Innovation, information, lobby and tort law under uncertainty

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Abstract

Recent environmental policies favour the 'pollutant-payer' Principle. This principle points out the pollutant financial liability for potential incident induced by its activities. Investing in technological innovations generates uncertainty on the future returns, as well as on the damages that such innovations could involve and on the cost to pay in case of troubles. To reduce this uncertainty, the firm has the opportunity to acquire information, for example through research activities, on its project's potential consequences on human health and on the environment. However, in their efforts to obtain and/or to maintain a marketing authorisation with the agency, firms may develop specific strategies to exploit scientific uncertainty. They may produce favourable scientific findings. In case of accident, the firm having this type of behaviour can be legally charged. We then analyse whether liability rules and tort law incentive the firm both to invest in research and development in order to reduce the uncertainty and to decrease miscommunication on the results. We find that the firm's decision to stop or continue to sell its product depends on the levels of precision of the exogenous and of the endogenous information it receives, and on the ratio between marginal benefit and damages from maintaining the product in the future. We then understand that the firm's decision to adopt a lobby behaviour depends on its expected payoff, its level of research, and its belief being sentenced when it has chosen to adopt a lobby behaviour. Finally, we clarify the effect of the penal liability on the firm's investment in research decision. The level of the fine pushes the firm to reduce its uncertainty about the risk of accident. However, if it perceives that the risk of accident is high, its investment in research will decrease with the level of the fine for maintaining its expected payoff.

Keywords: health and environmental risks, industrial risks, information acquisition, innovation, liability rules, lobby.

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1 Introduction

Public management of risks of harms coming from industrial processes uses both *ex-ante* and *ex-post* policy tools. *The ex-ante* tool consists in requiring authorisation before a public agency for using new production processes and/or marketing new products: the firm has to provide the public agency (say agency hereafter) with a risk assessment and, after checking methodology and results, the agency grants the authorisation (or not). In addition to this *ex-ante* control, *ex-post* compensation takes place after an accident occurring using civil liability. Civil liability obliges any tortfeasor to compensate (financially) injuries coming from its activity. Following the emergence of the 'pollutant-payer' Principle, recent environmental policies extend civil liability for harms on the environment.[1] Consequently, environmental civil liability obliges any polluter to pay for the pollution (or harms) caused by its activity. Such a policy aims both to reach *ex-post* justice and to *ex-ante* provide the polluter with incentives to regulate the externality it causes.[2]

Competition pushes the firms to innovate, by developing more cost-efficient processes and/or by developing innovative (and attractive) products. However, investing in technological innovations generates uncertainty on the future returns, as well as on the risk of damage that such innovations could involve, on health and/or on the environment, and on the cost to pay in case of troubles. Tuncak (2013) document case of "regrettable substitutions", where dangerous products were substituted by new ones, which were later on recognised of being more dangerous than the products they replaced (e.g. flame retardants). To reduce this uncertainty, the firm can have the opportunity to acquire information, for example through research activities or technical tests, on its project's potential consequences on human health and the environment. Actually, in 2018, Bayer spends €1.2 billion, Sanofi €1 billion and Roche €1.5 billion of their research and development budget to experimental development to improve their knowledge of existing products. Moreover, in their efforts to obtain and/or to maintain a marketing authorisation from the agency in the frame of the *ex-ante* control, firms may develop specific strategies to exploit scientific uncertainty: they may produce favourable scientific findings and/or hide adverse findings. In the economics literature, this behaviour is associated to indirect lobbying, where special interest groups try to influence public authorities. In fact, this term has already been employed in Yu (2005) who examines an industrial and an environmental lobby competing for political influence through communication campaigns, Baron (2005) and Shapiro (2016) who study special-interest groups' political influence through the news media, and Bramoullé and Orset (2018) who analyse how firms' miscommunication may affect public policies. We find the doubt manufacturing. Uncertainty is maintained by the firm which does not provide precise results to the Agency to promote its own commercial interests. We remember the "Monsanto Papers" which exposed how the multinational created doubt, claiming that glyphosate was not dangerous by secretly writing so-called independent studies by its own scientists. The firm would have convinced eminent researchers to perform for it "ghostwriters" and to sign these studies. In case of accident, the firm having this kind of behaviour can be legally charged: penal liability can be stated to penalise a deviant behaviour, and the firm can, for instance, be forced to pay a fine (like in the VW diesel cheating scandal, see

[1] For the USA, see *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA, 1980). For the EU, see the 2004/35/*CE* directive.

[2] Among the classics in the economic analysis of incentives provided by civil liability, we can cite Brown (1973), Shavell (1980, 1986).

The Detroit News (2017)). Both civil and penal liabilities can therefore be applied after an accident occurring.

Therefore, three public policy tools are combined to, ideally, provide the firms with incentives to take on all "due diligence" in risk management. At the heart of concerns is the ability of public policy tools to provide the firms with incentives for producing sufficient efforts in information research, and for pushing the firms to tell to the agency all information on the dangerousness of the processes and/or products they want to use. Our paper aims at analysing how (and in what extent) the *ex-post* liability system, which combines civil and penal liability, helps the *ex-ante* authorisation control process in providing the firm with incentives both to invest in information research in order to reduce the uncertainty, and to decrease miscommunication on the results.

