits:

$$\begin{aligned}
p_1^*\left(\widehat{\Delta}\right) &= \frac{3t + \widehat{\Delta}}{3}, \quad p_0^*\left(\widehat{\Delta}\right) = \frac{3t - \widehat{\Delta}}{3}; \\
d_1^*\left(\widehat{\Delta}\right) &= 1 - \widehat{x}^* = \frac{3t + \widehat{\Delta}}{6t}, \quad d_0^*\left(\widehat{\Delta}\right) = \widehat{x}^* = \frac{3t - \widehat{\Delta}}{6t}; \\
\pi_1^*\left(\widehat{\Delta}\right) &= \frac{\left(3t + \widehat{\Delta}\right)^2}{18t}, \quad \pi_0^*\left(\widehat{\Delta}\right) = \frac{\left(3t - \widehat{\Delta}\right)^2}{18t}.
\end{aligned}$$

It is now readily checked that

$$\pi(l,h) = \pi(h,h) = \pi_1^*(\Delta) \geq \pi^P(l) = \pi^P(h) = \pi_1^*\left(\Delta^P\right) \geq \pi_1^*(0) = \pi(l,l),$$

where $\Delta := \overline{\theta} - \underline{\theta}$ and $\Delta^P = \theta^P - \underline{\theta} = e^P\left(\overline{\theta} - \underline{\theta}\right) = e^P\Delta$. We continue to assume

$$\overline{F} < \frac{\pi(l,h) - \pi(l,l)}{\rho} = \frac{\Delta(6t + \Delta)}{18t\rho}, \tag{15}$$

implying that quality separation can only be attained by way of *ex-ante* regulation. We then find the separating cost to be $C(l, \overline{q}) = A\left[\pi(l,h) - \pi(l,l) - \rho\overline{F}\right] = A\left[\frac{\Delta(6t+\Delta)}{18t} - \rho\overline{F}\right]$.

8.1 Innovation incentives

As is readily checked we obtain

$$\begin{aligned}
e^S &= \max\left\{\frac{1-\delta^T}{1-\delta}\frac{\Delta(6t+\Delta)}{18t} - sA[\frac{\Delta(6t+\Delta)}{18t} - \rho\overline{F}]; 0\right\}, \\
e^P &= \max\left\{\frac{1-\delta^T}{1-\delta}\frac{\Delta(6t+\Delta)}{18t} - A[\frac{\left(\Delta - \Delta^P\right)\left(6t + \Delta + \Delta^P\right)}{18t} + \frac{\Delta^P\left(6t + \Delta^P\right)}{18t}]; 0\right\}.
\end{aligned}$$

and, thus,

$$e^S - e^P \geq 0 \Leftrightarrow \frac{(1-s)\Delta(6t+\Delta)}{18t} + s\rho\overline{F} \geq 0,$$

which is always satisfied.

8.2 Welfare

Consumer surplus can be written as

$$\begin{aligned} CS\left(\widehat{\Delta},\theta_1\right) &= \int_0^{\widehat{x}^*}\left(\underline{\theta}-p_0^*-tx\right)dx+\int_{\widehat{x}^*}^1\left[\theta_1-p_1^*-t\left(1-x\right)\right]dx \\ &= \theta_1-\frac{3t+\widehat{\Delta}}{3}-\left(\theta_1-\underline{\theta}-\frac{2\widehat{\Delta}}{3}\right)\frac{3t-\widehat{\Delta}}{6t}-\frac{9t^2+\widehat{\Delta}^2}{36t}. \end{aligned}$$

Note here that a greater perceived quality differential, $\widehat{\Delta}$, bears on consumer surplus through three channels: (i) it raises the selling price p_1^* and lowers the selling price p_0^*; (ii) it shifts consumers from variant 0 to variant 1, implying a lower $\widehat{x}^*$; and (iii) it increases the loss of consumer surplus due to mismatch. In particular in regard to its impact on the mismatch (transportation) cost, pooling has again an ambivalent role: If the true quality offered by firm 1 is low, pooling is creating mismatch costs by diverting some consumers away from their otherwise preferred specification 0. If the true quality offered by firm 1 is high, however, then while creating a mismatch in terms of consumers' underestimating quality, pooling is at the same time lowering the quality-unrelated mismatch costs.

Overall, we obtain

$$\begin{aligned} CS\left(l,l\right) &= CS\left(0,\underline{\theta}\right)=\underline{\theta}-\frac{5t}{4}>0, \\ CS\left(h,h\right) &= CS\left(\Delta,\overline{\theta}\right)=CS\left(l,l\right)+\frac{\Delta}{2}+\frac{\Delta^2}{36t}>CS\left(l,l\right), \\ CS^P\left(l\right) &= CS\left(\Delta^P,\underline{\theta}\right)=CS\left(l,l\right)-\frac{5\left(\Delta^P\right)^2}{36t}\le CS\left(l,l\right), \\ CS^P\left(h\right) &= CS\left(\Delta^P,\overline{\theta}\right)=CS\left(l,l\right)+\frac{\Delta}{2}+\frac{\Delta^P\left(6\Delta-5\Delta^P\right)}{36t}>CS\left(l,l\right), \end{aligned}$$

where the ranking of consumer surplus follows the expected pattern. Note, however, that

$$\begin{aligned} CS^P\left(h\right) &\le CS\left(h,h\right)\Longleftrightarrow\Delta^P\left(6\Delta-5\Delta^P\right)\le\Delta^2 \\ &\Longleftrightarrow e^P\left(6-5e^P\right)\le 1\Longleftrightarrow e^P\le 1/5. \end{aligned}$$

Hence, in contrast to the vertical differentiation case, pooling unambiguously lowers consumer surplus if the innovation effort is sufficiently low. Finally, it is easy to establish that

$$\begin{aligned} \Delta_W &= \underbrace{\Delta_e\left\{\frac{1-\delta^T}{1-\delta}\left(\frac{\Delta}{2}+\frac{\Delta^2}{36t}\right)+\frac{\alpha}{2}(e^S+e^P)-\frac{1-\delta^T}{1-\delta}\alpha\left(\frac{\Delta}{3}-\frac{\Delta^2}{18t}\right)\right\}}_{\textit{Effort-related}} \\ &\quad \underbrace{+Ae^P\left\{(1-e^P)\frac{\Delta^2}{36t}-\alpha\left(\frac{\Delta}{3}+\frac{\Delta^2}{18t}\right)\right\}}_{\textit{Information-related}}, \end{aligned}$$

where in similarity to the case of vertically differentiated duopoly, the profit differential for the producer of the baseline quality, $\Delta_{\pi_0}:=\left(1-e^P\right)\pi_0^*\left(0\right)+e^P\pi_0^*(\Delta)-\pi_0^*(\Delta^P)$ is taken into account. The following can now be established.

