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Innovation, information, lobby and tort law under uncertainty

Julien Jacob* and Caroline Orset†

Abstract

Innovative firms have developed strategies to protect their business interests, such as concealing unfavourable results to avoid product withdrawal from the market (e.g. Monsanto, Servier). This behaviour poses a social challenge, as marketing hazardous products can have costly effects on Society (e.g. health and environment). This paper presents a model where a firm markets a product with unknown dangerousness. However, research investment may furnish valuable insights. A regulatory agency can grant or revoke marketing authorisation for the product based on its determination of the product's safety. The firm is liable for civil and penal penalties if it causes harm. According to our study, deploying a combination of market authorisation and civil and penal liabilities can effectively disincentive the firm's advocacy strategy. There is an emphasis on the need to impose penal liability if such lobbying conduct by the firm is uncovered. We examine the effects of these measures on firms' motivations to invest in research to mitigate scientific uncertainty and the relationship between public and private research.

Keywords: health and environmental risks, information acquisition, innovation, civil liability, penal liability, market authorisation, lobby.

JEL Classification: D01, D72, K32, Q57.

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1 Introduction

Competition drives firms to innovate by creating more cost-effective processes and/or attractive and innovative products. Nonetheless, investing in technological innovations leads to uncertainty regarding future returns and the potential risks of harm to health or the environment that may result. Tuncak (2013) reported on occurrences of "regrettable substitutions" whereby hazardous products were substituted by new ones, only to discover later that the latter were more dangerous than the former (e.g. flame retardants). To mitigate this uncertainty, firms can gather information about the potential impacts of their projects on human health and the environment through research activities or technical tests. In fact, in 2022, Bayer with €1.4 billion, Sanofi with €1.6 billion, and Roche with €3.1 billion, allocate a significant portion of their research and development budget towards experimental development in order to enhance their understanding of existing products.[1]

To gain or maintain marketing authorisation from the agency in the context of ex-ante control, firms can formulate targeted strategies to capitalise on scientific uncertainties. They may report favourable scientific findings and conceal adverse findings. Indirect lobbying, as defined in economic literature, describes this conduct as special interest groups endeavouring to influence public authorities. This term has already been employed by Yu (2005), Baron (2005), Shapiro (2016), and Bramoullé and Orset (2018). Yu (2005) investigated the competition between an industrial and an environmental lobby regarding political influence through communication campaigns. In addition, Baron (2005) and Shapiro (2016) examined the political influence of special interest groups through the news media. Moreover, Bramoullé and Orset (2018) analysed how firms' miscommunication can affect public policies. The research findings indicate that the firm deliberately maintains uncertainty by withholding precise results from the agency in order to advance its commercial agenda. This echoes the revelations of the "Monsanto Papers", which exposed the firm's creation of doubt by commissioning independent studies by its own scientists, claiming that Roundup (glyphosate) posed no risks. The firm allegedly persuaded reputable scientists to ghost-write these studies and sign off on them (Oreskes & Conway, 2011). Such conduct incurs high costs for Society. The case of the Mediator (benfluorex) serves as an example of the societal consequences of this approach taken by Servier Laboratory. Servier Laboratory has been found accountable for keeping a faulty drug available on the market despite acknowledging the risks as early as 2015. The Mediator was charged with causing fatalities of 1,500 to 2,100 individuals, let alone those who still endure the aftermath of its side effects a decade later (Frachon, 2010; Danis-Fatôme & Roux-Demare, 2021).

[1] Sources: https://www.bayer.com/en/innovation/research-and-development; https://www.sanofi.com/en; https://www.fiercebiotech.com/biotech/top-10-pharma-rd-budgets-2022.

Public management of harm risks arising from industrial processes employs both *ex-ante* and *ex-post* policy tools. In order to use new production processes or market new products, the *ex-ante* tool mandates authorisation by a public agency. The firm must provide the agency with a risk assessment, which undergoes the scrutiny of methodology and results before the agency decides to grant the authorisation. In addition to this upfront control, two penalties may apply retrospectively. Firstly, tortfeasors are held civilly liable for compensating any injuries sustained due to their actions post-accident. Moreover, current environmental policies extend this civil liability to any harm caused to the environment as a result of their actions, following the emergence of the 'pollutant-payer' principle.[2] For the European Union, please refer to the 2004/35/CE directive, which enforces environmental civil liability on polluters to pay for their activities' deleterious effects. The objective of this policy is twofold: to provide compensation for damage already done (*ex-post* justice) and to incentivise polluters to regulate their externalities in the future (*ex-ante*).[3] Second, penal liability can also be imposed on the firm by paying a fine if it is found to have criminal behaviour, such as hiding information on the product's dangerousness from the agency.

Therefore, a combination of three public policy tools is used to incentivise firms to undertake "due diligence" in risk management. The main concern is how effective these tools are in encouraging firms to conduct adequate information research and disclose all information regarding the danger of their chosen processes and/or products to the agency. Our paper analyses to what extent the combined civil and penal *ex-post* liability system aids the *ex-ante* authorisation control process by incentivising firms to invest in research to reduce uncertainty and improve communication on the outcomes. Our goal is to assess the effectiveness of this system.

We focus on a firm that trades products that could harm human health and/or the environment. The exact likelihood of causing harm has yet to be fully understood. Both the firm and the agency will obtain information through public research. Furthermore, the firm can collect additional data as part of its own research, which it may share with the agency. The agency will assess whether to maintain or revoke the marketing authorisation. If harm is caused and the firm has withheld pertinent information, it may be held accountable for civil and penal liability.

Our approach is grounded in two fundamental building blocks. Firstly, it is based on the principles of fundamental options theory. Obtaining information is considered an expensive

[2]Refer to *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA, 1980) for information on the USA.

[3]Classic works on economic analysis of incentives provided by civil liability include Brown (1973) and Shavell (1980, 1986).

right rather than an obligation for the firm. This real option enables the firm to terminate the project if it proves unprofitable or hazardous while recouping a portion of its initial investment. This differs from the typical literature, where investments are considered irreversible, and the flow of information is external (Arrow-Fisher, 1974; Henry, 1974; Brocas and Carrillo, 2000, 2004). Our theoretical approach measures the significance of management flexibility in an uncertain world. Consequently, we contribute a fresh dimension by incorporating endogenous information.

Secondly, the article proposes three contributions to the literature concerning the effects of public policies on the firm's risk management decisions. Shavell (1984) and Hiriart *et al.* (2004) investigated the optimal implementation of *ex-ante* safety regulations and *ex-post* civil liability. Furthermore, Hiriart *et al.* (2004) expanded on Shavell's (1984) study by examining the possibility of ex-ante transfers between the firm and the agency. These studies shed light on how public policies can affect firms regarding risk management strategies. In 2004, it was demonstrated that insufficient information regarding the extent of harm can hinder the enforcement of optimal levels of care. Hiriart and Martimort (2012) conducted a more in-depth analysis of the interactions between firms and regulatory agencies and identified the circumstances giving rise to collusion between these parties. Following the seminal research of Tirole (1992) and Laffont and Martimort (1997), they posited that the Judge's duty is not limited to resolving ex-post conflicts but also serves as an implicit disciplinary measure to prevent clandestine agreements between corporations and agencies ex-ante. Nevertheless, the analysis fails to consider the scenario of poorly comprehended risks, where additional information is anticipated (that firms could exploit strategically). Moreover, the joint utility maximisation problem between the Judge and firms has yet to be examined in this context. However, these studies need to consider situations where risks are not perfectly known and where supplementary information could be provided by firms who may strategically use it. Additionally, the combined use of civil and penal liabilities is not considered. Our initial contribution to this literature is the consideration of this imprecision of risk information and the combination of civil and penal liabilities.

Shavell (1992) was the first to analyse the incentives provided by different civil liability rules for seeking additional information about an imperfectly known risk of harm. Chemarin and Orset (2011) extended Shavell's (1992) analysis by considering the possibility of receiving an imprecise signal about the nature of the risk and studying how a present bias may affect decisions regarding information-seeking. However, these previous two papers have not considered the potential strategic implementation of information towards an agency that acts before the firm enters the market. As such, our secondary contribution to this field is to address this shortfall.

Immordino et al. (2011) compared ex-ante regulations and ex-post fines to incentivise the development of innovative products and prevent 'regrettable substitution.' Jacob et al. (2019)

extended the analysis of Immordino et al. (2011) by including additional policies such as strict and limited civil liability and the potential for prohibiting obsolete products. They also incorporated the probability of the new product being hazardous. However, neither the analyses by Immordino *et al.* nor those by Jacob *et al.* allow the firm to conduct further information searches or experience communication difficulties with the agency. Furthermore, neither study does not present the combination of *ex-ante* authorisation and *ex-post* civil and penal liabilities. Our third contribution to this area of research is to present an analysis that combines *ex-ante* marketing authorisation with *ex-post* civil and penal liabilities. This approach aims to reduce a firm's incentive for miscommunication whilst increasing the incentive for prevention.

The analysis produces two sets of findings. The first pertains to the conduct of the firm, wherein the role of the interplay between public research-provided information and internally generated information in the firm's determination to persist or terminate sales of its merchandise is demonstrated. The circumstances under which the firm may conceal facts from the agency to advance its commercial objectives are particularly emphasised. In addition, it should be noted that the firm's research investment relies on the first impression of the product's hazardousness. The firm may invest solely in information if the initial impression is reasonable. Firstly, it may choose to invest to reduce uncertainty regarding the potential danger of its product and avoid liability by ceasing its sale if necessary. Secondly, the firm may decide to refrain from investing in research if new information is not likely to impact its decision on whether to continue or cease production and will not influence the agency's decisions. In addition, we highlight cases where the firm may decide to decrease its research investments due to fears of withdrawing its profitable product if bad news is received. Moreover, cases may arise whereby public and private research are substituted. On the one hand, if public information is highly dependable, the firm can decrease its research investment to benefit from cost-efficient information. On the contrary, in cases where the dependability of public data is projected to be inadequate, the firm may be motivated to allocate resources towards diminishing uncertainty.

A further set of findings examines the effects of the *ex-ante* (authorisation) and *ex-post* (civil and penal liability) policy instruments. Initially, we highlight the circumstances under which penal liability discourages the firm from concealing adverse information from the agency. Penal liability is necessary to deter lobbying behaviour, while civil liability influences the firm's decision to stop or continue selling its product. Furthermore, we have observed that when there is a greater disparity in the damage resulting from a prolonged versus a brief exposure to the product, the firm is more inclined to invest in obtaining information in various situations and to intensify its efforts in information acquisition.

The remainder of the paper is organised as follows. Section 2 presents the model. Section 3 outlines the optimal decisions made by both the agency and the firm. The paper concludes with section 4. All the proofs are in the Appendix.

2 The model

We are examining a model consisting of three periods. Figure 1 illustrates the different phases of this model.