Our approach relies on two building blocks. First, it is related to the real options theory. Getting information is both costly and defined as a right, not as an obligation for the firm. This real option allows him both to stop its project if not profitable or dangerous and to recover a part of its initial investment. This contrasts with the standard literature where the investment is irreversible, and the flow of information is exogenous (Arrow-Fisher (1974), Henry (1974), Brocas and Carrillo, (2000, 2004)). This theoretical approach quantifies the value of management flexibility in a world of uncertainty. It then contributes to add a new dimension with the introduction of endogenous information.

Secondly, it also examines the literature on the impact of public policies on the firm's decisions relative to risk management. Shavell (1984) and Hiriart *et al.* (2004) study the optimal use of *ex-ante* safety regulations and *ex post* civil liability. Hiriart *et al.* (2004) extends the Shavell's (1984) analysis to the possibility of ex-ante transfers between the firm and the agency. Both Shavell (1984) and Hiriart *et al.* (2004) show that when imperfect information on the magnitude of harm exists, first-best levels of care cannot be enforced. Hiriart and Martimort (2012) analyse more deeply the interactions between the firms and the regulatory agencies, and study the conditions under which conspiracy between these two agents might arise. Following the seminal work of Tirole (1992) and Laffont and Martimort (1997), they argue that the role of the judge is not only to settle ex-post disputes, but also to remain a factor of implicit discipline to avoid secret understanding between firms and agencies ex-ante. However, these studies do not consider the case of imperfectly known risks, for which supplementary information is expected (and could be provided by firms, which could make a strategic use of it). Further, the combined used of civil and penal liabilities is excluded. Shavell (1992) is the first contribution which analyses the incentives provided by different civil liability rules in seeking more information about an imperfectly known risk of harm. Chemarin and Orset (2011) extend Shavell (1992)'s analysis. However, these last two contributions do not consider the possibility for strategic use of information towards an agency acting before the firm operates onto the market. Focusing on the case of product liability, Demougin and Deffains (2008) recall the debate on the necessity, for innovators, to have the possibility of being exempted from liability (in case of harms resulting from their new products) in order to not undermine incentives for R&D. They show that the trade-off innovation *vs.* safety could be overcome by implementing a "state-of-the-art" defence for liability using a "technological advancement test" method. However, only a deterministic care decision model is considered, putting aside the uncertainties surrounding the innovative process, and *ex-ante* regulation is not considered. A first contribution which aims to compare *ex-ante* and *ex-post* policies in a framework including the possibility of designing a new but hazardous product is the one of Immordino *et al.* (2011). Both incentives to innovate and to not introducing dangerous products are analysed. Jacob *et al.* (2019) extend Immordino *et al.* (2011) analysis by including other policies, like civil (strict and limited) liability and the possibility of banning the obsolete product. They also endogeneise the probability the new product being dangerous (or not). But in both Immordino *et al.* and in Jacob *et al.* analyses, there is no possibility for miscommunication towards the *ex-ante* agency, and *ex-ante* authorisation, civil and penal liabilities are not all three combined. Immordino et al. (2011) provide a comparison between ex-ante regulations and ex-post fines in terms of incentives to develop an innovative product and avoid 'regrettable substitution.' Both incentives to innovate and to not employing risky processes are analysed. They do not introduce the possibility for the firm to search for additional information, therefore having the possibility to contribute on the state of knowledge and affect the agency's decision-making. In this paper, we provide an analysis in which ex-ante marketing authorisation and both ex-post civil and penal liabilities are all three combined to reduce the firm's incentive for the miscommunication and increase the one for prevention.

In this paper, we provide an analysis in which *ex-ante* marketing authorisation and both *ex-post* civil *and* penal liabilities are all three combined to reduce the firm's incentive for the miscommunication.[3] From this model, we analyse the optimal firm's decisions. We discover the conditions for which the firm will decide to stop or continue to sell its product. We get that its decision depends on the levels of precision of the exogenous and of the endogenous information it receives, and on the ratio between marginal benefit and damages from maintaining the product until period 2: the higher the marginal benefit from maintaining its product the more the firm is prone to maintain its product. The higher the marginal damages from maintaining its product the less the firm is prone to maintain its product.

Next, we examine the conditions for which the firm will decide to behave (or not) as a lobby. We understand that a firm is less prone to adopt a lobby behaviour if: the amount of money it can recover by stopping selling its product increases, the financial cost when it continues to sell its product increases, the level of research increases, and its belief being sentenced when it has chosen to adopt a lobby behaviour increases. On the other hand, it is more prone to adopt a lobby behaviour: if the payoff by continuing to sell its product increases, the financial cost when it stops selling its product increases, and the discount rate increases.