Proposition 8.1. *Under horizontally differentiated duopoly with $c=0$, ex-ante regulation (i) (weakly) raises welfare for $\alpha=0$; (ii) raises welfare for $\Delta_e\to 0$ if and only if $\alpha\in(0,\overline{\alpha})$ and $e^P\in\left(0,1-\frac{\alpha}{\overline{\alpha}}\right)$, where* $\overline{\alpha}:=\frac{3\Delta}{4(\Delta+9t)}\in(0,1)$.

Similar to the previous examples, ex-ante regulation contributes unambiguously to welfare if the innovative product is not associated with a higher marginal cost of production and if profits do not count toward welfare. Ex-ante regulation contributes to welfare on informational grounds if and only if profits are not weighted to heavily and innovation effort is sufficiently low. Notably, the benchmark value $\overline{\alpha}$ increases in the extent of quality differentiation Δ and decreases in the degree of horizontal differentiation, as measured by the mismatch cost, t. Thus ex-ante regulation tends to be the more likely to be preferable on information grounds when quality differences "dominate" other symmetric dimensions of product differentiation. Overall the result illustrates that the welfare impact of ex-ante regulation relative to a laissez-faire regime is subject to rather similar influences regardless of the specific structure of the industry.

9 Extensions

This section addresses a couple of extensions to the model which allow us to assess whether our results are robust to a number of economic mechanisms and institutional features we have abstracted from in the model we have considered so far.

9.1 Signalling

By characterizing the laissez-faire regime as a pooling equilibrium our model abstracts from the scope for an innovating firm to actively signal its quality. by choosing a price and advertising strategy which is unprofitable to a producer of low quality (Milgrom and Roberts, 1986). In the following we will derive a condition under which signalling is unprofitable to a high quality firm, implying that a pooling equilibrium arises unless firms are forced to disclose their quality within a regime of entry regulation.

In order to facilitate the analysis we consider a setting with $c = 0$, implying that signalling through price is not feasible (see e.g. Milgrom and Roberts, 1986). Assume, however, that a firm can spend an amount $K \geq 0$ on dissipative advertising in order to signal its quality. As misleading signals through dissipative advertising cannot be verified, we let $F \equiv 0$. Following the analysis in sub-section 4.2 in all other aspects, but applying the signalling approach in Milgrom and Roberts (1986) rather than a screening argument, it is straightforward to show the following.

Proposition 9.1. *(i) An innovating (high quality) firm can signal its type and, thereby, induce a separating allocation, by spending* $\overline{K} = A\left[\pi(l,h) - \pi(l,l)\right]$ *on dissipative advertising. (ii) The innovating firm prefers to pool*

Proof. See Appendix A ■

Thus, while an innovating firm could use dissipative advertising in order to signal its type, in the absence of differences in the variable cost of production, the firm prefers to be pooled. Recalling that $\pi(l,h) = \pi(h,h)$ for $c = 0$, we see that separation requires advertising investments amounting to the full return of innovation, $\pi(h,h) - \pi(l,l)$, over the time span, A, over which asymmetric information is expected to prevail. Pooling, in contrast, leaves a return $\pi^P(h) > \pi(l,l)$ to the innovating firm.

Remark 1. *For the case of a vertical monopoly, as characterized in Section 6, with* $c > 0$, *it can be established (i) that an innovating firm can separate by choosing a price* $\overline{p} = \frac{\overline{\theta}}{2}\left(1 + \sqrt{1 - \frac{\underline{\theta}}{\overline{\theta}}}\right)$ *and advertising outlays* $K = 0$; *and (ii) that the firm prefers a pooling allocation if* $\overline{\theta} \geq \frac{4}{3}\underline{\theta}$ *A detailed proof is available on request.*

Under conditions supporting the above result, the market cannot be relied on for an early resolution of the information problem. Thus, should the immediate revelation of information be the socially preferred option, then its implementation will necessitate regulatory intervention. Provided that the regulatory process is more effective in separating quality types, as it would be for $s < 1$ and/or for $\rho\overline{F} > 0$, additional gains accrue to innovators.

9.2 Punishment of False Claims

So far we have not specified explicitly how a pooling allocation comes about. In the most simple case pooling could simply be the consequence of a situation in which the innovating firm does not send any message about its type.[25] Alternatively, one could follow Rhodes and Wilson (2015) by deriving a pooling equilibrium as the outcome of an advertising game, in which both firms make costless, and possibly false, claims about their quality. Suppose that while advertising itself is costless (and cannot therefore be used as a signalling device), the firms' claims $j \in \{h, l\}$ are verified ex-post at some probability ρ and subjected to a fine $\phi \geq 0$ if they are found to be false, i.e. if $j \neq i$. It is easy to see that an innovating firm will then always declare $j = i = h$. In contrast, a firm that has not innovated will falsely declare $j = h \neq l = i$ if and only if $A\left[\pi^P(l) - \rho\phi\right] \geq A\pi(l,l)$ or

$$\phi < \frac{\pi^P(l) - \pi(l,l)}{\rho} =: \widehat{\phi}.$$

The following is then immediate[26].

Proposition 9.2. *Pooling is the unique outcome of a game with costless advertising if and only if the maximum feasible fine for false claims, $\overline{\phi}$, satisfies $\overline{\phi} < \widehat{\phi}$.*

Hence, a pooling equilibrium arises in the absence of entry regulation if limited liability on the part of the firm rules out the imposition of a fine on false advertising claims for which the types separate. Note that $\widehat{\phi} < \widehat{F} = \frac{\pi(l,h) - \pi(l,l)}{\rho}$, implying that the limited liability condition $\overline{\phi} < \widehat{\phi}$ is stronger than our previous assumption $\overline{F} < \widehat{F}$ This notwithstanding, it is clear that $\overline{\phi} < \widehat{\phi}$ is likely to be satisfied in many instances in which the probability of discovering a false claim (and enforcing it through judicial procedures) is sufficiently low. Whether or not the maximal feasible fines, $\overline{\phi}$ and $\overline{F}$ are equivalent depends on the particular institutional context: If maximal fines are levied regardless of the presence or absence of ex-ante regulation and if these fines are consequently determined only by limited liability, then $\overline{\phi} = \overline{F}$ appears a plausible assumption. In many cases, however, we would expect that the maximal fines are also determined through judicial and institutional details. In this case, one could argue that the manipulation of access trials is likely to be punished more severely than false advertising in the absence of other regulatory intervention. Thus, generally we would expect that $\overline{\phi} \leq \overline{F}$.