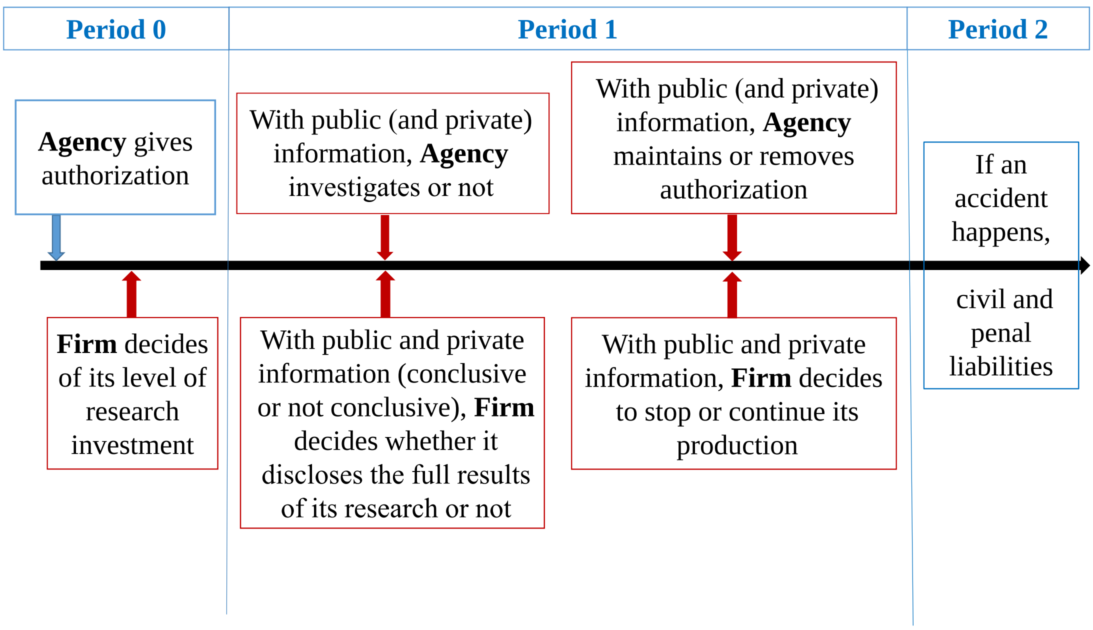

Figure 1: Timing of the model.

At period 0, the agency approves the firm to carry out a process and/or market a product[4] that could potentially harm human health and/or the environment. Two potential occurrences, H and L, are linked to varying probabilities of resulting in damage, specifically θ^H and θ^L. We will assume that H embodies a greater risk than L, allowing for:

$$0 < \theta^L < \theta^H < 1.$$

The agency and the firm have the same prior beliefs p_0 on state H, and $1 - p_0$ on state L, with $0 < p_0 < 1$. The agency grants the marketing authorisation when its belief in being in state H is below the threshold belief defined thanks to scientists as associated with an acceptable risk to society $\bar{p}$. We, therefore, have $p_0 \leq \bar{p}$. The firm can pay $C \geq 0$ to

[4]Both scenarios will be considered, although the paper focuses on product authorisation for marketing. The model applies to situations where a new product requires authorisation. However, prior knowledge of its hazardous effects may facilitate its marketing.

obtain more information at period 1 through a signal $\sigma_F \in \{h, l\}$ on the true state of Nature.

At period 1, the firm and the agency receive exogenous information from independent public scientific studies. This is free and public information. The arrival of this new information is expected, and the reliability of this information (see after) is known in advance.[5] This information is given through a signal $\sigma \in \{h, l\}$ on the true state of Nature. We define the precision or reliability of the signal, f, as the probability that the signal corresponds to the state. We represent it such that:

$$P(h|H) = P(l|L) = f,\ P(h|L) = P(l|H) = 1 - f \text{ and } f > \tfrac{1}{2}.^{6}$$

Then, at the same instant, the firm receives private information from its investment in research, C. However, we assume that information may not be conclusive with a $q \in [0, 1]$ probability. This implies that even if the firm invested in research $C > 0$, its private signal has a precision $f_F(C)$ defined as:

$$f_F(C) = \begin{cases} g_F(C) & \text{with probability 1-q} \\ \frac{1}{2} & \text{with probability q} \end{cases},$$

with $g_F(C)$, an increasing and concave function such that for $\sigma_F \in \{h, l\}$:

$$P(h|H, C) = P(l|L, C) = g_F(C) \text{ and } P(h|L, C) = P(l|H, C) = 1 - g_F(C)$$

and

$$g_F(0) = \tfrac{1}{2},\ g_F(+\infty) \to 1,\ g_F'(+\infty) = 0$$

with the subscript F denoting that this information is private to the firm. Hence, if the firm does not invest, i.e. $C = 0$, or invests in research, i.e. $C > 0$, but the research provides non-conclusive results, it does not hold any additional private information on the risk. On the other hand, when the research provides conclusive results, the information precision depends on the amount C the firm has invested in information acquisition. In that case, the higher the value of C, the higher the precision of the signal σ_F. This information is only known by the firm. It is private information that it may reveal to the agency at its convenience.

We then define the exogenous public information precision combined with the endogenous private information precision such that:[7]

$$P((h,h)|H, f_F(C)) = P((l,l)|L, f_F(C)) = f f_F(C), P((l,l)|H, f_F(C)) = P((h,h)|L, f_F(C)) = (1-f)(1-f_F(C))$$
$$P((h,l)|H, f_F(C)) = P((l,h)|L, f_F(C)) = f(1-f_F(C)), P((l,h)|H, f_F(C)) = P((h,l)|L, f_F(C)) = (1-f) f_F(C).$$

[5]This can be known from past observations.

[6]We assume that this belief is identical for all economic agents.

[7]We consider that endogenous and exogenous information have the same weight.

According to Bayes' rule, for the firm, the probabilities of being in state H depending on signals (σ and σ_F) and C are, respectively:

$$P^F(H|(h,h), f_F(C)) = \frac{p_0 f f_F(C)}{p_0 f f_F(C)+(1-p_0)(1-f)(1-f_F(C))},$$
$$P^F(H|(l,l), f_F(C)) = \frac{p_0(1-f)(1-f_F(C))}{p_0(1-f)(1-f_F(C))+(1-p_0)f f_F(C)},$$
$$P^F(H|(h,l), f_F(C)) = \frac{p_0 f(1-f_F(C))}{p_0 f(1-f_F(C))+(1-p_0)(1-f)f_F(C)},$$
$$\text{and } P^F(H|(l,h), f_F(C)) = \frac{p_0(1-f)f_F(C)}{p_0(1-f)f_F(C)+(1-p_0)f(1-f_F(C))}.$$

After receiving public and private information and updating its belief, we suppose the firm has the possibility $t^F \in \{0,1\}$ to choose between two behaviours. $t^F = 1$ means the firm decides not to disclose the full results of its research. By doing so, the firm decides to provide non-conclusive results to the agency, no matter if the results it received were conclusive or not (i.e., the agency receives the firm's private information with precision $f_F(C) = \frac{1}{2}$, whatever the real value of $f_F(C)$ which the firm received by). If the firm chooses $t^F = 0$, it provides all its results to the agency, i.e., the agency receives its private information with the real precision $f_F(C)$ received by the firm. As a consequence, in that case, the firm and the agency have similar information, and we have $P^A(.|(.,.), f_F(C)) = P^F(.|(.,.), f_F(C))$, the superscripts A and F denoting the agency and the firm respectively.[8]

According to signal $\sigma \in \{l,h\}$ and $\sigma_F \in \{l,h\}$, we define $x^A_{\sigma,\sigma_F,f_F(C)} \in \{0,1\}$ as the agency's decision to maintain the authorization ($x^A_{\sigma,\sigma_F,f_F(C)} = 1$), or to withdraw it ($x^A_{\sigma,\sigma_F,f_F(C)} = 0$), and z as the agency's decision to investigate ($z = 1$) or not ($z = 0$). Indeed, after receiving information and deciding to maintain or withdraw the market authorisation, the agency can investigate the real information signal the firm received (privately). This investigation succeeds with a probability δ, with $0 < \delta < 1$. In case of success of the investigation, if it is revealed to the agency that the firm had concealed a signal $\sigma_F = h$, the agency informs the Judge who applies a fine ($M > 0$) to the firm, and the agency withdraws the market authorisation.

The agency removes the authorisation, i.e. $x^{A*}_{\sigma,\sigma_F,f_F(C)} = 0$, when its belief $P^A(H|(\sigma,\sigma_F), f_F(C))$ on state H is higher than the threshold belief defined by scientists as that associated with the acceptable risk to Society, $\bar{p}$. In this situation, the agency does not have any interest in investigating the firm's behaviour, $z^* = 0$.[9] However, when its belief $P^A(H|(\sigma,\sigma_F), f_F(C))$ on state H is below the threshold belief, if the agency has received non-conclusive results from the firm, i.e. $f_F(C) = 1/2$, then the agency may suspect the firm to not reporting all of its research results, and it may decide to investigate.

[8] The agency also revised its belief according to Bayes' rule as the firm.

[9] Indeed, in that case, the firm has no interest in concealing information: conclusive favourable information could lead the agency to maintain the product, and in case of conclusive unfavourable information, the information provided by the firm cannot change the agency's decision. The firm is interested in providing it to escape any fine for not disclosing the full results of its research (see later).

Naturally, if the agency withdraws the market authorisation, the firm cannot sell its product any more. In such a case, the firm recovers $D > 0$, which is lower than the benefit it could earn if it could continue to sell its product until period 2 (see later). However, the firm can remove its product from the market by itself. We denote as $x^F_{\sigma,\sigma_F,f_F(C)} \in \{0,1\}$ the firm's decision to remove by itself ($x^F_{\sigma,\sigma_F,f_F(C)} = 0$), or not to remove ($x^F_{\sigma,\sigma_F,f_F(C)} = 1$), its product from the market. Removing by itself its product allows the firm to recover $D > 0$, it also allows the firm not to be investigated by the agency, and to decrease the amount of harm that its product may cause at period 2.

At period 2, an accident may happen (with probability θ^H or θ^L depending on the state of Nature). If the product is sold until period 2, the firm gets a payoff $R_2 > 0$, and the magnitude of the harm caused by the product is $K > 0$. Because (strict) civil liability applies, the firm has to pay K to repair the damage. However, if the product has been withdrawn at period 1 (by the agency or the firm), the magnitude of harm is reduced: $K' > 0$ with $K \geq K'$. So, the magnitude of harm depends on the time of exposure. In case of an accident, a penal investigation is automatically opened by a Judge (of a penal court),[10] except where the firm has already been detected (and punished) in period 1. The penal investigation aimed to check if all the information the firm possessed had been transmitted to the agency. Suppose the penal Judge proves that the firm decided not to disclose the full results of its research. In this case, it applies penal liability and condemns the firm to pay a $M > 0$ fine. The probability that the Judge gathers enough elements during this investigation to enforce penal liability is $p_J \in [0,1]$. In other words, when the firm chooses not to disclose the full results of its research, then, after damage occurs, it has a probability p_J to pay a fine of M.