We examine the optimal firm's investment in research to obtain more information on the dangerousness of the production. We first note that for low and high levels of the prior belief being in the most dangerous state of the world, the firm does not invest in research. Actually, if the firm perceives that the dangerousness is low, it does not see any interest to invest in research. On the other hand, if it perceives that the dangerousness is high, it knows that the agency will remove the authorisation and then does not make a supplementary expense in investing in research. We then clarify the effect of the penal liability on the firm's investment in research decision. We obtain that the higher the probability of paying a fine (in the case where the firm adopts a lobby behaviour), the higher the investment in research. Indeed, if the firm adopts a lobbying behaviour, the greater the probability of being caught, the more it will seek to obtain a better signal precision to reduce its own uncertainty. In addition, we understand that the highest the penalty for behaving as a lobby, the highest the firm has an interest in reducing the un-

[3] Contrary to Hiriart and Martimort (2012)we consider a benevolent agency, which is only devoted to public interest. Nevertheless, this agency has imperfect degree of expertise and can be fooled by the firm, which can lie on the true degree of dangerousness of its product and increase the one for prevention.

certainty about the true state (by making a high effort in research for information) and to behave accordingly the received signal (and, especially, to stop marketing the product when a high dangerousness is suspected). In fact, the level of the fine pushes the firm to reduce its uncertainty about the risk of accident. However, if it perceives that the risk of accident is high, its investment in research will decrease with the level of the fine for maintaining its expected payoff.

The remainder of the paper is organised as follows. Section 2 introduces our model. Section 3 characterises the agencies' optimal decision to maintain or suspend authorisation, the firm's optimal decisions to adopt a lobby/non-lobbying behaviour and to stop or continue the sale of its product. Section 4 presents the firm's optimal investment in research from simulations. We conclude in Section 5. All the proofs are in the appendix.

2 The model

We consider a three-period model. Figure 1 describes the various stages of the model.

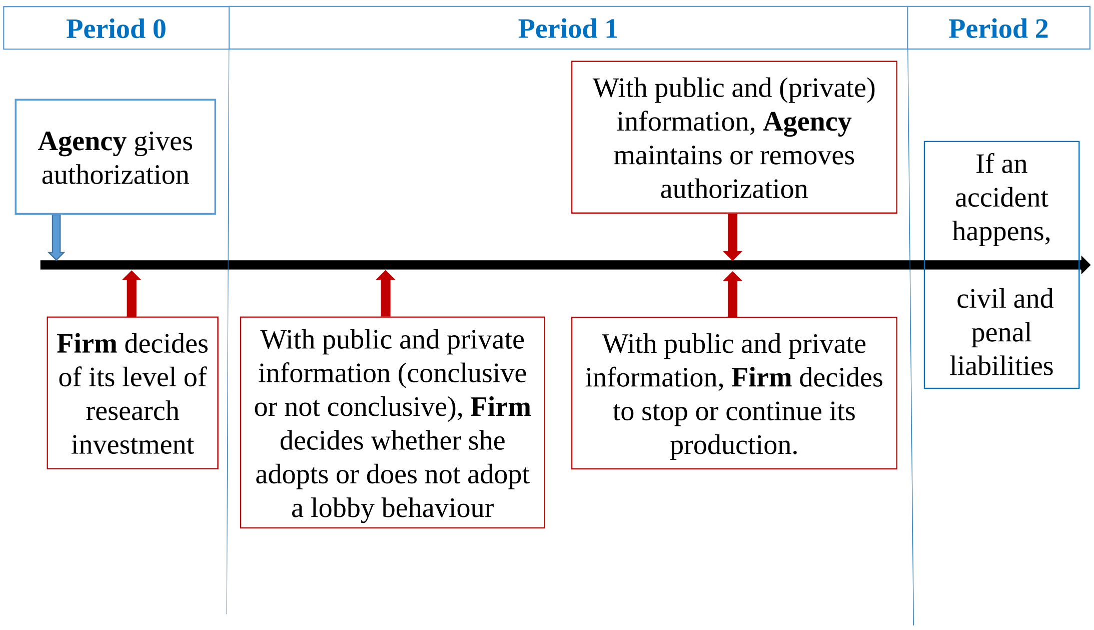

Figure 1: Timing of the model.

At period 0, the agency grants the firm with approval to implement a process and/or market a product[4] which can cause damage to people's health and/or to the environment. There are two possible states of Nature H and L associated with different probabilities of causing damage θ^H and θ^L, respectively. We assume that state H is more dangerous

[4]The two cases can be considered even if, in the rest of the paper, we will talk about market authorisation of a product,

than state L, so:

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

The agency and the firm have both the same prior beliefs p_0 on state H, and $1-p_0$ on state L. The agency grants the marketing authorisation when its belief on being in state H is below the threshold belief defined thanks to scientists as that associated with an acceptable risk to society$\bar{p_0}$. We therefore have: $p_0 \leq \bar{p_0}$. The firm has the possibility to pay an amount $C \geq 0$ to 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 new exogenous information from independent scientific studies. This is a public information. This information is given through a signal $\sigma \in \{h, l\}$ on the true state of Nature. We define the precision of the signal, f, as the probability the signal corresponds to the state. We represent it such that:

$$P(h|H) = P(l|L) = f,\ P(h|L) = P(l|H) = 1-f \text{ and } f > \tfrac{1}{2}.$$[5]

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

$$g_F(0) = \tfrac{1}{2} \text{ and } g'_F(+\infty) = 0.$$

Hence, if the firm does not invest, i.e. $C = 0$, or if it invests in research, i.e. $C > 0$ but the research provides non-conclusive results then the signal is not informative. 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. The higher the value of C, the higher the precision of the signal σ_F. This information is only observed by the firm. It is a private information that it may reveal (to the agency) at its convenience.