It is easy to verify that the only difference such a set-up makes in comparison to our previous analysis is that the effort level with a subsequent pooling equilibrium is now given by

$$e^P = \max\left\{0; \frac{1-\delta^T}{1-\delta}\left[\pi(h,h) - \pi(l,l)\right] - A\left\{\left[\pi(h,h) - \pi^P(h)\right] + \left[\pi^P(l) - \rho\overline{\phi} - \pi(l,l)\right]\right\}\right\},$$

such that

$$\Delta_e \geq 0 \Leftrightarrow \left[\pi(h,h) - s\pi(l,h)\right] - \left[\pi^P(h) - \pi^P(l)\right] - (1-s)\,\pi(l,l) + \rho\left(s\overline{F} - \overline{\phi}\right)\right] \geq 0.$$

It is no longer clear then whether a higher probability of ex-post quality revelation, ρ, is contributing towards an increase or a decrease in the effort differential Δ_e. Indeed, a higher ρ is more conducive to the provision of effort under pooling if $\overline{\phi} = \overline{F}$. But even if false advertising is more mildly punished than $\overline{\phi} < \overline{F}$ it holds that an increase in ρ is more conducive to the provision of effort under pooling if $s \to 0$, i.e. if the trial is sufficiently effective in generating separation. Apart from this, the explicit modeling of false advertising claims does not have any further qualitative implications for our analysis.

[25] Indeed, it could be true that in the absence of a costly verification prodedure, such as a clinical trial, the firm itself is uninformed about the outcome of the R&D stage.

[26] This equilibrium corresponds to the "lower" boundary equilibrium described by Rhodes and Wilson (2015) in their Proposition 1 for the case that the fine ϕ falls short of threshold $\phi < \phi_1$ (see first bullet in part iii). Rhodes and Wilson (2015) go on to characterise additional separating and mixed strategy equilibria for $\phi > \phi_1$. These are of no further consequence for the purpose of our analysis.

10 Conclusion and policy implications

Our results show that the impact of regulation on innovation and welfare is rather complex. It is generally assumed that tougher regulation in the access to markets should be associated with lower incentives for R&D. Although intuitively reasonable, this argument understates the information problem that is underlying and, in effect, motivating regulatory intervention. Product trials are necessary in order to reveal private information about product quality to consumers and to the regulator. Provided that product trials are prone to be subject to falsification of information about low quality, it makes sense to interpret them as screening mechanisms.

Incentive compatibility implies that only high quality firms register to a trial in the first place but also that a cost needs to be imposed on the participating firms. While the latter stifles R&D incentives, our model shows that it is not a priori clear whether or not free access would give rise to greater R&D incentives. This is because the pooling allocation that would arise in the absence of access regulation also lowers the rewards to product innovation. Thus, our model illustrates that the problem in regard to access regulation should be viewed as one of minimizing the cost to innovating providers of asymmetric information. Whether access regulation is a suitable means to do so then depends on (i) the screening effectiveness of the product trial, (ii) the probability at which information is revealed during the market stage, (iii) the cost, preference and market structures that determine the profit streams under the different entry regimes.

A second argument overlooked in discussions about access regulation is that the role of regulation is to maximize welfare, not R&D per se. This implies that the expected welfare gains from product innovation need to be complemented by the welfare impact of eliminating asymmetric information right from the outset of the market stage rather than leaving it to a possibly lengthy and random process. As others have shown before us, it is not always clear whether the early disclosure of information is leading to a welfare improvement. In particular, when innovation has occurred consumers may be better off remaining ignorant about this information, as the resulting pooling allocation is associated with a lower price for the product. In contrast, if the firm has failed to innovate consumers would typically benefit from disclosure. Hence, there is an ambiguity about the welfare impact of access regulation along both the "innovation" margin and the "information" margin. Our examples show that access regulation is prone to raise welfare if the production of high quality is not associated with a (larger) variable cost of production and if profit does not count (too much) toward welfare. Regulation is then welfare improving both by providing greater R&D incentives and by leading to an immediate disclosure of information. In regard to the latter it turns out for the market structures we consider that consumers tend to prefer disclosure in expected terms.

Against these results, our model also shows how the optimal regulation turns on a number of relevant features relating to the regulatory process. Temin (1980) first noted that the more difficult it is for consumers to assess the true value of a product, the higher the benefits from regulation. In our model, market transparency is captured by the probability of ex-post discovery/verification of quality, which turns out to play a crucial role. While it is intuitively clear that low transparency is stifling innovation under laissez-faire, this is also true in the case of access regulation. Incentive compatibility then requires more demanding and more costly trials.

The extent to which low transparency is stifling innovation effort in the presence of access regulation then depends on the screening effectiveness of the trial and on the scope to set ex-post fines for the manipulation of trials. If screening is very effective, the lack of market transparency is predominantly harming R&D incentives under free entry. Conversely, if trials are ineffective, then transparency has a greater leverage on R&D incentives in the presence of access regulation whenever it also increases the expected fines associated with the ex-post punishment of manipulation.

It is worthwhile to note that low market transparency itself is the reason for why ex-ante access regulation is necessary at all. In principle, the falsification of quality information could be deterred by appropriate ex-post fines for the misreporting of quality. However, if transparency and thus the probability of ex-post discovery is low, then an incentive compatible fine will typically exceed the level of the fine that is feasible under limited liability.

A final result of our analysis is that the discussion surrounding the high cost of clinical and other access trials should not focus on the stringency of the quality requirements but rather on the screening-effectiveness of the trial. All else equal, regulators should rather structure trials in a way that makes it particularly costly for non-innovating (low quality firms) to falsify information and document a high quality. By linking the sample size to the effectiveness level, randomized controlled trials do indeed fulfill this requirement, even if their screening effectiveness is by no means close to zero.

When studying a monopoly with vertical preferences, we find that the welfare impact of access regulation hinges crucially on the extent to which profit counts toward welfare, as well as on the variable cost associated with the provision of quality. If welfare is solely measured on the basis of consumer surplus and if quality related production costs are not too high, regulation raises welfare both by enhancing R&D effort and by leading to an early disclosure of information. Conversely, when profits count toward welfare, the net welfare gain to access regulation is typically lower and turns negative if the screening effectiveness of a trial and the extent to which ex-post fines can be levied are low. The overall welfare impact of regulation is then negative if regulation is ineffective in generating additional effort incentives. We find as similar result for the case where an innovating firms acts as "product" leader in a vertically differentiated duopoly: Again, a focus on consumer surplus suggests that entry regulation should be implemented on grounds of both, enhancing R&D effort and allowing the early revelation of information. In contrast, regulation is detrimental to total welfare, once profits are included, if market transparency is sufficiently large or if the product trials are poorly effective in screening out low quality types. When giving a political economy interpretation to these findings, they suggest that entry regulation should be much more likely in environments in which producers have limited political influence.