Before receiving any additional information (neither σ nor σ_F), at period 0, let the probability of causing harm be:

$$E(\theta) = p_0\theta^H + (1 - p_0)\theta^L.$$

After receiving the two signals σ and σ_F in period 1, the updated expected probability of damage for the firm is:

$$E(\theta|(\sigma,\sigma_F), f_F(C)) = P^F(H|(\sigma,\sigma_F), f_F(C))\theta^H + (1 - P^F(H|(\sigma,\sigma_F), f_F(C)))\theta^L.$$

Therefore, we can define the expected payoffs of the firm at each period. We suppose each period is discounted by a discount factor β, with $\beta \in]0,1]$. First, consider the case where the firm invests a strictly positive amount $C > 0$ in research. At the end of period 1 (after having made all decisions from period 1), the firm's expected payoff for period 2 is:

[10] We can take the VW diesel cheating scandal as an example; see The Detroit News (2017).

$$
\begin{aligned}
V_2 &= V_2(x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, t^F, z, x^N_\delta) \\
&= t^F[z[x^N_\delta[E(\theta|(\sigma,\sigma_F), f_F(C))(-K')] \\
&+(1-x^N_\delta)[((1-x^A_{\sigma,\sigma_F,\frac{1}{2}}) + x^A_{\sigma,\sigma_F,\frac{1}{2}}(1-x^F_{\sigma,\sigma_F,f_F(C)}))E(\theta|(\sigma,\sigma_F), f_F(C))(-K'-p_J M) \\
&+x^A_{\sigma,\sigma_F,\frac{1}{2}} x^F_{\sigma,\sigma_F,f_F(C)}(R_2 - E(\theta|(\sigma,\sigma_F), f_F(C))(K+p_J M))]] \\
&+(1-z)[((1-x^A_{\sigma,\sigma_F,\frac{1}{2}}) + x^A_{\sigma,\sigma_F,\frac{1}{2}}(1-x^F_{\sigma,\sigma_F,f_F(C)}))E(\theta|(\sigma,\sigma_F), f_F(C))(-K'-p_J M) \\
&+x^A_{\sigma,\sigma_F,\frac{1}{2}} x^F_{\sigma,\sigma_F,f_F(C)}(R_2 - E(\theta|(\sigma,\sigma_F), f_F(C))(K+p_J M))]] \\
&+(1-t^F)[((1-x^A_{\sigma,\sigma_F,f_F(C)}) + x^A_{\sigma,\sigma_F,f_F(C)}(1-x^F_{\sigma,\sigma_F,f_F(C)}))E(\theta|(\sigma,\sigma_F), f_F(C))(-K') \\
&+x^A_{\sigma,\sigma_F,f_F(C)} x^F_{\sigma,\sigma_F,f_F(C)}(R_2 - E(\theta|(\sigma,\sigma_F), f_F(C))K)]
\end{aligned}
$$

with x^N_δ being a binary variable which takes the value 1 where the agency's investigation is successful and the value 0 otherwise.[11]

The first line relates to the case where the firm has decided not to disclose the full results of its research ($t^F = 1$), the agency decides to investigate ($z = 1$) and finds evidence against the firm ($x^N_\delta = 1$). In that case, the product was withdrawn from the market in period 1; the firm was fined for not disclosing all results of its research in period 1, so for period 2, the firm only expected to pay the cost of K' in damages in case of harm.
In the cases where the agency does not investigate ($z = 0$) or when the investigation is not conclusive ($x^N_\delta = 0$), then if the firm decided in period 1 to market its product until period 2, it has to pay the expected cost of damage K and the expected cost of a fine M (if the Judge finds evidence of not disclosure during the investigation that takes place after the occurrence of harm). If the firm had to stop selling its product in period 1, then in period 2, it has to pay a lower expected cost of damage K'. However, it remains subject to an acceptable risk during the investigation after the occurrence of harm.
Finally, when the firm has decided to disclose its research's full results ($t^F = 0$), in period 2, it can pay in damages K or K' (in case of harm), depending on whether it had to stop selling its product in period 1 or not.

Then, we can define the firm's expected payoffs for period 1, when it is at the end of period 0 (after having made all decisions from period 0):

$$
\begin{aligned}
V_1 &= V_1(x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, t^F, z, x^N_\delta) \\
&= t^F[z[x^N_\delta[D + \beta V_2(0, x^F_{\sigma,\sigma_F,f_F(C)}, 1, 1, 1) - M] \\
&+(1-x^N_\delta)[((1-x^A_{\sigma,\sigma_F,\frac{1}{2}}) + x^A_{\sigma,\sigma_F,\frac{1}{2}}(1-x^F_{\sigma,\sigma_F,f_F(C)}))D + \beta V_2(x^A_{\sigma,\sigma_F,\frac{1}{2}}, x^F_{\sigma,\sigma_F,f_F(C)}, 1, 1, 0)]] \\
&+(1-z)[((1-x^A_{\sigma,\sigma_F,\frac{1}{2}}) + x^A_{\sigma,\sigma_F,\frac{1}{2}}(1-x^F_{\sigma,\sigma_F,f_F(C)}))D + \beta V_2(x^A_{\sigma,\sigma_F,\frac{1}{2}}, x^F_{\sigma,\sigma_F,f_F(C)}, 1, 0, x^N_\delta)]] \\
&+(1-t^F)[((1-x^A_{\sigma,\sigma_F,f_F(C)}) + x^A_{\sigma,\sigma_F,f_F(C)}(1-x^F_{\sigma,\sigma_F,f_F(C)}))D + \beta V_2(x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, 0, z, x^N_\delta)]
\end{aligned}
$$

[11] In other words, x^N_δ is the result of the lottery about the success of the agency's investigation (probability δ of success, $1-\delta$ of failure), decided by Nature.

with β the discount factor, which also applies to the (expected) payoffs for the next period 2.

The first line relates to the case where the firm has decided not to disclose the full results of its research ($t^F = 1$), the agency decides to investigate ($z = 1$) and finds evidence against the firm ($x_\delta^N = 1$). As stated before, in that case, the agency automatically decides to withdraw the product from the market (i.e., $x^A_{\sigma,\sigma_F,\frac{1}{2}} = 0$ when $t^F = 1$, $z = 1$ and the investigation succeeds ($x_\delta^N = 1$)), and informs the Judge to apply penal liability (fine M). The firm recovers $D < R_2$ from having sold the product during periods 0 and 1 (but not period 2). In the cases where the agency does not investigate ($z = 0$) or when the investigation is not conclusive (probability $x_\delta^N = 0$), if the firm and/or the agency decides to stop selling the product, then the firm recovers D in period 1. This is the same when the firm has decided to disclose the full results of its research (i.e., $t^F = 0$).

Next, we can define the firm's expected payoffs at the beginning of period 0. We first define:

$$\begin{aligned} V_0|q \; &= [p_0 f \tfrac{1}{2} + (1-p_0)(1-f)\left(1-\tfrac{1}{2}\right)]V_1(x^A_{h,h,\frac{1}{2}}, x^F_{h,h,\frac{1}{2}}, t^F, z, x^N_\delta) \\ &+ [p_0(1-f)\left(1-\tfrac{1}{2}\right) + (1-p_0)f\tfrac{1}{2}]V_1(x^A_{l,l,\frac{1}{2}}, x^F_{l,l,\frac{1}{2}}, t^F, z, x^N_\delta) \\ &+ [p_0 f\left(1-\tfrac{1}{2}\right) + (1-p_0)(1-f)\tfrac{1}{2}]V_1(x^A_{h,l,\frac{1}{2}}, x^F_{h,l,\frac{1}{2}}, t^F, z, x^N_\delta) \\ &+ [p_0(1-f)\tfrac{1}{2} + (1-p_0)f\left(1-\tfrac{1}{2}\right)]V_1(x^A_{l,h,\frac{1}{2}}, x^F_{l,h,\frac{1}{2}}, t^F, z, x^N_\delta). \end{aligned}$$

as the expected payoffs at the end of period 0, conditional on the firm's private information being inconclusive, and:

$$\begin{aligned} V_0|(1-q) \; &= [p_0 f f_F(C) + (1-p_0)(1-f)(1-f_F(C))]V_1(x^A_{h,h,f_F(C)}, x^F_{h,h,f_F(C)}, t^F, z, x^N_\delta) \\ &+ [p_0(1-f)(1-f_F(C)) + (1-p_0)f f_F(C)]V_1(x^A_{l,l,f_F(C)}, x^F_{l,l,f_F(C)}, t^F, z, x^N_\delta) \\ &+ [p_0 f(1-f_F(C)) + (1-p_0)(1-f) f_F(C)]V_1(x^A_{h,l,f_F(C)}, x^F_{h,l,f_F(C)}, t^F, z, x^N_\delta) \\ &+ [p_0(1-f) f_F(C) + (1-p_0)f(1-f_F(C))]V_1(x^A_{l,h,f_F(C)}, x^F_{l,h,f_F(C)}, t^F, z, x^N_\delta) \end{aligned}$$

as the expected payoffs at the end of period 0, conditional on the firm's private information being conclusive. Hence, the firm's expected payoff at the beginning of period 0 when it invests a strictly positive amount $C > 0$ in research is:

$$V_0(x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, t^F, z, x^N_\delta, C) \; = -C + \beta[qV_0|q + (1-q)V_0|(1-q)].$$

In the case where the firm chooses not to invest in research (i.e., $C = 0$), its expected payoff at the end of period 0, say $V_0|(C = 0)$, is similar to the case where information is inconclusive. So, we have:

$$V_0|(C = 0) = V_0|q.$$

As a result, the firm's expected payoff at the beginning of period 0 when it decides not to invest in research is:

$$V_0(x^A_{\sigma,\sigma_F,\frac{1}{2}}, x^F_{\sigma,\sigma_F,\frac{1}{2}}, t^F, z, x^N_\delta, 0) \; = \beta V_0|(C = 0) = \beta V_0|q.$$

Finally, by assumption, we consider that if there is neither exogenous nor endogenous information, the firm is authorised by the agency to sell its product and will always continue to sell it (until period 2).[12] Therefore, we have:

$$V_1(1, 0, t^F, z, x_\delta^N) < V_1(1, 1, t^F, z, x_\delta^N)$$
$$\Rightarrow E(\theta) < \frac{\beta R_2 - D}{\beta(K - K')} \text{ with } E(\theta) = p_0\theta^H + (1 - p_0)\theta^L. \quad (1)$$

which is equivalent to:

$$p_0 < \frac{(\beta R_2 - D) - \beta\theta^L(K - K')}{\beta(K - K')(\theta^H - \theta^L)}$$

As a result, the agency and the firm do not share different criteria regarding the decision to stop or continue to market the product. While the agency's decision is driven by its belief relative to the threshold of acceptable risk $\bar{p}$, the firm's decision is driven by its own threshold, $\frac{(\beta R_2 - D) - \beta\theta^L(K - K')}{\beta(K - K')(\theta^H - \theta^L)}$, which depends on the net benefit from continuing to sell the product, $\beta R_2 - D$, and on the increase in expected damages when continuing to sell the product instead of stopping, $\beta(K - K')(\theta^H - \theta^L)$. An increase in $\beta R_2 - D$ leads to a broader range of the firm's beliefs to be compatible with the decision to continue to market the product. In contrast, an increase in $\beta(K - K')(\theta^H - \theta^L)$ gives more possibility to stop marketing the product. Initially, without additional information, we assume both the agency and the firm want to continue to market the product: $p_0 < \bar{p}$ and $p_0 < \frac{(\beta R_2 - D) - \beta\theta^L(K - K')}{\beta(K - K')(\theta^H - \theta^L)}$.