We then define the exogenous combined with the endogenous information precision such that:[6]

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

According to Bayes' rule, for the firm, the probabilities of being in state H depending on signals (h and l) and C, and therefore the updated beliefs are, respectively:

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

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

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

After receiving public and private information and updating its belief, we suppose that the firm has the possibility $t^F \in \{0, 1\}$ to choose between two behaviours. $t^F = 1$ means the firm to behave as a lobby. By doing so, the firm decides to not give unfavourable information (i.e. a signal h) to the agency if such a signal leads the agency to withdraw the market authorisation. The firm, therefore, hides information to the agency to be authorised to market its product. In other words, if the firm adopts a lobby behaviour, it will only transfer its private information to the agency when this signal is l. If the firm received a h signal, it transfers not conclusive information to the agency, i.e. the agency receives the signal h from private information with precision $f_F(C) = \frac{1}{2}$. This implies that a necessary condition for the possibility of adopting a lobby behaviour to exist is to satisfy both $P^A(H|(\sigma, l), \frac{1}{2}) \leq \bar{p}_0$ and $P^A(H|(\sigma, h), f_F(C)) > \bar{p}_0$. If the firm chooses $t^F = 0$, it does not behave as a lobby and it provides all the available information to the agency. As a consequence, the firm and the agency have similar information, and we have: $P^A(.|(.,.), f_F(C)) = P^F(.|(.,.), f_F(C))$.[7] As the agency knows there is a possibility the firm's research does not give any results, it does not suspect the firm to hide from it the results (reliability).

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 authorisation ($x^A_{\sigma,\sigma_F,f_F(C)} = 1$), or to withdraw it ($x^A_{\sigma,\sigma_F,f_F(C)} = 0$). The agency maintains the authorisation when its belief $P^A(H|(\sigma, \sigma_F), C)$ on state H is below the threshold belief defined by scientists as that associated with an acceptable risk to society, $\bar{p}_0$. $x^{A*}_{\sigma,\sigma_F,f_F(C)} \in \{0, 1\}$, which is the agency's optimal decision to maintain or remove the authorisation to the firm is as follows:

$$x^{A*}_{\sigma,\sigma_F,f_F(C)} = \begin{cases} 0 & \text{if} \quad P^A(H|(\sigma, \sigma_F), f_F(C)) > \bar{p}_0; \\ 1 & \text{if} \quad P^A(H|(\sigma, \sigma_F), f_F(C)) \leq \bar{p}_0. \end{cases}$$

Naturally, if the agency withdraws the market authorisation, the firm cannot sell its product any more. In such a case, the firm recovers an amount $D > 0$, which is lower than the benefit it could earn if it could continue to sell its product until period 2 (see later). However, we suppose that the firm has the possibility to remove, by itself, its product from the market. 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 $D > 0$ and to decrease the amount of harm that its product may cause at period 2 (see later).

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 $R_2 > 0$. Nevertheless, 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 by the firm), the magnitude of harm is reduced: $K' > 0$ with $K' \geq K$. Moreover, in the case where the firm has chosen to behave as a lobby, it may be penalised for having such a deviant behaviour. After an accident, investigations are carried out. The judge in charge of the case must check if all the information that the firm possessed has been transmitted to the agency. If the judge discovers that this is not the case (i.e. the firm has adopted a lobby behaviour), it enforces penal liability and sentenced the firm to pay a fine $M > 0$. We suppose that the

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

probability the judge gathers sufficient elements to apply penal liability is $p_J \in [0,1]$: in other words, when it chooses to behave as a lobby, the firm, after an accident occurring has a probability p_J to pay a fine of M.

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

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

After receiving the two signals σ and σ_F, the revised expected probability of damage for the firm is:

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

We consider that the firm depreciates each following period with a discount rate $\beta \leq 1$. Therefore, the expected payoffs of the firm at period 2 may be expressed as follows.

$$\begin{aligned} V_2(t^F, x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, \sigma, \sigma_F) = \;& t^F[-(1-x^A_{\sigma,\sigma_F,f_F(C)})E(\theta|(\sigma,\sigma_F), f_F(C))\,(K'+p_JM) \\ & +x^A_{\sigma,\sigma_F,f_F(C)}x^F_{\sigma,\sigma_F,f_F(C)}\,(R_2 - E(\theta|(\sigma,\sigma_F), f_F(C))\,(K+p_JM)) \\ & -x^A_{\sigma,\sigma_F,f_F(C)}(1-x^F_{\sigma,\sigma_F,f_F(C)})E(\theta|(\sigma,\sigma_F), f_F(C))\,(K'+p_JM)] \\ & +(1-t^F)[-(1-x^A_{\sigma,\sigma_F,f_F(C)})E(\theta|(\sigma,\sigma_F), f_F(C))K' \\ & +x^A_{\sigma,\sigma_F,f_F(C)}x^F_{\sigma,\sigma_F,f_F(C)}\,(R_2 - E(\theta|(\sigma,\sigma_F), f_F(C))K) \\ & -x^A_{\sigma,\sigma_F,f_F(C)}(1-x^F_{\sigma,\sigma_F,f_F(C)})E(\theta|(\sigma,\sigma_F), f_F(C))K']. \end{aligned}$$