While our results thus prove to be broadly robust in respect to three different types of market structure (monopoly and duopoly with vertical preferences; and horizontally differentiated duopoly), we could also demonstrate that under plausible circumstances signalling by high quality producers or false advertising legislation will not resolve the informational problem. We conclude by noting that our model is open to a number of further extensions and generalizations. First, one could think of more detailed modeling of the regulatory decision-making and the flow of information in the course of the regulatory process. For instance, one could conceive of regulatory efforts aimed at increasing market transparency; or about policies involving mandatory after-market trials leading to a re-certification whenever there is residual uncertainty on the part of the regulator and perhaps even on the part of firms. While such policies would relax the information problem, the benefits from such transparency policies would need to be offset against their costs. Second, there is clear scope for applying our model to other preference, cost and market structures. In regard to the modeling of preferences it would be particularly interesting to relax the assumption of risk neutrality that is implicitly underlying our examples. This is important, as in many cases access regulation is viewed as a means of safe-guarding consumers against product risks which are rare but lead to high damages. Finally, one may think of more complex innovation dynamics, involving, e.g., follow-up innovation on the part of rival firms which may be enhanced by the disclosure of information generated by the trial.

References

Atella V, Bhattacharya J, Carbonari L (2008): Pharmaceutical industry, drug quality and regulation: evidence from US and Italy. NBER Working Paper 14567.

Baron D, Besanko D (1984): Regulation, asymmetric information, and auditing. *RAND Journal of Economics* 15, pg 447-470.

Board O (2009): Competition and disclosure. *Journal of Industrial Economics* 67, pg. 197-213.

Corts, KS (2014): Finite optimal penalties for false advertising. *Journal of Industrial Economics* 62, pg. 661-681.

Creane, A (2008): A note on welfare-improving ignorance on product quality. *Economic Theory* 34, pg. 585-590.

Dahm M, Gonzalez P, Porteiro N (2009): Trials, tricks and transparency: How disclosure rules affect clinical knowledge. *Journal of Health Economics* 28, pg. 1141-1153.

Danzon P (2000): The pharmaceutical industry. *Encyclopedia of Law and Economics*, pg 1055-1091.

Danzon P, Wang YR, Wang L (2005): The impact of price regulation on the launch delay of new drugs: evidence from twenty-five major markets in the 1990s. *Health Economics* 14, pg 269-292.

Darby M, Karni E (1973): Free competition and optimal amount of fraud. *Journal of Law and Economics*, 16(1), pg 67-88.

Daughety AF, Reinganum JF (2008): Communicating quality: a unified model of disclosure and signalling. *RAND Journal of Economics* 39, pg. 973-989.

DiMasi JA, Hansen RW, Grabowski HG, Lasagna L (1991): Cost of innovation in the pharmaceutical industry. *Journal of Health Economics* 10, pg 107-142.

DiMasi JA, Hansen RW, Grabowski HG (2003):The price of innovation: new estimates of drug development costs. *Journal of Health Economics* 22(2), pg 151-185.

Dranove D, Jin GZ (2010): Quality disclosure and certification: theory and practice. *Journal of Economic Literature* 48, pg. 935-963.

Dranove D, Meltzer D (1994): Do Important Drugs reach the Market Sooner? *RAND Journal of Economics* 25, pg 402-423.

Dulleck U, Kerschbamer R (2006): On doctors, mechanics and computer specialists: the economics of credence goods. *Journal of Economic Literature* 47, pg 5-42.

Economides N (1989): Quality variations and maximal variety differentiation. *Regional Science and Urban Economics* 19, pg. 21-29.

Garattini L, Ghislandi S (2007): Should we really worry about launch delays in OECD countries? *European Journal of Health Economics* 8(1), pg 1-3.

Golec J, Vernon JA (2010): Financial effects of pharmaceutical price regulation on R&D spending by EU versus US firms. *Pharmacoeconomics* 28(8), pg. 615-628.

Grabowski H, Vernon J, Thomas L (1978): Estimating the effects of regulation on innovation: an international comparative analysis of the pharmaceutical industry. *Journal of Law and Economics* 21, pg 133-163.

Henry E, Ottaviani M (2015): Reserach and the Approval Process. *Mimeo.*

Hotz VJ, Xiao M (2013): Strategic information disclosure: the case of multiattribute products with heterogeneous consumers. *Economic Inquiry* 31, pg. 865-881.

Katz A (2007): Pharmaceutical lemons: innovation and regulation in the drug industry. *Michigan Telecommunications and Technology Law Review* 14(1), pg 1-41.

Levin D, Peck J, Ye L (2009): Quality disclosure and competition, *Journal of Industrial Economics* 67, pg. 167-196.

Matthews S, Postlewaite A (1985): Quality testing and disclosure. *RAND Journal of Economics* 16, pg. 328-340.

Milgrom P, Roberts J (1986): Price and advertising signals of product quality. *Journal of Political Economy* 94, pg. 796-821.

Munos (2009): Lessons from 60 years of pharmaceutical innovation. *Nature Reviews Drugs Discovery* 8, pg 959-968.

Olson MK (2008): The risk we bear: the effects of drug speed and industry user fees on new drugs safety. *Journal of Health Economics* 27(2), pg 175-200.

Peltzman S (1973): An evaluation of consumer protection legislation: the 1962 Drug Amendments. *Journal of Political Economy* 8, pg 1049-1091.

Piccolo S, Tedeschi P, Ursino G (2015): How limiting deceptive practices harms consumers. *RAND Journal of Economics* 46, pg. 611-624.

Polinsky AM, Shavell S (2012): Mandatory versus voluntary disclosure of product risks. *Journal of Law, Economics and Organization* 28, pg. 360-379.

Rhodes A, Wilson CM (2015): False advertising and consumer protection policy. *Mimeo.*

Spence M (1977): Consumer misperceptions, product failure and producer liability. *Review of Economic Studies* 44, pg. 561-572.

Temin P (1980): *Taking Your Medicine: Drug regulation in the United States.* Cambridge, MA, Harvard University Press.

Vernon JA (2005): Examining the link between price regulation and pharmaceutical R&D investment. *Health Economics* 14, pg. 1-16.