3 The optimal decision-making

In this section, we present the optimal decision-making. The model is backwards solved. First, at period 1, according to signal $\sigma \in \{l, h\}$ and $\sigma_F \in \{l, h\}$ and for $C \geq 0$, the firm has to decide whether it would like to remove or to continue to sell its product. The firm wants to continue to market its product if its expected payoff by continuing to sell it is higher than that when removing it from the market. That is:

$$V_1(x^A_{\sigma, \sigma_F, f_F(C)}, 0, t^F, z, x_\delta^N) < V_1(x^A_{\sigma, \sigma_F, f_F(C)}, 1, t^F, z, x_\delta^N).$$

The following proposition gives conditions under which the firm wants to remove its product or wants to continue to sell it.

Proposition 1 *For $x^A_{\sigma, \sigma_F, f_F(C)} \in \{0, 1\}$, $t^F \in \{0, 1\}$, $z \in \{0, 1\}$, $x_\delta^N \in \{0, 1\}$, $\sigma \in \{l, h\}$, $\sigma_F = \{l, h\}$, $f_F(C) \geq \frac{1}{2}$, and $f > \frac{1}{2}$:*

1. *If $P^F(H|(\sigma, \sigma_F), f_F(C)) < \frac{(\beta R_2 - D) - \beta\theta^L(K - K')}{\beta(K - K')(\theta^H - \theta^L)}$ then the firm would like to keep selling its product, i.e., $x^{F*}_{\sigma, \sigma_F, f_F(C)} = 1$;*

[12] In this situation, there is no investigation or signal, which implies that $x_\delta^N = 0$ and $t^F = 0$.

2. *If* $P^F(H|(\sigma,\sigma_F), f_F(C)) > \frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$ *then the firm removes its product from the market, i.e.,* $x^{F*}_{\sigma,\sigma_F,f_F(C)} = 0$;

3. *If* $P^F(H|(\sigma,\sigma_F), f_F(C)) = \frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$ *then the firm is indifferent between continuing to sell its product and removing it from the market, i.e.,* $x^{F*}_{\sigma,\sigma_F,f_F(C)} \in \{0,1\}$.

As said above, Proposition 1 confirms that a higher benefit from maintaining the product $(\beta R_2 - D)$ increases the firm's willingness to keep selling its product. In contrast, the increase in expected damages refrains it. This highlights the incentives provided by civil liability to decrease the exposition of consumers (who are potential victims) to the product.

Lemma 1 *For* $\sigma \in \{l,h\}$, $\sigma_F = \{l,h\}$, $f_F(C) \geq \frac{1}{2}$, $f > \frac{1}{2}$, *and* $i \in \{A,F\}$:

1. *If* $f_F(C) < f$ *then* $P^i(H|(l,l), f_F(C)) < P^i(H|(l,h), f_F(C)) < p_0 < P^i(H|(h,l), f_F(C)) < P^i(H|(h,h), f_F(C))$;
2. *If* $f_F(C) > f$ *then* $P^i(H|(l,l), f_F(C)) < P^i(H|(h,l), f_F(C)) < p_0 < P^i(H|(l,h), f_F(C)) < P^i(H|(h,h), f_F(C))$;
3. *If* $f_F(C) = f$ *then* $P^i(H|(l,l), f_F(C)) < P^i(H|(h,l), f_F(C)) = p_0 = P^i(H|(l,h), f_F(C)) < P^i(H|(h,h), f_F(C))$.

Finally, $P^i(H|(h,h), f_F(C))$ *and* $P^i(H|(l,h), f_F(C))$ *are increasing with* $f_F(C)$ *while* $P^i(H|(l,l), f_F(C))$ *and* $P^i(H|(h,l), f_F(C))$ *are decreasing with* $f_F(C)$.

From Lemma 1 and Proposition 1, we can first highlight the effect of the signals and the investment C on the firm's decisions: the higher the level of C, the less the firm's willingness to continue to market the product while receiving a signal $\sigma_F = h$. The higher C, the higher the firm's willingness to continue to market while receiving $\sigma_F = l$. By assumption, the firm always wants to continue to market after receiving two favourable signals $\sigma = l$ and $\sigma_F = l$, i.e., $x^{F*}_{l,l,f_F(C)} = 1$. In the opposite case, when $\sigma = \sigma_F = h$, the firm can stop by itself to market its product if both public and private signals lead its updated belief, $P^F(H|(h,h), f_F(C))$, to be higher than $\frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$. Next, if it receives $\sigma = l$ and $\sigma_F = h$, public information indicates a low risk and private information a high risk. It wants to continue to market the product ($x^{F*}_{l,h,f_F(C)} = 1$) except when the precision of its private information signal is sufficiently higher than the public information precision, i.e. $f_F(C) > f$ (necessary condition). Finally, if $\sigma = h$ and $\sigma_F = l$, that is, public information indicates a high risk and private information a low risk, it wants to keep marketing ($x^{F*}_{h,l,f_F(C)} = 1$) except when the private information precision is sufficiently lower than the public information precision, i.e. $f_F(C) < f$ (necessary condition). Therefore, the firm's decision depends on the reliability of the private signal relative to the public one, which is endogenous to the firm through its investment of C in research.

Then, given the public signal and, if any, the private one, the agency decides whether to maintain or withdraw the market authorisation.

From Lemma 1, we understand that the agency always maintains the authorisation when it receives two signals l, that is when all information indicates that the risk seems to be low

($x^{A*}_{l,l,f_F(C)} = 1$). However, on the other hand, when it receives two signals h, all information indicates that the risk seems to be high. Therefore, the agency removes the authorisation ($x^{A*}_{h,h,f_F(C)} = 0$) except in the case where the least favourable state is considered as an acceptable risk to Society, i.e., $P^A(H|(h,h), f_F(C)) < \bar{p_0}$, or if both signals are of law reliability (both f and $f_F(C)$ are sufficiently low). Next, if it receives $\sigma = l$ and $\sigma_F = h$, public information indicates a low risk and private information a high risk. Therefore, it maintains the authorisation ($x^{A*}_{l,h,f_F(C)} = 1$) except when the private information precision is sufficiently higher than the public information precision (i.e. $f_F(C) > f$ is a necessary condition). Finally, suppose the agency receives $\sigma = h$ and $\sigma_F = l$. In that case, that is, public information indicates a high risk and private information a low risk, it maintains the authorisation ($x^{A*}_{h,l,f_F(C)} = 1$) except when the public information precision is sufficiently higher than the private information precision (i.e. $f_F(C) < f$ is a necessary condition). Therefore, the agency's decision depends on the levels of precision of the exogenous and endogenous information it receives.

Below, Figure 2 highlights how the agency and the firm decide about product marketing. While they treat the information similarly, their decisions are made relatively to different belief thresholds.

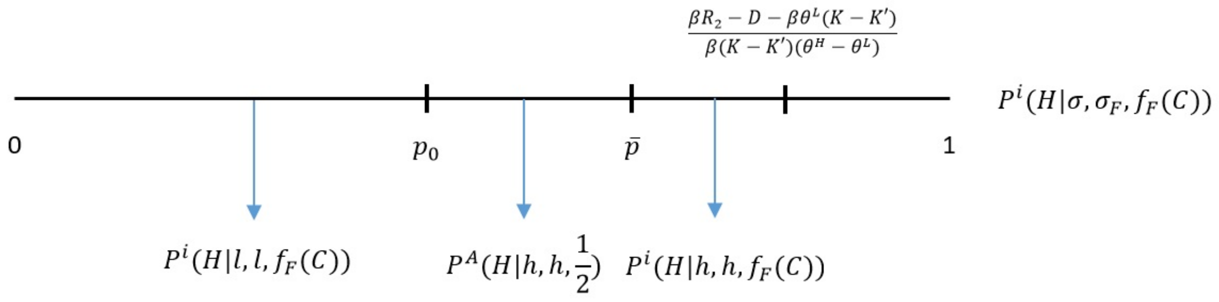

Figure 2: Decisions to market: firm and agency

According to Lemma 1, $P^A(H|(h,h), f_F(C))$ and $P^A(H|(l,h), f_F(C))$ are increasing with C, therefore $x^{A*}_{\sigma,h,f_F(C)} \leq x^{A*}_{\sigma,h,\frac{1}{2}}$. In words, when the agency receives a signal $\sigma_F = h$ from the firm (with a reliability $f_F(C) > \frac{1}{2}$), the likelihood of withdrawing the authorisation is higher than when it receives an inconclusive signal ($f_F(C) = \frac{1}{2}$). So, in some cases, the agency receiving inconclusive information may then decide to maintain the authorisation while, when receiving a conclusive $\sigma_F = h$ signal, it would have withdrawn it. This opens the door to the possibility of lobby from the firm, as illustrated in Figure 2 in the case where: $P^i(H|(h,h), \frac{1}{2}) < \bar{p} < P^i(H|(h,h), f_F(C)) < \frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$. In words, when the firm's decision threshold $\frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$ is higher than the agency's one ($\bar{p}$), it is possible to have a firm who, despite two signals $\sigma = \sigma_F = h$ (with $f_F(C) > \frac{1}{2}$), wants to keep continuing to market the product (i.e., $x^{F*}_{\sigma,h,f_F(C)} = 1$) while the agency would not (i.e., $x^{A*}_{\sigma,h,f_F(C)} = 0$).

Nevertheless, in the case where the agency, in the face of an inconclusive signal from the firm, would maintain the authorisation (i.e., $x^{A*}_{\sigma,h,\frac{1}{2}} = 1$), there is an incentive for the firm to conceal the signal to keep benefiting from marketing the product. The lobby can thus take place.

Still, in period 1, the firm has to decide whether to disclose the full results of its research. The firm decides to keep the full results of its research private (i.e., to lobby, $t^F = 1$) if its expected payoff by doing so is higher than when it does not. That is:

$$V_1(x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, 0, z, x^N_\delta) < V_1(x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, 1, z, x^N_\delta).$$

As highlighted above, a necessary condition for the firm to lobby is $P^i(H|(h,h),\frac{1}{2}) < \bar{p} < P^i(H|(h,h), f_F(C)) < \frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H - \theta^L)}$. In words, the firm wants to market the product, despite unfavourable signals, and can hide its private signal to maintain the market authorization.[13] The penal system can deter Such behaviour, which can be detrimental to Society because of maintaining a product that it considers too dangerous. We note:

$$\bar{M} = \frac{(1-\delta z)\left(\beta\left(R_2 - E(\theta|(\sigma,h), f_F(C))\left(K-K'\right)\right) - D\right)}{\delta z + (1-\delta z)\,\beta E(\theta|(\sigma,h), f_F(C))p_J}.$$

The following proposition gives the conditions under which the firm decides to disclose the full results of its research or not.