Likewise, expected payoffs of the firm at period 2 is:

$$\begin{aligned} V_1(t^F, x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, \sigma, \sigma_F) \;&= \left[x^A_{\sigma,\sigma_F,f_F(C)}(1-x^F_{\sigma,\sigma_F,f_F(C)}) + (1-x^A_{\sigma,\sigma_F,f_F(C)})\right] D \\ & +\beta V_2(t^F, x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, \sigma, \sigma_F). \end{aligned}$$

Finally, we note:

$$\begin{aligned} \hat{V}_0(t^F, x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, \sigma, \sigma_F) \;&= [p_0 f f_F(C) + (1-p_0)\,(1-f)\,(1-f_F(C))] \\ & \left[t^F V_1(t^F, x^A_{hh,\frac{1}{2}}, x^F_{hh,f_F(C)}, h, h) + (1-t^F)V_1(t^F, x^A_{hh,f_F(C)}, x^F_{hh,f_F(C)}, h, h)\right] \\ & +[p_0\,(1-f)\,(1-f_F(C)) + (1-p_0)f f_F(C)]V_1(t^F, x^A_{ll,f_F(C)}, x^F_{ll,f_F(C)}, l, l) \\ & +[p_0 f\,(1-f_F(C)) + (1-p_0)\,(1-f)\,f_F(C)]V_1(t^F, x^A_{hl,f_F(C)}, x^F_{hl,f_F(C)}, h, l) \\ & +[p_0\,(1-f)\,f_F(C) + (1-p_0)f\,(1-f_F(C))] \\ & \left[t^F V_1(t^F, x^A_{lh,\frac{1}{2}}, x^F_{lh,f_F(C)}, l, h) + (1-t^F)V_1(t^F, x^A_{lh,f_F(C)}, x^F_{lh,f_F(C)}, l, h)\right]. \end{aligned}$$

Therefore, expected payoffs of the firm at period 0 can be expressed as follows:

$$\begin{aligned} V_0(t^F, x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, \sigma, \sigma_F, C, q) \;&= -C + q\beta\hat{V}_0(t^F, x^A_{\sigma,\sigma_F,\frac{1}{2}}, x^F_{\sigma,\sigma_F,\frac{1}{2}}, \sigma, \sigma_F) \\ & +(1-q)\beta\hat{V}_0(t^F, x^A_{\sigma,\sigma_F,f_F(C)}, x^F_{\sigma,\sigma_F,f_F(C)}, \sigma, \sigma_F). \end{aligned}$$

Finally, by assumption, we consider that if there is no exogenous nor endogenous information, the firm is authorised by the agency to sell its product and will always continue to sell it (until period 3). Therefore, we have:

$$V_1(t^F, 1, 0, \sigma, \sigma_F) < V_1(t^F, 1, 1, \sigma, \sigma_F)$$

$$\Rightarrow E(\theta) < \frac{\beta R_2 - D}{\beta(K-K')} \text{ with } E(\theta) = p_0\theta^H + (1-p_0)\theta^L. \tag{1}$$

This implies that in our study, $p_0 < \frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$. When $p_0 \geq \frac{(\beta R_2 - D) - \beta\theta^L(K-K')}{\beta(K-K')(\theta^H-\theta^L)}$, the firm does not make its project.

3 The optimal decision-making

In this section, we present the optimal decision-making. First, at period 1, according to signal $\sigma \in \{l, h\}$ and $\sigma_F \in \{l, h\}$, the agency has to decide between maintaining the authorisation and removing it. The agency maintains the authorisation when its belief $P^A(H|(\sigma, \sigma_F), f_F(C))$ on state H is below the threshold belief defined by scientists as that associated with an acceptable risk to society, $\bar{p_0}$.

Lemma 1 *For all $f_F(C) \geq \frac{1}{2}$,*

If $f_F(C) < f$ **then:** $P^i(H|(l,l), f_F(C)) < P^i(H|(l,h), f_F(C)) < p_0 < P^i(H|(h,l), f_F(C)) < P^i(H|(h,h), f_F(C))$;

If $f_F(C) > f$ **then:** $P^i(H|(l,l), f_F(C)) < P^i(H|(h,l), f_F(C)) < p_0 < P^i(H|(l,h), f_F(C)) < P^i(H|(h,h), f_F(C))$;

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, we understand that the agency always maintains the authorisation when it receives two signals l, that is $x^{A*}_{l,l,f_F(C)} = 1$, the danger is low. When it receives other signals, we observe that its decision depends on the levels of precision of the exogenous and the endogenous information it receives. We then summarise the agency's decisions in Table 1.

Case	$x^{A*}_{h,h,C}$	$x^{A*}_{h,h,½}$	$x^{A*}_{l,h,C}$	$x^{A*}_{l,h,½}$	$x^{A*}_{h,l,C}$	$x^{A*}_{h,l,½}$	$x^{A*}_{l,l,C}$	$x^{A*}_{l,l,½}$	Conditions	
1	1	1	1	1	1	1	1	1	$P^A(H|h,h,f_F(C)) \leq \bar{p}_0$	
2	0	1	1	1	1	1	1	1	$P^A(H|h,h,½) = P^A(H|h,l,½) \leq \bar{p}_0$ and $P^A(H|h,h,f_F(C))) > \bar{p}_0$	
3	0	0	1	1	1	0	1	1	$P^A(H|h,l,f_F(C))) \leq \bar{p}_0$ and $P^A(H|h,h,½) = P^A(H|h,l,½) > \bar{p}_0$	$f_F(C) < f$
4	0	0	1	1	0	0	1	1	$P^A(H|h,l,f_F(C))) > \bar{p}_0$	$f_F(C) < f$
5	0	0	0	1	1	0	1	1	$P^A(H|l,h,f_F(C))) > \bar{p}_0$	$f_F(C) > f$

Table 1: agencies' optimal decision to maintain or suspend authorisation, $x^{A*}_{\sigma,\sigma_F,f_F(C)}$.