11 Appendix A: Proofs

Proof of Proposition 4.1: Separation requires that

$$\bar{\pi}(l,h) - C(l,q) \leq \bar{\pi}(l,l) \quad (16)$$
$$\bar{\pi}(h,h) - C(h,q) \geq \bar{\pi}(h,l) \quad (17)$$

Since $C(h,q) \leq C(l,q)$, the level of $C(l,q)$ defines the maximum cost associated with the quality standard q. Using this together with the monotonicity condition (6) it follows that the incentive constraint for the $h-$type (17) is slack if the incentive constraint for the l-type (16) is satisfied (a) as an inequality for $C(l,q) = C(h,q) = 0$ or (b) as an equality for $C(l,q) > 0$. But then by construction any fine $F \geq \widehat{F}$ will satisfy (16) at $C(l,q) = C(h,q) = 0$. Consider now $F < \widehat{F}$. In this case the minimum level of costs that satisfies (16) is given by

$$C(l,\overline{q}) = A[\pi(l,h) - \pi(l,l) - \rho F]. \quad (18)$$

This implicitly defines the separating quality level $\overline{q}$ as reported in the Lemma. Since $\frac{\partial C(l,\overline{q})}{\partial F} = \frac{\partial C(l,\overline{q})}{\partial q}\frac{d\overline{q}}{dF} < 0$, with $\frac{d\overline{q}}{dF} = \frac{-A\rho}{\partial C(l,\overline{q})/\partial q} < 0$ following from partial-total differentiation of (18) with respect to F, cost-minimizing separation is always attained at $F = \max\left\{\overline{F}, \widehat{F}\right\}$. The Lemma then follows immediately.

Proof of Corollary 4.1.1: The Corollary follows immediately when noting that

$$\frac{\partial C(h,\overline{q})}{\partial x} = s\frac{\partial C(l,\overline{q})}{\partial q}\frac{d\overline{q}}{dx}; \quad x \in \left\{\overline{F}, \rho, \delta, T\right\}$$

with

$$\begin{aligned}
\frac{d\overline{q}}{d\overline{F}} &= \frac{-A\rho}{\partial C(l,\overline{q})/\partial q} < 0 \\
\frac{d\overline{q}}{d\rho} &= \frac{-A\overline{F} + (\partial A/\partial\rho)\left[\pi(l,h) - \pi(l,l) - \rho\overline{F}\right]}{\partial C(l,\overline{q})/\partial q} < 0 \\
\frac{d\overline{q}}{d\delta} &= \frac{(\partial A/\partial\delta)\left[\pi(l,h) - \pi(l,l) - \rho\overline{F}\right]}{\partial C(l,\overline{q})/\partial q} > 0 \\
\frac{d\overline{q}}{dT} &= \frac{(\partial A/\partial T)\left[\pi(l,h) - \pi(l,l) - \rho\overline{F}\right]}{\partial C(l,\overline{q})/\partial q} > 0
\end{aligned}$$

following from partial-total differentiation of (18) with respect to x, where $\frac{\partial A}{\partial\delta} = -\frac{\partial A}{\partial\rho} > 0$ and $\frac{\partial A}{\partial T} > 0$ can be verified. Finally, we have $\frac{\partial C(h,\overline{q})}{\partial s} = C(l,\overline{q})$.

Proof of Proposition 4.2: Part (i) Without regulation, the stage-2 equilibrium is pooling. The firm will set e in such a way that

$$e^P = \arg\max_e E(\pi) = e\overline{\pi}^P(h) + (1-e)\overline{\pi}^P(l) - \frac{e^2}{2}.$$

Maximizing this expression with respect to e gives

$$e^P = \max\left\{0; \frac{1-\delta^T}{1-\delta}[\pi(h,h) - \pi(l,l)] - A\left\{\left[\pi(h,h) - \pi^P(h)\right] + \left[\pi^P(l) - \pi(l,l)\right]\right\}\right\}.$$

The result follows when employing the relationship $A + \frac{\rho\delta}{1-\delta}B = \frac{1-\delta^T}{1-\delta}$.

Part (ii): With regulation, the stage-2 equilibrium is separating. Hence,

$$\begin{aligned} e^S &= \arg\max_e E(\pi) = e(\overline{\pi}(h,h) - C(h,\overline{q})) + (1-e)\overline{\pi}(l,l) - \frac{e^2}{2} \\ &= \max\left\{0; A[\pi^P(h) - \pi^P(l)] + \frac{\rho\delta}{1-\delta}B[\pi(h,h) - \pi(l,l)]\right\} \\ &. \end{aligned}$$

where the last equality follows from substituting $C(h,\overline{q}) = sC(l,\overline{q}) = \pi(l,h) - \pi(l,l) - \rho\overline{F}$ as from Lemma 1 and maximizing with respect to e.

Part (iii) follows immediately.

Proof of Proposition 5.1:

Part (i): First note that

$$W^P = \left(1-e^P\right)\left[\overline{CS}^P(l) + \alpha\overline{\pi}^P(l)\right] + e^P\left[\overline{CS}^P(h) + \alpha\overline{\pi}^P(h)\right] - \frac{\alpha(e^P)^2}{2}$$

Then we obtain the result by noting that $\overline{CS}^P(i) = A\times CS^P(i) + \frac{\rho\delta}{1-\delta}B\times CS(i,i) = A\left[CS^P(i) - CS(i,i)\right] + \frac{1-\delta^T}{1-\delta}CS(i,i)$, with $i = h,l$; $\overline{\pi}^P(l) = A\left[\pi^P(l) - \pi(l,l)\right] + \frac{1-\delta^T}{1-\delta}\pi(l,l)$; and $e^P = \frac{\overline{\pi}^P(h) - \overline{\pi}^P(l)}{2}$.

Part (ii): Similarly, note that:

$$W^S = \left(1-e^S\right)\left[\overline{CS}(l,l) + \alpha\overline{\pi}(l,l)\right] + e^S\left\{\overline{CS}(h,h) + \alpha\left[\overline{\pi}(h,h) - C(h,\overline{q})\right]\right\} - \frac{\alpha(e^S)^2}{2}$$

We obtain the result when noting that $\overline{CS}(i,i) = \frac{1-\delta^T}{1-\delta}CS(i,i)$, with $i = h,l$; $\overline{\pi}(l,l) = \frac{1-\delta^T}{1-\delta}\pi(l,l)$ and $e^S = \frac{\overline{\pi}(h,h) - C(h,\overline{q}) - \overline{\pi}(l,l)}{2}$. Part (iii) follows immediately.