Proposition 2 *For $z \in \{0,1\}$, $x^N_\delta \in \{0,1\}$, $\sigma \in \{l,h\}$, $\sigma_F = \{l,h\}$, $f_F(C) \geq \frac{1}{2}$, and $f > \frac{1}{2}$:*

1. *If $\sigma_F = l$, the firm always chooses to disclose the full results of its research, i.e. $t^{F*} = 0$.*
2. *If $\sigma_F = h$, there is a financial penalty threshold $\bar{M}$ such that: if $M > \bar{M}$, then the firm always chooses to disclose the full results of its research, i.e. $t^{F*} = 0$; if $M < \bar{M}$, then the firm always chooses not to disclose the full results of its research, i.e., $t^{F*} = 1$; if $M = \bar{M}$, then the firm is indifferent between disclosing the full results of its research or not, i.e. $t^{F*} \in \{0,1\}$.*

The minimum amount for the fine to deter a lobby behaviour increases with the value of the net benefit from continuing (relatively to stopping, i.e., $\beta(R_2 - E(\theta|(\sigma,h), f_F(C))(K - K')) - D)$. However, the need to deter the firm from lobbying decreases with the firm's investment C in information seeking, with the willingness of the agency to investigate (z)

[13] It is evident that the firm has no interest in concealing a signal $\sigma_F = l$. As regards cases for which the firm receives a signal $\sigma_F = h$: (i) when the firm, by itself, would not want to maintain the product (i.e., $x^{F*}_{\sigma,h,f_F(C)} = 0$ because $P^F(H|(h,h), f_F(C))$ exceeds the firm's decision threshold), it has no incentive to hide information (and to risk to be fined) ; (ii) when the agency, even partially informed, wants to withdraw the authorisation: it is not helpful for the firm to hide information if this does not have any influence on the agency's decision.

and the efficacy of the investigations (δ and p_J) as regards the role of investment in information seeking, an increase in C leads to a more precise signal. When receiving a signal $\sigma_F = h$, the firm's belief on the state h increases with C, thus making it less prone to lobby for marketing the product.

Let us take a moment to make a remark concerning the firm's willingness (and possibility) to lobby and the possibility of deterring it from doing that. On one hand, we remark that a necessary condition for a firm to lobby is having its decision-threshold $\frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$ to be higher than the agency's level of acceptable risk $\bar{p}$. On the other hand, the firm is deterred from lobbying when the level of fine M exceeds $\bar{M} = \frac{(1-\delta z)(\beta(R_2 - E(\theta|(\sigma,h),f_F(C))(K-K')) - D)}{\delta z + (1-\delta z)\beta E(\theta|(\sigma,h),f_F(C))p_J}$. We observe that the firm's decision threshold and the level of $\bar{M}$ are decreasing in $(K - K')$. A greater disparity in damages between scenarios where a firm persists in vending their product versus when they terminate sales dwindles the likeliness of lobbying and the minimum penalty required to dissuade it. It is possible to boost the gap $(K - K')$ by elevating K or diminishing K'; the former can be accomplished with the application of punitive damages (when the product is sold until period 2), and the latter by implementing inadequate compensation (when the product is retracted in period 1). However, both solutions could be difficult to apply from a political perspective.[14] Moreover, decreasing the firm's decision threshold causes it to act more cautiously (i.e., halt its projects more frequently), which may not always be beneficial.[15] However, we also observe that the firm's decision threshold is independent of the level of the fine M. As a consequence, increasing the level of fine (above $\bar{M}$) deters the firm from lobbying without altering its decision rule as regards stopping or continuing its projects from the moment that the firm can pay the fine[16].

[14]In most European countries (including France and Germany), punitive damages are still not allowed. Incomplete compensation leads to the victims not being fully compensated for the harm they suffer, which can lead to political opposition.

[15]In this paper, we consider that the agency's decision threshold is in line with what Society considers to be an acceptable risk, i.e., $\bar{p}$. However, the agency's decision rule could be different from the Society's definition of acceptable risk: the agency could be more conservative (i.e., with a decision threshold lower than $\bar{p}$) in order to decrease the risk of being blamed by Society in case of harm occurring. Consequently, in that case, decreasing the firm's decision threshold to the level of the agency could be too conservative of a policy from a social point of view.

[16]The firm's insolvency could introduce a cap on ability to deter from lobbying by applying a high level of fine. However, the penalty can also be non-monetary, thus making it possible to solve the insolvency problem: penal liability could also be enforced through a term of imprisonment.

Proposition 3

1. *Increasing the difference in damages between the scenario where the firm sells its goods until period 2 and the situation where it stops selling in period 1 has two effects on the firm's decision-making: first, it reduces the likelihood of the firm's lobbying efforts, and second, it causes the firm to stop its ventures more often, making the firm more conservative.*

2. *Enforcing penal liability (through a sufficiently high level of fine M) deters the firm from lobbying without altering its decision-making regarding stopping or continuing to sell its product.*

Now, we examine the agency's investigation choice. First, the agency will never investigate, $z^* = 0$, when: (1) the agency will remove the authorisation, i.e., $P^A(H|(\sigma, \sigma_F), C) > \bar{p}$; (2) the agency receives precise information from the firm, i.e., $f_F(C) > 1/2$. On the other hand, when the agency, while having received inconclusive results from the firm (i.e., $f_F(C) = 1/2$), would not be prone to remove the market authorisation, it may suspect the firm from concealing a conclusive $\sigma_F = h$ signal and thus initiate an investigation (i.e., $z^* = 1$). This is especially the case when the agency expects that the firm, despite the reception of a conclusive $\sigma_F = h$ signal (with $f_F(C) > 1/2$), would enjoy a higher profit when making lobby than when disclosing to the agency the conclusive signal (if the agency would not investigate when receiving an inconclusive result from the firm). In other words, the agency decides $z^* = 1$ if:

$$V_1(x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, 0, 0, x^N_\delta) < V_1(x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, 1, 0, x^N_\delta),$$

otherwise $z^* = 0$. Since C and $f_F(C)$ (but not the success of the signal) are common knowledge, the agency can anticipate when the firm decides only to provide partial results of its research.

Let us note:

$$\bar{\bar{M}} = \frac{(\beta\,(R_2 - E(\theta|(\sigma, h), f_F(C))\,(K - K')) - D)}{\beta E(\theta|(\sigma, h), f_F(C))p_J}$$

which is equal to $\bar{M}$ for $z = 0$, and

$$\underline{M} = \frac{(1-\delta)\,(\beta\,(R_2 - E(\theta|(\sigma, h), f_F(C))\,(K - K')) - D)}{\delta + (1-\delta)\,\beta E(\theta|(\sigma, h), f_F(C))p_J}$$

which is equal to $\bar{M}$ for $z = 1$, Then, we obtain the following proposition.

Proposition 4

1. *If* $P^A(H|(\sigma, \sigma_F), C) > \bar{p}$ *or* $f_F(C) > 1/2$*, then the agency does not investigate, i.e.,* $z^* = 0$*;*

2. *If* $P^A(H|(\sigma, h), C) \leq \bar{p}$ *and* $f_F(C) = 1/2$*, there are two financial penalty thresholds* $\underline{M}$ *and* $\bar{\bar{M}}$*, with* $0 < \underline{M} < \bar{\bar{M}}$*, such that: if* $M < \underline{M}$ *or* $M > \bar{\bar{M}}$*, then the agency does not investigate, i.e.,* $z^* = 0$*; if* $M > \underline{M}$ *or* $M < \bar{\bar{M}}$*, then the agency investigates, i.e.,* $z^* = 1$*; if* $M = \underline{M}$ *or* $M = \bar{\bar{M}}$*, then the agency is indifferent between investigating and not investigating, i.e.* $z^* \in \{0, 1\}$*.*

Proposition 4 implies that, on the one hand, the agency never investigates when it anticipates that it will withdraw the authorisation, given σ, and whatever σ_F. On the other hand, when an inconclusive private signal (i.e., $f_F(C) = 1/2$) would lead the agency to keep the authorisation while the firm's profit would be higher when concealing information (than when disclosing it), the agency decides to investigate when its investigation can deter the firm from lobbying. This is the case when the level of fine is sufficiently high to prevent the firm from lobbying in the event of an investigation (i.e., $M > \underline{M}$) but not sufficiently high to let the *ex-post* investigation (after an accident occurring) to sufficient to prevent a lobby behaviour ($M < \bar{\bar{M}}$). The $\bar{\bar{M}}$ level increases with the expected profit difference between stopping or continuing to sell the product. It decreases with the efficiency of the *ex-post* investigation by the Judge.

To sum up, the interplay between the penal policy (i.e., the level of fine M) and the agency's decision to investigate or not to deter the firm's decision to lobby can be described by Figure 3.

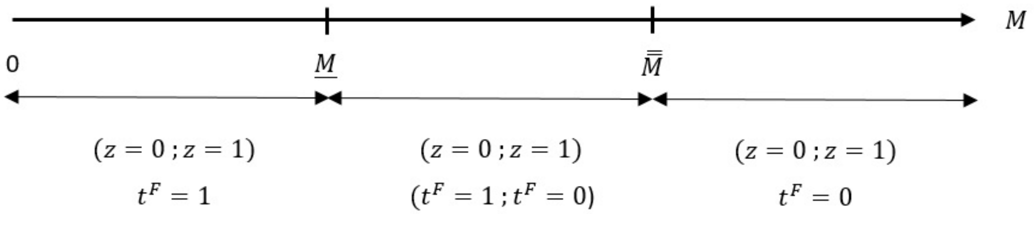

Figure 3: The interplay between the agency and the penal policy

From the left to the right. A level of fine M lower than $\underline{M}$ has no deterring effect: whatever the agency's decision about the investigation in period 1 following an inconclusive signal $f_F(C) = 1/2$ (i.e., whether it decides to investigate ($z = 1$), or not to investigate ($z = 0$)), the firm always chooses to lobby ($t^F = 1$). Investigating in period 1 is useless. When the level of fine lies in $\left[\underline{M}, \bar{\bar{M}}\right]$, then the firm's decision depends on what it expects to be the agency's decision: if the agency always investigate ($z = 1$) when it suspects the firm to have an interest in concealing information, it builds credibility that leads the firm to expect about an investigation, and the level of fine is in that case sufficiently high to deter the firm to lobby ($t^F = 0$). On the contrary, if the agency decides not to investigate in cases where the firm could have an interest in concealing information (or if the agency is not credible in making an investigation so that $z = 0$ is expected by the firm), then the firm will lobby ($t^F = 1$): in that case where $M < \bar{\bar{M}}$ the fine is too low for making the *ex-post* investigation deterrent from lobbying. So, in that case, investigating is useful to deter any lobby behaviour. Finally, when $M > \bar{\bar{M}}$, then the perspective of an *ex-post* investigation in case of harm occurring is sufficient to deter the firm from lobbying ($t^F = 0$), whatever the agency's decision about the investigation in period 1. Again, investigating in period 1 is useless.