We observe that the precision of the information will be important when the signals diverge. Note that for case 4, the agency is in a situation where it receives public information is more precise than that of the private one and decides to withdraw the product as soon as private research indicates a strong danger signal to it. We have the exact opposite for case 5. We also note that in case 2 and case 5, the agency will withdraw its authorisation from the firm if it receives precise information from it and will maintain its authorisation if the inconclusive information.

Next, 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 wants to remove or to continue to sell its product (if the agency has not withdrawn the market authorisation). The firm continues to sell its product if its expected payoff by continuing to sell its product is higher than that when removing its product from the market. That is:

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

Lemma 2 *For all $f_F(C) \geq \frac{1}{2}$,*

If $f_F(C) < f$ **then** $E(\theta|(l,l), f_F(C)) < E(\theta|(l,h), f_F(C)) < E(\theta) < E(\theta|(h,l), f_F(C)) < E(\theta|(h,h), f_F(C))$;

If $f_F(C) > f$ **then** $E(\theta|(l,l), f_F(C)) < E(\theta|(h,l), f_F(C)) < E(\theta) < E(\theta|(l,h), f_F(C)) < E(\theta|(h,h), f_F(C))$;

If $f_F(C) = f$ **then** $E(\theta|(l,l), f_F(C)) < E(\theta|(h,l), f_F(C)) = E(\theta) = E(\theta|(l,h), f_F(C)) < E(\theta|(h,h), f_F(C))$.

Moreover, $E(\theta|(h,h), f_F(C))$ *and* $E(\theta|(l,h), f_F(C))$ *are increasing with* $f_F(C)$ *while* $E(\theta|(l,l), f_F(C))$ *and* $E(\theta|(h,l), f_F(C))$ *are decreasing with* $f_F(C)$.

Conditions under which the firm removes its product or continues to sell it are given by the following proposition.

Proposition 1 *For* $t^F \in \{0,1\}$, $x^A_{\sigma,\sigma_F,f_F(C)} \in \{0,1\}$, $\sigma \in \{l,h\}$, $\sigma_F = \{l,h\}$, *and* $f_F(C) \geq \frac{1}{2}$*: If* $E(\theta|(\sigma,\sigma_F), f_F(C)) < \frac{\beta R_2 - D}{\beta(K-K')}$ *then the firm continues to sell its product, i.e.,* $x^{F*}_{\sigma,\sigma_F,f_F(C)} = 1$*; If* $E(\theta|(\sigma,\sigma_F), f_F(C)) > \frac{\beta R_2 - D}{\beta(K-K')}$*, then the agent removes its product from the market, i.e.,* $x^{F*}_{\sigma,\sigma_F,f_F(C)} = 0$*; Finally, if* $E(\theta|(\sigma,\sigma_F), f_F(C)) = \frac{\beta R_2 - D}{\beta(K-K')}$*, then the agent is indifferent between continuing to sell its product and removing it from the market, i.e.,* $x^{F*}_{\sigma,\sigma_F,f_F(C)} \in \{0,1\}$.

From Lemma 2 and Proposition 1, we can see that the firm always continues to sell its product when it receives two signal l, that is $x^{F*}_{l,l,f_F(C)} = 1$, the danger is low. When it receives other signals, we observe that its decision depends on the levels of precision of the exogenous and of the endogenous information it receives, and on the ratio between marginal benefit and damages from maintaining the product until period 2: the higher the marginal benefit from maintaining its product, $R_2 - D$, the more the firm is prone to maintain its product. The higher the marginal damages from maintaining its product, $K - K'$, the less the firm is prone to maintain its product. The effect of the magnitude of the investment in information acquisition, C, depends on the received signal: the higher the level of C, the less the firm is prone to maintain its product when it has received the signal h, and the more it is prone to maintain its product when it has received the signal l. Finally, a higher discount rate β provides incentives to maintain the product. We then summarise the firm's optimal decision to stop or continue the sale of its product in Table 2.