Proof of Proposition 6.2: Using (11), we obtain

$$\begin{aligned} CS(l,l) &= CS\left(\underline{\theta},\underline{\theta},p\left(\underline{\theta},\underline{\theta}\right)\right) = \frac{\underline{\theta}}{8}, \\ CS^P(l) &= CS\left(\underline{\theta},\theta^P,p^*\left(\overline{\theta},\theta^P\right)\right) = CS(l,l) - \Delta^l_{CS}\left(\theta^P,c\right), \\ CS(h,h) &= CS\left(\overline{\theta},\overline{\theta},p^*\left(\overline{\theta},\overline{\theta}\right)\right) = \frac{\left(\overline{\theta}-c\right)^2}{8\overline{\theta}}, \\ CS^P(h) &= CS\left(\overline{\theta},\theta^P,p^*\left(\overline{\theta},\theta^P\right)\right) = CS(h,h) - \Delta^h_{CS}\left(\theta^P,c\right), \end{aligned}$$

with

$$\begin{aligned} \Delta^l_{CS}\left(\theta^P,c\right) &: = CS(l,l) - CS^P(l) = \frac{\theta^P - \underline{\theta}}{4} + \frac{c\left[2\left(\underline{\theta}-c\right)\theta^P + c\underline{\theta}\right]}{8\left(\theta^P\right)^2}, \\ \Delta^h_{CS}\left(\theta^P,c\right) &: = CS(h,h) - CS^P(h) = -\frac{\overline{\theta} - \theta^P}{4} + \frac{c\left(\overline{\theta}-\theta^P\right)\left[2\overline{\theta}\theta^P - c\left(\overline{\theta}-\theta^P\right)\right]}{8\left(\theta^P\right)^2\overline{\theta}}. \end{aligned}$$

Defining, in addition,

$$\Delta_{CS}^{Info} := \left(1-e^P\right)\left[CS(l,l)-CS^P(l)\right]+e^P\left[CS(h,h)-CS^P(h)\right]=\left(1-e^P\right)\Delta_{CS}^{l}\left(\theta^P,c\right)+e^P\Delta_{CS}^{h}\left(\theta^P,c\right)$$

the proposition can be established as follows.

Part (i): As is readily checked, we have $\Delta_{CS}^{l}\left(\theta^P,c\right)\geq\Delta_{CS}^{l}\left(\underline{\theta},c\right)\geq\Delta_{CS}^{l}\left(\underline{\theta},0\right)=0$ for all $\left(\theta^P,c\right)$.

Part (ii): Rewriting $\Delta_{CS}^{h}\left(\theta^P,c\right)=\frac{\left(\overline{\theta}-\theta^P\right)\Psi\left(\theta^P,c\right)}{8\left(\theta^P\right)^2\overline{\theta}}$ with $\Psi\left(\theta^P,c\right):=-2\left(\theta^P-c\right)\overline{\theta}\theta^P+c^2\left(\overline{\theta}-\theta^P\right)$ we see that $\Delta_{CS}^{h}\left(\theta^P,c\right)\geq 0\Leftrightarrow\Psi\left(\theta^P,c\right)\geq 0$, where $\Psi_{\theta^P}\left(\theta^P,c\right)<0$ and $\Psi_c\left(\theta^P,c\right)>0$. It can then be shown that $\Psi\left(\theta^P,c\right)\geq 0$ if and only if $c\in[\underline{c},\underline{\theta}]$, with $\underline{c}:=\frac{\underline{\theta}}{\overline{\theta}-\underline{\theta}}\left[-\overline{\theta}+\sqrt{\overline{\theta}^2+2\overline{\theta}\left(\overline{\theta}-\underline{\theta}\right)}\right]\in[0,\underline{\theta}]$, and $e^P\in[0,\overline{e}]$, with $\overline{e}:=\frac{c}{4\overline{\theta}\left(\overline{\theta}-\underline{\theta}\right)}\left[2\overline{\theta}-c+\sqrt{\left(2\overline{\theta}-c\right)^2+8\overline{\theta}^2}\right]-\frac{\underline{\theta}}{\overline{\theta}-\underline{\theta}}\in[0,1]$.

Part (iii): Noting that $\Delta_{CS}^{i}\left(\theta^P,c\right)\geq\Delta_{CS}^{i}\left(\theta^P,0\right)$ for $i=h,l$, it follows that $\Delta_{CS}^{Info}\geq\left(1-e^P\right)\Delta_{CS}^{l}\left(\theta^P,0\right)+e^P\Delta_{CS}^{h}\left(\theta^P,0\right)=\left(1-e^P\right)\frac{\theta^P-\underline{\theta}}{4}-e^P\frac{\overline{\theta}-\theta^P}{4}=0$, where the last equality follows when substituting $\theta^P=\left(1-e^P\right)\underline{\theta}+e^P\overline{\theta}$.

Proof of Proposition 7.1: Part (i): Note first that $CS(h,h)\geq CS(l,l)$ together with $\Delta_e\geq 0$ guarantee that the first line of (14) is non-negative. Thus, $\Delta_W\geq 0$ if $\left(1-e^P\right)\left[CS(l,l)-CS^P(l)\right]+e^P\left[CS(h,h)-CS^P(h)\right]\geq 0$. We defer a proof of this to part (ii).

Part (ii): For $\Delta_e\to 0$, it follows that $\Delta_W\geq 0$ if and only if the term in bracelets in the second line of (14) is non-negative. Note that we can rewrite this expression as $\Omega\left(e^P,\alpha\right)-\alpha e^P\left[\pi(h,h)-\pi(l,l)\right]$, with

$$\Omega\left(e^P,\alpha\right):=\left(1-e^P\right)\left[W(\underline{\theta},\underline{\theta},\alpha)-W(\underline{\theta},\theta^P,\alpha)\right]+e^P\left[W(\overline{\theta},\overline{\theta},\alpha)-W(\overline{\theta},\theta^P,\alpha)\right],$$

and

$$W(\theta,\widehat{\theta},\alpha):=CS(\theta,\widehat{\theta})+\alpha\left[\pi^*\left(\widehat{\theta},\theta_0\right)+\pi_0^*\left(\widehat{\theta},\theta_0\right)\right];\quad\theta\in\left\{\underline{\theta},\overline{\theta}\right\};\widehat{\theta}\in\left\{\underline{\theta},\overline{\theta},\theta^P\right\}.$$

Note that $\Omega\left(e^P,0\right)=\left(1-e^P\right)\left[CS(l,l)-CS^P(l)\right]+e^P\left[CS(h,h)-CS^P(h)\right]$, implying that for part (i) we need to establish that $\Omega\left(e^P,0\right)\geq 0$ for all $e^P\in[0,1]$. For part (ii) we need to show that for $\alpha\in(0,\overline{\alpha})$ it holds that $\Omega\left(e^P,\alpha\right)-\alpha e^P\left[\pi(h,h)-\pi(l,l)\right]\geq 0\Longleftrightarrow e^P\in[0,\overline{e}]$. To do so, we rewrite

$$\Omega\left(e^P,\alpha\right)=\left(1-e^P\right)W(\underline{\theta},\underline{\theta},\alpha)+e^PW(\overline{\theta},\overline{\theta},\alpha)-W(\underline{\theta},\theta^P,\alpha)+e^P\left[W(\underline{\theta},\theta^P,\alpha)-W(\overline{\theta},\theta^P,\alpha)\right]\tag{19}$$