Finally, at period 0 and anticipating all decisions made in period 1, the firm has to choose whether it invests or not for acquiring its own information and which amounts to invest. We will distinguish the amount the firm invests from the decision to invest. When the firm chooses to invest a positive amount $C > 0$ in acquiring information, that optimal amount $C^* > 0$ responds to:[17]

$$\max_{C>0} V_0(x^{A*}_{\sigma,\sigma_F,f_F(C)}, x^{F*}_{\sigma,\sigma_F,f_F(C)}, t^{F*}, z^*, x^N_\delta, C).$$

From the first order condition, we obtain:

$$f_F'(C^*) = \frac{1}{(1-q)\left((\beta D - \beta^2 R_2)Z_1 + \beta^2(K - K')Z_2\right)}, \tag{2}$$

$$\begin{aligned}
\text{with } Z_1 = \; & (-1+f+p_0)(1-t^{F*})\left(x^{A*}_{h,l,f_F(C)}x^{F*}_{h,l,f_F(C)} - x^{A*}_{h,h,f_F(C)}x^{F*}_{h,h,f_F(C)}\right) \\
& +(f-p_0)(1-t^{F*})\left(x^{A*}_{l,h,f_F(C)}x^{F*}_{l,h,f_F(C)} - x^{A*}_{l,l,f_F(C)}x^{F*}_{l,l,f_F(C)}\right) \\
& +t^{F*}(-1+f+p_0)(1-z^*\delta)\left(x^{A*}_{h,l,\frac{1}{2}}x^{F*}_{h,l,f_F(C)} - x^{A*}_{h,h,\frac{1}{2}}x^{F*}_{h,h,f_F(C)}\right) \\
& +t^{F*}(f-p_0)(1-z^*\delta)\left(x^{A*}_{l,h,\frac{1}{2}}x^{F*}_{l,h,f_F(C)} - x^{A*}_{l,l,\frac{1}{2}}x^{F*}_{l,l,f_F(C)}\right), \\
\text{and } Z_2 = \; & (1-t^{F*})(p_0\theta^H f - (1-p_0)\theta^L(1-f))\left(x^{A*}_{h,l,f_F(C)}x^{F*}_{h,l,f_F(C)} - x^{A*}_{h,h,f_F(C)}x^{F*}_{h,h,f_F(C)}\right) \\
& +(1-t^{F*})(-p_0\theta^H(1-f) + (1-p_0)\theta^L f)\left(x^{A*}_{l,h,f_F(C)}x^{F*}_{l,h,f_F(C)} - x^{A*}_{l,l,f_F(C)}x^{F*}_{l,l,f_F(C)}\right) \\
& +t^{F*}(1-z^*\delta)(p_0\theta^H f - (1-p_0)\theta^L(1-f))\left(x^{A*}_{h,l,\frac{1}{2}}x^{F*}_{h,l,f_F(C)} - x^{A*}_{h,h,\frac{1}{2}}x^{F*}_{h,h,f_F(C)}\right) \\
& +t^{F*}(1-z^*\delta)(-p_0\theta^H(1-f) + (1-p_0)\theta^L f)\left(x^{A*}_{l,h,\frac{1}{2}}x^{F*}_{l,h,f_F(C)} - x^{A*}_{l,l,\frac{1}{2}}x^{F*}_{l,l,f_F(C)}\right).
\end{aligned}$$

Depending on the value of f, the reliability of the public information, and the firm's interest in the lobby or not, the value C^* can take three different values (see the Comparative statistics in Appendix). We provide more comments on these values hereafter. Before, we

[17] We have verified that for all the interior solutions, the problem was concave.

had to determine when the firm decided to invest a positive amount in information acquisition or not to invest.

Proposition 5 *For* $x^{A*}_{\sigma,\sigma_F,f_F(C)} \in \{0,1\}$*,* $x^{F*}_{\sigma,\sigma_F,f_F(C)} \in \{0,1\}$*,* $t^{F*} \in \{0,1\}$*,* $z^* \in \{0,1\}$*,* $x^N_\delta \in \{0,1\}$*,* $\sigma \in \{l,h\}$*,* $\sigma_F = \{l,h\}$*,* $f_F(C) \geq \frac{1}{2}$*, and* $f > \frac{1}{2}$*, there exists a threshold,* $\tilde{p}$*,*[18] *such that:*

1. *If* $p_0 < \tilde{p}$*, the firm will invest for acquiring information except when:*
   (a) *the firm anticipates that whatever the received private and public information, both the firm and the agency will never want to stop marketing the product;*
   (b) *the firm anticipates that it will only be able to convince the agency to maintain the authorisation.*
2. *If* $p_0 > \tilde{p}$*, the firm will never invest in research.*

Thus, point 1 of Proposition 5 underlines that when its initial belief level on the most dangerous state of Nature is below a certain threshold, the firm may invest in research to reduce the uncertainty about the dangerousness of its product and stop marketing the product if necessary. However, it may also not invest in research in cases where it considers that producing new information will not change its decision on the continuity or cessation of its production and/or will not influence the agency's decisions, i.e., when $P^i(H|(\sigma,\sigma_F), f_F(C)) < \min\left[\bar{p}; \frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}\right]$, with $\frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$ the firm's decision threshold. This is case (a), which arrives when the level of the prior p_0 is too low. Another reason for the firm to not invest is to be faced with a case where, because the reliability of its signal $f_F(C)$ is lower than those of the public signal, f, the firm is unable to convince the agency to maintain the authorisation, after receiving $\sigma = h$ and $\sigma_F = l$. This may arrive for higher values of the prior p_0 than those prevailing in the case (a). This is case (b), which is illustrated by Figure 4 in Appendix. Point 2 of Proposition 5 shows that when the initial belief p_0 is above a certain threshold, the firm does not invest in research to avoid additional expenses. In such a case, p_0 is high (in absolute terms) and close to the level which defines an acceptable risk for Society, $\bar{p}$. Hence, the possibility of receiving signals $\sigma = h$ and $\sigma_F = h$ are high, and these signals would quickly lead to $P^A(H|(h,h), f_F(C)) > \bar{p}$ so that the agency will withdraw the authorisation. In that case, investing in information can be useless for the firm.

Next, we focus on the amounts the firm invests in acquiring information (if it invests), that is, $C^* > 0$. As said above, depending on the value of f and the firm's choice to lobby or not at equilibrium, three different optimal values of $C^* > 0$ exist (see Comparative Statics

[18] $\tilde{p}$ is defined in Appendix in the Proof of Proposition 5.

in Appendix). Below, we describe how these values evolve with the different variables of our setup.

First, we define: $\tilde{p}_0(f) = 1 - f$ and $\tilde{\tilde{p}}_0(f) = \frac{(1-f)\theta^L}{f\theta^H + (1-f)\theta^L}$ with $f \in [1/2; 1[$. We note that when the firm decides to invest, it increases its investments in research when:

(i) the discount rate, β, and/or the probability of harm in the most dangerous state of Nature, θ^H, increase. A higher value for the future and/or a higher risk of harming others leads the firm to invest more to reduce uncertainty in the future.

(ii) the payoff R_2 by continuing to sell the product increases, for $p_0 < \tilde{p}_0(f)$. It means that when the initial belief to be in state H is low (or the belief to be in state B is high) and the precision of the public information is low, there is a risk that the public information leads the agency to withdraw the authorisation wrongfully. If the revenue from selling the product until period 2 is high, then wrongly stopping selling the product is more detrimental, leading the firm to invest more in acquiring information.

(iii) the amount of money the firm can recover by stopping selling its product, D, increases, for $p_0 > \tilde{p}_0(f)$. Recall that to stop marketing the product may be detrimental to the firm (since $D < R_2$). When the value of p_0 is relatively high, the perspective to receive "bad news" (signal h) is high, and the firm may want to invest less in information acquisition to avoid receiving such bad news. In other words, the firm sticks its head in the sand. When D increases, this effect is reduced, so the amount invested in information acquisition (if positive) is higher.

(iv) the financial cost, K, when it continues to sell its product increases when $p_0 > \tilde{\tilde{p}}_0(f)$; and the financial cost, K' when it stops selling its product increases when $p_0 < \tilde{\tilde{p}}_0(f)$; for the two reasons introduced above.

On the other hand, the firm decreases the amount it invests in research when:

(i) the precision of the public information, f, increases; thus, highlighting a substitution between public and private information.

(ii) the probability of being in the less dangerous state of Nature, θ^L, increases; the prior belief being in the most dangerous state of Nature, p_0, increases; the probability that the private information is not conclusive, q, increases; the probability that the investigation finds the firm at fault, δ, increases (only in the case in which the firm will decide not to disclose the full results of its research);

(iii) the payoff, R_2, by continuing to sell its product increases, for $p_0 > \tilde{p}_0$; again, if the revenue from continuing to sell the product is high, then stopping marketing is costly. When the initial belief p_0 is high and the public information reliable, the firm keeps its investment to avoid receiving bad news that would lead it to stop marketing the product; again, the firm sticks its head in the sand.

(iv) the amount of money, D, it can recover by stopping selling its product increases, for $p_0 < \tilde{p}_0(f)$. Here, if the perspective of stopping marketing the product is not too detrimental, it reduces the firm's incentive to acquire information for convincing the agency to maintain the authorisation (thus counterbalancing a "bad" public signal);

(v) the financial cost, K, when it continues to sell its product increases when $p_0 < \tilde{\tilde{p}}_0(f)$; the financial cost, K', when it stops selling its product increases when $p_0 > \tilde{\tilde{p}}_0(f)$.[19]

Therefore, when the firm decides to invest a positive amount $C^* > 0$ in information acquisition, our results show a substitution between public and private research. Indeed, when the precision of public information increases, the firm decreases its investment in research. It benefits from public information for free and avoids additional expenses, which could decrease its payoff. On the other hand, when the level of precision of public information decreases, the firm increases its investment in research to reduce its uncertainty on the risk (of causing harm and paying damages) inherent to its production.

Moreover, the impact of the civil liability (K and K') depends on the initial prior belief p_0 and the public research precision f. When the prior belief is higher than a certain threshold, a higher difference $K - K'$ (i.e., a higher difference in damages between continuing until period 2 or stopping in period 1) leads the firm to increase its research investment to acquire more precise information and reduce uncertainty. Indeed, the firm wants to know whether the project is *really* dangerous, and thus, to stop it in case of receiving bad news to avoid paying costly damages. On the other hand, when the prior belief is lower than a certain threshold, an increase in $K - K'$ reduces the firm's investment since the option of continuing to market the product until period 2 is less attractive. So, the firm has less interest in acquiring information to convince the agency to maintain the authorisation.

We also note that a higher precision public research f implies a better efficiency of civil liability in providing incentives to reduce uncertainty. Indeed, when f tends towards one, then $\tilde{\tilde{p}}_0(f)$ tends towards zero, implying that an increase in the cost of damage K leads to an increase in investment in research C.