Case	$x^{F*}_{h,h,C}$	$x^{F*}_{h,h,½}$	$x^{F*}_{l,h,C}$	$x^{F*}_{l,h,½}$	$x^{F*}_{h,l,C}$	$x^{F*}_{h,l,½}$	$x^{F*}_{l,l,C}$	$x^{F*}_{l,l,½}$	Conditions	
A	1	1	1	1	1	1	1	1	$E(\theta|(h,h), f_F(C)) \leq \frac{\beta R_2 - D}{\beta(K-K')}$	
B	0	1	1	1	1	1	1	1	$E(\theta|(h,h), ½) = E(\theta|(h,l), ½) \leq \frac{\beta R_2 - D}{\beta(K-K')}$, and $E(\theta|(h,h), f_F(C)) > \frac{\beta R_2 - D}{\beta(K-K')}$	
C	0	0	1	1	1	0	1	1	$E(\theta|(h,l), f_F(C)) \leq \frac{\beta R_2 - D}{\beta(K-K')}$ and $E(\theta|(h,h), ½) = E(\theta|(h,l), ½) > \frac{\beta R_2 - D}{\beta(K-K')}$	$f_F(C) < f$
D	0	0	1	1	0	0	1	1	$E(\theta|(h,l), f_F(C)) > \frac{\beta R_2 - D}{\beta(K-K')}$	$f_F(C) < f$
E	0	0	0	1	1	0	1	1	$E(\theta|(l,h), f_F(C)) > \frac{\beta R_2 - D}{\beta(K-K')}$	$f_F(C) > f$

Table 2: Firm's optimal decision to stop or continue the sale of its product, $x^{F*}_{\sigma,\sigma_F,f_F(C)}$.

We see that if the signals diverge or if it receives two signals indicating that the danger is great, the firm may decide to stop. In addition, if these tests are not conclusive, it will tend to stop production more often.

Now at period 1, for all the cases, the firm has to decide whether to behave as a lobby, or not. Recall that adopting a lobby behaviour consists in transmitting not conclusive result when it receives the $\sigma_F = h$ signal that could lead the agency to withdraw the market authorisation[8]. The firm chooses to adopt a lobby behaviour if its expected payoff by doing so is higher than when it does not. That is:

$$V_1(0, x^{A*}_{\sigma,\sigma_F,f_F(C)}, x^{F*}_{\sigma,\sigma_F,f_F(C)}, \sigma, \sigma_F) < V_1(1, x^{A*}_{\sigma,\sigma_F,f_F(C)}, x^{F*}_{\sigma,\sigma_F,f_F(C)}, \sigma, \sigma_F).$$

For each case, the conditions under which the firm chooses to adopt a "lobby" behaviour or a "non-lobby" behaviour are given by the following proposition. We note

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

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 $f_F(C) \geq \frac{1}{2}$:*

1. *If $\sigma_F = l$, the firm always chooses not to adopt a lobby behaviour, 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 not to adopt a lobby behaviour, i.e. $t^{F*} = 0$; if $M < \bar{M}$, then the firm always chooses to adopt a lobby behaviour, i.e., $t^{F*} = 1$; if $M = \bar{M}$, then the firm is indifferent between adopting a lobby and not adopting it, i.e. $t^{F*} \in \{0,1\}$.*

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 $x^{A*}_{\sigma,h,f_F(C)} \leq x^{A*}_{\sigma,h,\frac{1}{2}}$, that is $x^{A*}_{\sigma,h,f_F(C)} - x^{A*}_{\sigma,h,\frac{1}{2}} \in \{-1, 0\}$. A firm is therefore less prone to adopt a lobby behaviour if: the amount of money, D, it can recover by stopping selling its product increases, the financial cost, K, when it continues to sell its product increases, the level of research, C, increases, and its belief being sentenced when it has chosen to adopt a lobby behaviour, p_J, increases. On the other hand, it is more prone to adopt a lobby behaviour: if the payoff, R_2, by continuing to sell its product increases, the financial cost, K', when it stops selling its product increases, and the discount rate, β, increases.

In addition, Point 2 of Proposition 2 implies that the firm always chooses not to adopt a lobby behaviour, i.e. $t^{F*} = 0$, for $\sigma = l$ under cases 1, 2, 3, 4, and E, and for $\sigma = h$ under cases 1, 3, 4, 5, B, C, D and E. In all other cases, this will depend on the value of M. Moreover, we note that if the tests are not conclusive, the firm never adopts a lobby behaviour ($x^A_{\sigma,h,f_F(C)} - x^A_{\sigma,h,\frac{1}{2}} = 0$ with $C = 0$).

Finally, at period 0, the firm chooses the magnitude of the investment $C \geq 0$ that it will make for acquiring information.[9] It chooses C^*, the level of C to maximise its expected payoff at period 0, that is:

$$\max_{C \geq 0} V_0(t^{F*}, x^{A*}_{\sigma,\sigma_F,f_F(C)}, x^{F*}_{\sigma,\sigma_F,f_F(C)}, \sigma, \sigma_F, C, q).$$

We obtain the following table:

[8] That is, if the agency had knowledge of this signal, it would choose to withdraw the market authorisation. However, if it does not have this information, it still maintains the market authorisation.

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

	t=0	t=1	Behaviour
Cases	C*	C*	
1A	0		No lobby
1B	C1		No lobby
1C	C1		No lobby
1D	0		No lobby
1E	C2		No lobby
2A	C1	C3	?
2B	C1		No lobby
2C	C1		No lobby
2D	0		No lobby
2E	C2		No lobby
3A	C1		No lobby
3B	C1		No lobby
3C	C1		No lobby
3D	0		No lobby
4A	0		No lobby
4B	0		No lobby
4C	0		No lobby
4D	0		No lobby
5A	C2	C4	?
5B	C2	C4	?
5E	C2		No lobby

Table 3: Optimal research investment.