and note that

$$\begin{aligned}\Omega\left(0,\alpha\right)&=W(\underline{\theta},\underline{\theta},\alpha)-W(\underline{\theta},\theta^P,\alpha)=0,\\ \Omega\left(1,\alpha\right)&=W(\overline{\theta},\overline{\theta},\alpha)-W(\overline{\theta},\theta^P,\alpha)=0,\end{aligned}$$

where the second equality in each line follows when observing that $\theta^P=\left(1-e^P\right)\underline{\theta}+e^P\overline{\theta}$ and inserting appropriately. Furthermore, we rewrite

$$\begin{aligned}e^P\left[W(\underline{\theta},\theta^P,\alpha)-W(\overline{\theta},\theta^P,\alpha)\right]&=e^P\left[CS(\underline{\theta},\theta^P)-CS(\overline{\theta},\theta^P)\right]\\&=-e^P\left(\overline{\theta}-\underline{\theta}\right)\frac{2\theta^P\left(3\theta^P-\theta_0\right)}{\left(4\theta^P-\theta_0\right)^2}=-\left(\theta^P-\underline{\theta}\right)\frac{2\theta^P\left(3\theta^P-\theta_0\right)}{\left(4\theta^P-\theta_0\right)^2}.\end{aligned}$$

Evaluating the terms in (12) and (13) at $\theta=\underline{\theta}$ and $\widehat{\theta}=\theta^P$, substituting the resulting expressions into (19) and summarizing terms, we then obtain

$$\begin{aligned}\Omega\left(e^P,\alpha\right)&=\left(1-e^P\right)W(\underline{\theta},\underline{\theta},\alpha)+e^PW(\overline{\theta},\overline{\theta},\alpha)\\&\quad-\left[\frac{\left(\theta^P\right)^2\left(4\theta^P+5\theta_0\right)}{2\left(4\theta^P-\theta_0\right)^2}+\alpha\frac{\theta^P\left(4\theta^P+\theta_0\right)\left(\theta^P-\theta_0\right)}{\left(4\theta^P-\theta_0\right)^2}\right].\end{aligned}$$

It follows that

$$\begin{aligned}
\frac{\partial\Omega\left(e^P,\alpha\right)}{\partial e^P} &= W(\overline{\theta},\overline{\theta},\alpha)-W(\underline{\theta},\underline{\theta},\alpha)\\
&\quad-\left\{\frac{\theta^P\left[8\left(\theta^P\right)^2-6\theta^P\theta_0-5\theta_0^2\right]}{\left(4\theta^P-\theta_0\right)^3}+\alpha\frac{16\left(\theta^P\right)^3-12\left(\theta^P\right)^2\theta_0+10\theta^P\theta_0^2+\theta_0^3}{\left(4\theta^P-\theta_0\right)^3}\right\}\left(\overline{\theta}-\underline{\theta}\right),\\
\frac{\partial^2\Omega\left(e^P,\alpha\right)}{\partial\left(e^P\right)^2} &= -\left[\frac{\theta_0^2\left(52\theta^P+5\theta_0\right)}{\left(4\theta^P-\theta_0\right)^4}-\alpha\frac{2\theta_0^2\left(28\theta^P+11\theta_0\right)}{\left(4\theta^P-\theta_0\right)^4}\right]\left(\overline{\theta}-\underline{\theta}\right)^2,
\end{aligned}$$

where we use $\frac{\partial\theta^P}{\partial e^P}=\overline{\theta}-\underline{\theta}$. Note that $\frac{\partial^2\Omega\left(e^P,\alpha\right)}{\partial\left(e^P\right)^2}<0\Longleftrightarrow\alpha<\frac{52\theta^P+5\theta_0}{2\left(28\theta^P+11\theta_0\right)}$. As is readily verified, we have $\frac{52\theta^P+5\theta_0}{2\left(28\theta^P+11\theta_0\right)}\geq\frac{52\underline{\theta}+5\theta_0}{2\left(28\underline{\theta}+11\theta_0\right)}=:\overline{\alpha}\in(0,1)$, implying that $\alpha<\overline{\alpha}$ is sufficient for $\frac{\partial^2\Omega\left(e^P,\alpha\right)}{\partial\left(e^P\right)^2}<0$. If this is true, $\Omega\left(e^P,\alpha\right)$ is a concave function in e^P, which together with $\Omega(0,\alpha)=\Omega(1,\alpha)=0$ implies that $\Omega\left(e^P,\alpha\right)\geq 0$ for all $\alpha<\overline{\alpha}$. This verifies part (i) of the proposition.

To prove part (ii) we note that $\Omega(1,\alpha)-\alpha\left[\pi(h,h)-\pi(l,l)\right]=-\alpha\left[\pi(h,h)-\pi(l,l)\right]<0$ and $\Omega\left(e^P,0\right)=0$. Given the concavity of $\Omega\left(e^P,\alpha\right)$ it then follows that there exists $\overline{e}\in(0,1)$ such that $\Omega\left(e^P,\alpha\right)-\alpha e^P\left[\pi(h,h)-\pi(l,l)\right]>0\Longleftrightarrow e^P\in(0,\overline{e})$ if

$$\begin{aligned}
\Phi\left(\alpha,\overline{\theta}\right) &:= \frac{\partial\Omega(0,\alpha)}{\partial e^P}-\alpha\left[\pi(h,h)-\pi(l,l)\right]\\
&= W(\overline{\theta},\overline{\theta},\alpha)-W(\underline{\theta},\underline{\theta},\alpha)-\alpha\left[\pi(h,h)-\pi(l,l)\right]\\
&\quad-\left\{\frac{\underline{\theta}\left[8\underline{\theta}^2-6\underline{\theta}\theta_0-5\theta_0^2\right]}{\left(4\underline{\theta}-\theta_0\right)^3}+\alpha\frac{16\underline{\theta}^3-12\underline{\theta}^2\theta_0+10\underline{\theta}\theta_0^2+\theta_0^3}{\left(4\underline{\theta}-\theta_0\right)^3}\right\}\left(\overline{\theta}-\underline{\theta}\right)\\
&= CS(\overline{\theta},\overline{\theta})+\alpha\pi_0^*\left(\overline{\theta},\theta_0\right)-\left[CS\left(\underline{\theta},\underline{\theta}\right)+\alpha\pi_0^*\left(\underline{\theta},\theta_0\right)\right]\\
&\quad-\left\{\frac{\underline{\theta}\left(8\underline{\theta}^2-6\underline{\theta}\theta_0-5\theta_0^2\right)}{\left(4\underline{\theta}-\theta_0\right)^3}+\alpha\frac{16\underline{\theta}^3-12\underline{\theta}^2\theta_0+10\underline{\theta}\theta_0^2+\theta_0^3}{\left(4\underline{\theta}-\theta_0\right)^3}\right\}\left(\overline{\theta}-\underline{\theta}\right)>0.
\end{aligned}$$