Finally, the results demonstrate that when a firm opts not to divulge all of the outcomes of its investigation, the higher the chance of exposure, the lower the investment in research to prevent incurring extra costs, potentially reducing its profits.

Proposition 6 *When the firm decides not to disclose the full results of its research (i.e., to lobby, $t^F = 1$):*

1. *it will invest less in research than when it does not;*

2. *it will stop investing in research earlier when the most dangerous state of Nature seems more likely than when it does not.*

[19]For more details, see Comparative statics in Appendix.

From Proposition 6, it is observed that the decision of the firm to withhold information from the agency impacts information acquisition. This behaviour leads to scientific uncertainty not only at the agency level but also at the firm, which would be better equipped to mitigate production damage if armed with more relevant information and able to halt production earlier.

4 Conclusion

In this paper, we investigated the practices of a firm that markets a product whose potential hazards still need to be fully understood. Such a firm may embrace tactics that could negatively impact the wider community. Our focus centred on the non-disclosure of unfavourable findings that may conflict with the firm's commercial interests. We identified the factors that motivate or hinder this behaviour and evaluated the efficacy of various risk management actions: marketing authorisation, civil and criminal liabilities, etc. We found that these tools effectively demotivate the firm to undertake this strategy, especially penal liability.

Our findings indicate the suitability of implementing the polluter pays principle amidst uncertain situations, coupled with sanctions for not disclosing relevant information. It was revealed that imposing civil liability on the firm, which includes paying for any damage to the environment caused, can guarantee alignment between the firm's decisions and the agency's objectives. Furthermore, our research demonstrated that the possibility of being fined for discovering concealed information deters the firm from adopting non-compliant behaviour.

Additionally, our findings stimulate the debate surrounding the implementation of punitive damages in French legislation. In contrast, some American states incorporate punitive damages into their laws. For instance, in the Pilliod case involving the Pilliod couple and Monsanto, the Superior Court of California enforced punitive damages on 13th May 2019. Following their exposure to Roundup (glyphosate), Pilliod's spouses contracted illnesses. The jury deemed the product the cause and identified Monsanto's failure to avert the danger. The couple, Pilliod, was awarded a total of $87 million ($17 million in compensatory damages and $70 million in punitive damages) after the jury concluded that the firm had acted maliciously (or fraudulently) and must be penalised for its actions. According to French law, punitive damages only apply for compensation rather than retribution. Nonetheless, the Servier Laboratory was fined €2.7 million for "aggravated deception" during the Mediator's trial on March 29, 2021. As outlined in our document, penal liability is accompanied by civil liability. This application of penal liability could apply to other scenarios in which firms have failed to disclose all of their results to public agencies.

Our study also investigated the acquisition of information behaviour. We demonstrate that civil liability inspires the firm to invest more in information acquisition and reduce uncertainty regarding the dangerousness of their production. To achieve this, the firm must first weigh the potential harm its product may cause to health and the environment. This drives it to decrease the uncertainty surrounding its product to avoid damage costs in the event of an accident. Our findings indicate that private research is replacing public research, as lowering budgets for public research gives firms authority over approvals for innovative products. This is reminiscent of the situation involving glyphosate.

Further research could benefit from the introduction of a solvency constraint for firms. Such a constraint could present a trade-off between the investment in research to understand better the risk and the compensation funds available for damage to victims. One solution could be penal responsibility, allowing for overcoming this problem. Additionally, an exciting avenue for the study could be the analysis of how competition between firms impacts investment in research and strategic behaviour, such as non-disclosure. A balance must be struck between conducting less research to capitalise on insights from other firms and carrying out more research to obtain superior information relative to competitors. Ultimately, assessing the effects of risk management tools on an additional strategic behaviour, persuasion, is imperative. This complements the work of Henry and Ottaviani (2019), who investigated information dissemination to convince an appraiser to approve an activity, and Dellis (2023), who analysed the approach of searching for commodity valuations by districts to acquire the allocation and plans of the legislature.

5 Appendix

Proof of Proposition 1.

The firm continues to sell its product if:

$V_1(x^A_{\sigma,\sigma_F,f_F(C)}, 0, t^F, z, x^N_\delta) < V_1(x^A_{\sigma,\sigma_F,f_F(C)}, 1, t^F, z, x^N_\delta)$

$\Leftrightarrow ((1 - z\delta)x^A_{\sigma,\sigma_F,\frac{1}{2}} + (1 - t^F)x^A_{\sigma,\sigma_F,f_F(C)})(D + \beta(-R_2 + E(\theta|(\sigma, \sigma_F), f_F(C))(K - K'))) < 0$

$\Leftrightarrow P^F(H|(\sigma, \sigma_F), f_F(C)) < \frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$.

The firm removes its product from the market if:

$V_1(x^A_{\sigma,\sigma_F,f_F(C)}, 0, t^F, z, x^N_\delta) > V_1(x^A_{\sigma,\sigma_F,f_F(C)}, 1, t^F, z, x^N_\delta) \Leftrightarrow P^F(H|(\sigma, \sigma_F), f_F(C)) > \frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$.

The firm is indifferent between continuing to sell its product and removing it from the market if:

$V_1(x^A_{\sigma,\sigma_F,f_F(C)},0,t^F,z,x^N_\delta) = V_1(x^A_{\sigma,\sigma_F,f_F(C)},1,t^F,z,x^N_\delta) \Leftrightarrow P^F(H|(\sigma,\sigma_F),f_F(C)) = \frac{(\beta R_2-D)-\beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$

■

Proof of Lemma 1.

$P^i(H|(l,l),f_F(C)) < P^i(H|(l,h),f_F(C))$
$\Leftrightarrow \frac{p_0(1-f)(1-f_F(C))}{p_0(1-f)(1-f_F(C))+(1-p_0)ff_F(C)} < \frac{p_0(1-f)f_F(C)}{p_0(1-f)f_F(C)+(1-p_0)f(1-f_F(C))} \Leftrightarrow \frac{1}{2} < f_F(C);$

$P^i(H|(l,l),f_F(C)) < P^i(H|(h,l),f_F(C))$
$\Leftrightarrow \frac{p_0(1-f)(1-f_F(C))}{p_0(1-f)(1-f_F(C))+(1-p_0)ff_F(C)} < \frac{p_0f(1-f_F(C))}{p_0f(1-f_F(C))+(1-p_0)(1-f)f_F(C)} \Leftrightarrow \frac{1}{2} < f;$

$P^i(H|(l,h),f_F(C)) < P^i(H|(h,h),f_F(C))$
$\Leftrightarrow \frac{p_0(1-f)f_F(C)}{p_0(1-f)f_F(C)+(1-p_0)f(1-f_F(C))} < \frac{p_0ff_F(C)}{p_0ff_F(C)+(1-p_0)(1-f)(1-f_F(C))} \Leftrightarrow \frac{1}{2} < f;$

$P^i(H|(h,l),f_F(C)) < P^i(H|(h,h),f_F(C))$
$\Leftrightarrow \frac{p_0f(1-f_F(C))}{p_0f(1-f_F(C))+(1-p_0)(1-f)f_F(C)} < \frac{p_0ff_F(C)}{p_0ff_F(C)+(1-p_0)(1-f)(1-f_F(C))} \Leftrightarrow \frac{1}{2} < f_F(C);$

$p_0 < P^i(H|(l,h),f_F(C)) \Leftrightarrow p_0 < \frac{p_0(1-f)f_F(C)}{p_0(1-f)f_F(C)+(1-p_0)f(1-f_F(C))} \Leftrightarrow f < f_F(C);$

$p_0 < P^i(H|(h,l),f_F(C)) \Leftrightarrow p_0 < \frac{p_0f(1-f_F(C))}{p_0f(1-f_F(C))+(1-p_0)(1-f)f_F(C)} \Leftrightarrow f_F(C) < f;$

$P^i(H|(l,h),f_F(C)) < P^i(H|(h,l),f_F(C))$
$\Leftrightarrow \frac{p_0(1-f)f_F(C)}{p_0(1-f)f_F(C)+(1-p_0)f(1-f_F(C))} < \frac{p_0f(1-f_F(C))}{p_0f(1-f_F(C))+(1-p_0)(1-f)f_F(C)} \Leftrightarrow f_F(C) < f;$

$\frac{\partial P^i(H|(h,h),f_F(C))}{\partial f_F(C)} = \frac{p_0(1-p_0)(1-f)f}{[p_0ff_F(C)+(1-p_0)(1-f)(1-f_F(C))]^2} > 0;$

$\frac{\partial P^i(H|(l,h),f_F(C))}{\partial f_F(C)} = \frac{p_0(1-p_0)(1-f)f}{[p_0(1-f)f_F(C)+(1-p_0)f(1-f_F(C))]^2} > 0;$

$\frac{\partial P^i(H|(h,l),f_F(C))}{\partial f_F(C)} = \frac{-p_0(1-p_0)(1-f)f}{[p_0f(1-f_F(C))+(1-p_0)(1-f)f_F(C)]^2} < 0;$

$\frac{\partial P^i(H|(l,l),f_F(C))}{\partial f_F(C)} = \frac{-p_0(1-p_0)(1-f)f}{[p_0(1-f)(1-f_F(C))+(1-p_0)ff_F(C)]^2} < 0.$

■

Proof of Proposition 2.

For $\sigma \in \{l,h\}$, $x^{A}_{\sigma,\sigma_F,f_F(C)} \in \{0,1\}$, $x^{F}_{\sigma,\sigma_F,f_F(C)} \in \{0,1\}$, and $C \geq 0$:

If $\sigma_F = l$, then the firm decides to disclose the full results of its research when:

$$V_1(x^{A}_{\sigma,l,f_F(C)}, x^{F}_{\sigma,l,f_F(C)}, 1, z, x^{N}_{\delta}) < V_1(x^{A}_{\sigma,l,f_F(C)}, x^{F}_{\sigma,l,f_F(C)}, 0, z, x^{N}_{\delta}) \Leftrightarrow \\ (\delta z + (1-\delta z)\, \beta E(\theta|(\sigma,h), f_F(C)) p_J) M > 0.$$

Since $\delta z + (1-\delta z)\, \beta E(\theta|(\sigma,h), f_F(C)) p_J > 0$ is always true if $\sigma_F = l$ then the firm always chooses to disclose the full results of its research, i.e., $t^{F*} = 0$.

If $\sigma_F = h$, then the firm decides to disclose the full results of its research when:

$$V_1(x^{A}_{\sigma,h,f_F(C)}, x^{F}_{\sigma,h,f_F(C)}, 1, z, x^{N}_{\delta}) < V_1(x^{A}_{\sigma,h,f_F(C)}, x^{F}_{\sigma,h,f_F(C)}, 0, z, x^{N}_{\delta})$$

$$\Leftrightarrow x^{F*}_{\sigma,h,f_F(C)} \left(x^{A*}_{\sigma,h,f_F(C)} - (1-\delta z) x^{A*}_{\sigma,h,\frac{1}{2}} \right) (D - \beta\left(R_2 - E(\theta|(\sigma,h), f_F(C))\left(K-K'\right)\right)) < M(\delta z + (1-\delta z)\, \beta E(\theta|(\sigma,h), f_F(C)) p_J)$$

$$\Leftrightarrow \frac{x^{F*}_{\sigma,h,f_F(C)} \left(x^{A*}_{\sigma,h,f_F(C)} - (1-\delta z) x^{A*}_{\sigma,h,\frac{1}{2}} \right) (D - \beta\left(R_2 - E(\theta|(\sigma,h), f_F(C))\left(K-K'\right)\right))}{\delta z + (1-\delta z) \beta E(\theta|(\sigma,h), f_F(C)) p_J} < M.$$

We define

$$\bar{M} = \frac{x^{F*}_{\sigma,h,f_F(C)} \left(x^{A*}_{\sigma,h,f_F(C)} - (1-\delta z) x^{A*}_{\sigma,h,\frac{1}{2}} \right) (D - \beta\left(R_2 - E(\theta|(\sigma,h), f_F(C))\left(K-K'\right)\right))}{\delta z + (1-\delta z)\, \beta E(\theta|(\sigma,h), f_F(C)) p_J}.$$

We then obtain that $\sigma_F = h$, there is a financial penalty threshold $\bar{M}$ such that if $M > \bar{M}$, then the firm always chooses to disclose the full results of its research, i.e., $t^{F*} = 0$; if $M < \bar{M}$, then the firm always chooses not to disclose the full results of its research, i.e., $t^{F*} = 1$; if $M = \bar{M}$, then the firm is indifferent between disclosing the full results of its research or hiding it, i.e., $t^{F*} \in \{0,1\}$. ■

Proof of Proposition 4 .

From the Proof of Proposition 2, the proof is easily deduced.

■

Proof of Proposition 5.

The results come from the equation (2) evaluated for all $x^{A*}_{\sigma,\sigma_F,f_F(C)} \in \{0,1\}$, $x^{F*}_{\sigma,\sigma_F,f_F(C)} \in \{0,1\}$, $t^{F*} \in \{0,1\}$, $z^* \in \{0,1\}$, $x^{N}_{\delta} \in \{0,1\}$, $\sigma \in \{l,h\}$, $\sigma_F = \{l,h\}$, $f_F(C) \geq \frac{1}{2}$. We obtain three different levels of investment in research, C_1, C_2 and C_3, which are defined as follows:

If $p_0 < \frac{(1-f)(\beta R_2 - D - \beta(K-K')\theta^L)}{\beta R_2 - D - \beta(K-K')(f\theta^H + (1-f)\theta^L)}$, C_1 is such that:

$$f_F^{'}(C_1) = \frac{1}{(1-q)\beta\left[(f + p_0 - 1)\left(D - \beta R_2\right) + \beta\left(K - K'\right)\left(f p_0 \theta^H - (1-f)(1-p_0)\theta^L\right)\right]}$$

otherwise, $C_1 = 0$.

If $p_0 < \frac{\beta R_2 - D - \beta(K-K')\theta^L}{2(\beta R_2 - D) - \beta(K-K')(\theta^H+\theta^L)}$, C_2 is such that:

$$f_F'(C_2) = \frac{1}{(1-q)\beta\left[(2p_0-1)(D-\beta R_2) + \beta(K-K')(p_0\theta^H - (1-p_0)\theta^L)\right]}.$$

otherwise, $C_2 = 0$.

If $p_0 < \frac{(1-f)(\beta R_2 - D - \beta(K-K')\theta^L)}{\beta R_2 - D - \beta(K-K')(f\theta^H+(1-f)\theta^L)}$, C_3 is such that:

$$f_F'(C_3) = \frac{1}{(1-q)(1-\delta)\beta\left[(f+p_0-1)(D-\beta R_2) + \beta(K-K')(fp_0\theta^H - (1-f)(1-p_0)\theta^L)\right]}$$

otherwise, $C_3 = 0$.

Therefore,

$$\tilde{p} = \begin{cases} \frac{(1-f)(\beta R_2 - D - \beta(K-K')\theta^L)}{\beta R_2 - D - \beta(K-K')(f\theta^H+(1-f)\theta^L)} & \text{if } C^* = C_1; \\ \frac{\beta R_2 - D - \beta(K-K')\theta^L}{2(\beta R_2 - D) - \beta(K-K')(\theta^H+\theta^L)} & \text{if } C^* = C_2; \\ \frac{(1-f)(\beta R_2 - D - \beta(K-K')\theta^L)}{\beta R_2 - D - \beta(K-K')(f\theta^H+(1-f)\theta^L)} & \text{if } C^* = C_3. \end{cases}$$

■

Complement for the point 1 of Proposition 5.

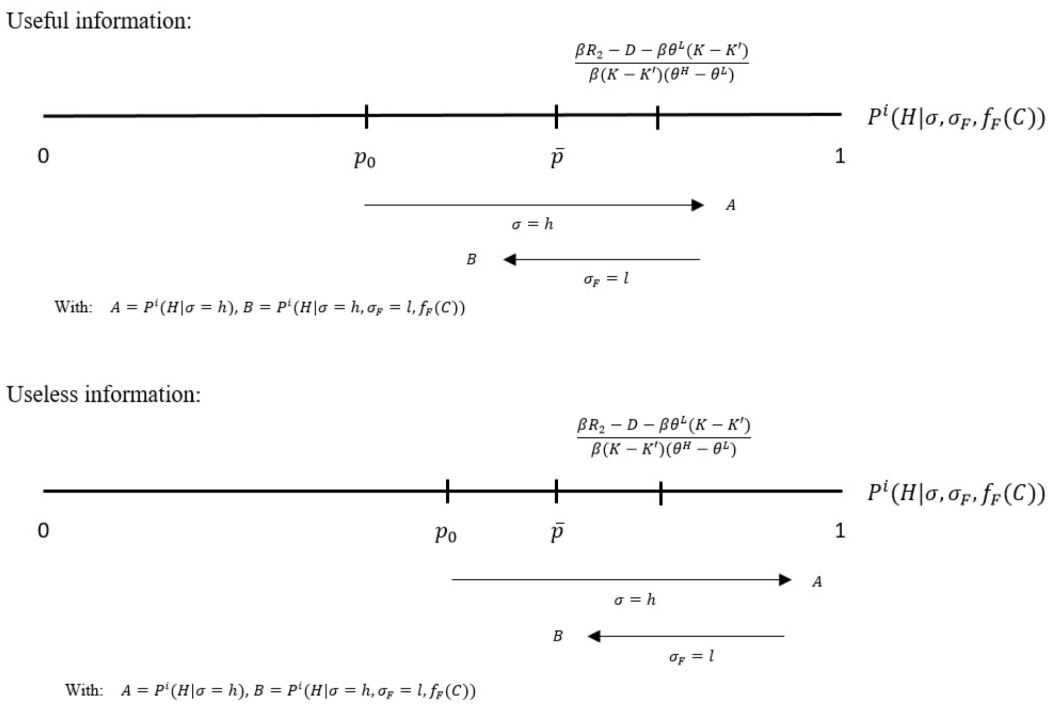

Figure 4: Useful or useless information in case where $f_C < f$.

On these two schemes, the reading is similar: starting from a prior belief p_0, the reception of a public signal $\sigma = h$ leads to a first update $P^i(H|\sigma = h)$; this is point A. When the private signal $\sigma_F = l$ adds, a second update occurs to obtain $P^i(H|\sigma = h, \sigma_F = l, f_F(C))$; this is point B. The reliabilities f and $f_F(C)$ of the signals are the same in both cases. In the first one, private information is useful since it allows the firm to convince the agency that the product is not too risky (the updated belief $P^i(H|\sigma = h, \sigma_F = l, f_F(C))$ is below $\bar{p}$ and the firm's decision threshold). Nevertheless, in the second case, information is useless for the firm since the updated belief $P^i(H|\sigma = h, \sigma_F = l, f_F(C))$ does not fall below $\bar{p}$: the firm would continue to sell the product, but the agency will withdraw the authorisation. So, the firm will not invest in acquiring information.

■

Comparative statistics.

From C_1, C_2 and C_3 defined in Proof of Proposition 5, Table 2 sums up the comparative statistics.

	Research investment		
Parameter	C1	C2	C3
β	+	+	+
f	-		-
R_2	+ if $p_0<1-f$ - if $p_0>1-f$	+ if $p_0<1/2$ - if $p_0>1/2$	+ if $p_0<1-f$ - if $p_0>1-f$
K	+ if $p_0>(1-f)\theta^L/(f\theta^H+(1-f)\theta^L)$ - if $p_0<(1-f)\theta^L/(f\theta^H+(1-f)\theta^L)$	+ if $p_0>\theta^L/(\theta^H+\theta^L)$ - if $p_0<\theta^L/(\theta^H+\theta^L)$	+ if $p_0>(1-f)\theta^L/(f\theta^H+(1-f)\theta^L)$ - if $p_0<(1-f)\theta^L/(f\theta^H+(1-f)\theta^L)$
K'	+ if $p_0<(1-f)\theta^L/(f\theta^H+(1-f)\theta^L)$ - if $p_0>(1-f)\theta^L/(f\theta^H+(1-f)\theta^L)$	+ if $p_0<\theta^L/(\theta^H+\theta^L)$ - if $p_0>\theta^L/(\theta^H+\theta^L)$	+ if $p_0<(1-f)\theta^L/(f\theta^H+(1-f)\theta^L)$ - if $p_0>(1-f)\theta^L/(f\theta^H+(1-f)\theta^L)$
D	+ if $p_0>1-f$ - if $p_0<1-f$	+ if $p_0>1/2$ - if $p_0<1/2$	+ if $p_0>1-f$ - if $p_0<1-f$
θ^H	+	+	+
θ^L	-	-	-
p_0	-		-
q	-	-	-
δ			-

Table 1: Static comparison.

■

Proof of Proposition 6.

We define : $J_1(f) = \frac{(1-f)(\beta R_2 - D - \beta(K-K')\theta^L)}{\beta R_2 - D - \beta(K-K')(f\theta^H + (1-f)\theta^L)}$. By deriving it with f, we obtain that J_1 is decreasing in f, so $J_1(\frac{1}{2}) > J_1(f)$ for all $f \in (\frac{1}{2}, 1]$.

From the proof of Comparative statistics, we first compare C_1 and C_3. We easily deduce that if $p_0 \geq J_1(f)$ then $C_1 = C_3 = 0$ and if $p_0 < J_1(f)$ then since f_F is increasing and concave and $\delta \in [0,1]$, $C_1 > C_3$.

Then, from the proof of Comparative statistics, we compare C_2 and C_3. Since J_1 is decreasing in f, we easily deduce that if $p_0 \geq J_1(\frac{1}{2})$ then $C_2 = C_3 = 0$; if $J_1(f) \leq p_0 < J_1(\frac{1}{2})$ then $C_2 > 0 = C_3$; and if $p_0 < J_1(f)$ then since f_F is increasing and concave and $\delta \in [0,1]$, $C_2 > C_3$. ■

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