It can be shown that

$$\Phi_\alpha\left(\alpha,\overline{\theta}\right)=\pi_0^*\left(\overline{\theta},\theta_0\right)-\pi_0^*\left(\underline{\theta},\theta_0\right)-\frac{16\underline{\theta}^3-12\underline{\theta}^2\theta_0+10\underline{\theta}\theta_0^2+\theta_0^3}{\left(4\underline{\theta}-\theta_0\right)^3}\left(\overline{\theta}-\underline{\theta}\right)<\Phi_\alpha\left(\alpha,\underline{\theta}\right)=0,$$

implying that

$$\begin{aligned}
\Phi\left(\alpha,\overline{\theta}\right) &> \Phi\left(1,\overline{\theta}\right)=CS(\overline{\theta},\overline{\theta})+\pi_0^*\left(\overline{\theta},\theta_0\right)-\left[CS\left(\underline{\theta},\underline{\theta}\right)+\pi_0^*\left(\underline{\theta},\theta_0\right)\right]-\frac{24\underline{\theta}^3-18\underline{\theta}^2\theta_0+5\underline{\theta}\theta_0^2+\theta_0^3}{\left(4\underline{\theta}-\theta_0\right)^3}\left(\overline{\theta}-\underline{\theta}\right)\\
&= \frac{\overline{\theta}\left(4\overline{\theta}^2+7\overline{\theta}\theta_0-2\theta_0^2\right)}{2\left(4\overline{\theta}-\theta_0\right)^2}-\frac{\underline{\theta}\left(4\underline{\theta}^2+7\underline{\theta}\theta_0-2\theta_0^2\right)}{2\left(4\underline{\theta}-\theta_0\right)^2}-\frac{24\underline{\theta}^3-18\underline{\theta}^2\theta_0+5\underline{\theta}\theta_0^2+\theta_0^3}{\left(4\underline{\theta}-\theta_0\right)^3}\left(\overline{\theta}-\underline{\theta}\right).
\end{aligned}$$

It can now be shown that $\Phi\left(1,\overline{\theta}\right)$ is a convex function in $\overline{\theta}$ with a minimum implicitly defined by $\frac{24\underline{\theta}^3-18\underline{\theta}^2\theta_0+5\underline{\theta}\theta_0^2+\theta_0^3}{\left(4\underline{\theta}-\theta_0\right)^3}=\frac{8\overline{\theta}^3-6\overline{\theta}^2\theta_0-3\overline{\theta}\theta_0^2+\theta_0^3}{\left(4\overline{\theta}-\theta_0\right)^3}$. Evaluating $\Phi\left(1,\overline{\theta}\right)$ at this value, it can be shown that $\min\Phi\left(1,\overline{\theta}\right)>0$ holds, implying that $\Phi\left(\alpha,\overline{\theta}\right)>0$ is true for all $\alpha\in[0,1]$ and, a fortiori, for all $\alpha\in(0,\overline{\alpha})$. This completes the proof.

Proof of Proposition 9.1: Part (i): A separating level of advertising outlays needs to satisfy the incentive compatibility constraints

$$\begin{aligned}
\overline{\pi}(l,h)-K &\leq \overline{\pi}(l,l),\\
\overline{\pi}(h,h)-K &\geq \overline{\pi}(h,l).
\end{aligned}$$

Recalling the monotonicity condition (6) and following the same steps as in the proof of Lemma **??** it is readily established that $\overline{K} = A\left[\pi\left(l,h\right) - \pi\left(l,l\right)\right]$ is the level of separating advertising outlays that satisfies the intuitive criterion. Part (ii): The provider of high quality prefers pooling if and only if $\bar{\pi}^P(h) \geq \bar{\pi}(h,h) - \overline{K}$ or, after simplifying, if and only if $\pi\left(l,h\right) - \pi\left(h,h\right) + \pi^P(h) - \pi\left(l,l\right) \geq 0$. For $c = 0$ it holds that $\pi\left(l,h\right) = \pi\left(h,h\right)$ and $\pi^P(h) = \pi^P(l) > \pi\left(l,l\right)$, implying that the condition is always satisfied.

12 Appendix B: Simulations

Simulations are based on the formulas in Example 1 (Monopoly) and Example 2 (Duopoly).

In the Monopoly scenario, the baseline parameters are: $\delta = 0.9$, $T = 10$, $\overline{\theta} = 0.9$, $\overline{\theta} = 0.2$, $F = 20\%\overline{F}$. The parameters ρ, c, s vary. In addition, in one scenario F is increased to 90%. Simulations follow straightforwardly from Section 6, except for e^P, which is defined implicitly. In particular, we have that $\theta^P = e^P\overline{\theta} + (1-e^P)\underline{\theta}$ and $e^P = \zeta(\theta^P)$, with ζ a function defined as in Section 6:

$$e^P = \frac{1-\delta^T}{1-\delta}[\pi(h,h) - \pi(l,l)] - A[\big(\pi(h,h) - \pi^P(h)\big) + \big(\pi^P(l) - \pi(l,l)\big)]$$

Given that:

$$\begin{aligned}
\pi^P(h) &= \frac{(\theta^P - c)^2}{4\theta^P} \\
\pi^P(l) &= \frac{\theta^P}{4}
\end{aligned}$$

plugging the expression for pooling profits into the one for the effort and isolating θ^P:

$$e^P = M_1 + A\left(\frac{(\theta^P - c)^2}{4\theta^P} - \frac{\theta^P}{4}\right)$$

where

$$M_1 = \left(\frac{1-\delta^T}{1-\delta} - A\right)(\pi(h,h) - \pi(l,l))$$

Rearranging,

$$e^P = M_1 - \frac{Ac}{2} + \frac{Ac^2}{4\theta^P} = M_2 + \gamma\frac{1}{\theta^P}$$

Note that for $c = 0$, $\gamma = 0$ and $e^P = M_1$, which does not depend on θ^P. This is the case underlined in the text.

When $c > 0$, θ^P can be substituted by its expression in e^P:

$$e^P\theta^P = (e^P)^2(\overline{\theta} - \underline{\theta}) + e^P\underline{\theta} = M_2 e^P(\overline{\theta} - \underline{\theta}) + M_2\underline{\theta} + \gamma$$

which defines a quadratic function of the form:

$$a(e^P)^2 + b(e^P) + d = 0$$

where:

$$\begin{aligned}
a &= \overline{\theta} - \underline{\theta} \\
b &= \underline{\theta} - M_2(\overline{\theta} - \underline{\theta}) \\
d &= -M_2\underline{\theta} - \gamma
\end{aligned}$$

Two solutions can thus be found:

$$e^P = \frac{-b \pm \sqrt{b^2 - 4ad}}{2a}$$

The chosen value is the one that maximizes π^P within the [0,1] interval.