From Table 3, we obtain that the firm never invests in research under situations **1A**, **1D**, **2D**, **3D**, **4A**, **4B**, **4C** and **4D** when $t = 0$ and under situations **2A** when $t = 1$. For the other cases, the levels of optimal investment are defined as follows:

C_1 is such that:

- if $p_0 < \frac{(1-f)(\beta R_2 - D - \beta(K-K')\theta^L)}{\beta R_2 - D - \beta(K-K')(f\theta^H + (1-f)\theta^L)}$ then $C_1 > 0$ and verifies that:

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

- otherwise $C_1 = 0$.

C_2 is such that:

- if $p_0 < \frac{\beta R_2 - D - \beta(K-K')\theta^L}{2(\beta R_2 - D) - \beta(K-K')(\theta^H + \theta^L)}$ then $C_2 > 0$ and verifies that:

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

- otherwise $C_2 = 0$.

C_3 is such that:

$$f_F'(C) = \frac{-(0.5(1-p_0) + f(-0.5 + p_0))(f(-0.5 + p_0) - 0.5p_0))}{0.5(1-q)\beta^2(1-f)f(1-p_0)p_0(K + p_J M)(\theta^H - \theta^L)}.$$

C_4 is such that if $C_4 > 0$ then it verifies that:

$$\frac{f_F^{'}(C)}{1-\beta^2(1-q)\gamma_3(K+p_JM)f_F^{'}(C)f_F(C)^2} = \frac{1}{(1-q)\beta\left[(f+p_0-1)\left(D-\beta R_2+\beta(\gamma_1(K+p_JM)-\gamma_2(K'+p_JM))\right)\right]}.$$

with $\gamma_1 = \frac{0.5(p_0-f)(f(1-p_0)\theta^L+p_0(1-f)\theta^H)}{-0.5p_0+f(-0.5+p_0)}$, $\gamma_2 = \frac{0.5((1-f)(1-p_0)\theta^L+fp_0\theta^H)}{0.5(1-p_0)+f(-0.5+p_0)}$ and
$\gamma_3 = \frac{(1-f)fp_0^2((-2+3p_0)\theta^H+(1-p_0)\theta^L)+(1-p_0)p_0(p_0(\theta^H-\theta^L)+\theta^L-2f(\theta^H+\theta^L)+2f^2(\theta^H+\theta^L))f_F(C)-(f-f^2-p_0+p_0^2)(p_0\theta^H-(1-p_0)\theta^L)}{((1-f)p_0-(p_0-f)f_F(C))(-fp_0+(f+p_0-1)f_F(C))}$
otherwise $C_4 = 0$.

We note that there are only three cases where the firm can decide to hide its results. Case 2A when the firm still wants to continue and the agency decides to withdraw its authorisation if it only receives the two information, one of which is private information, indicate that the danger is high. Case 5A when the firm still wants to continue and the agency decides to withdraw its authorisation if it receives public information that the danger is low and private information specifies that the danger is high. And finally, case 5B when the firm decides to stop only if the tests are conclusive and indicate to it that the danger is high and the agency wants to withdraw its authorisation if it receives public information that the danger is low and private information indicates that the danger is high.

We also note that the firm will invest in research in all the cases where it wants to prevent the agency from withdrawing its product, taking into account only the results of public research. It invests in research to be a counterweight in case of troubles on the results. In addition, it also invests in research to obtain precise information which will lead it to stop its production if it is postponed to be dangerous. It will thus avoid marketing too long a dangerous product, which has a high risk of damage and cost.

Now, we analyse how the research investment varies with parameters. Table 4 sums up the results.

	Research investment			
Parameter	C1	C2	C3	C4
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 $p_0<A1$ - if $A1<p_0$
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 $p_0<1-f$ - if $p_0>1-f$
D	+ if 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	-	-	+ if $p_0<1/2$ - if $p_0>1/2$	?
q	-	-	-	?
M			+	+
p_J			+	+

Table 4: Static comparison.

4 Numerical Simulation

To explore the impact of the civil and penal liabilities on the firm's investment in research and whether private information is more or less precise than public information (exogenous signal) at equilibrium, we assign functional form and numerical values to relevant parameters. In simulating the model, care must be taken to assign numerical values to relevant parameters. The parameters to which we must assign numerical values include (i) the level of the probabilities of causing damage: θ^H and θ^L; (ii) the firm's return on its production: D, R_2; (iii) damages to be paid in case of harm: K and K'; (iv) the discount parameter β; and (v) the probability that the private research fails q.

Parameter	*Value*
θ^H	0.8
θ^L	0.2
R_2	160
K	150
K'	50
D	80
β	0.9
q	0.3

From these specifications, we subsequently obtain $\frac{\beta R_2 - D}{\beta(K-K')} \approx 0.7$ and condition (1) is verified for $p_0 < 0.85$. We consider the firm's precision of the signal is represented by:

$$f_F(C) = \frac{1+C}{2+C}.$$

We initially consider that the threshold belief defined with the help of scientists as associated with an acceptable risk to society is at $\bar{p_0} = 0.5$ and the level of precision of the exogenous information is $f = 0.7$. The determination of the optimal private investment C^* in research for information follows this process: first, we calculate the optimal level of investment for all the cases. Then, among the various cases introduced in Table 1 and Table 2, we have to isolate the cases that come true (which depend on the values of exogenous parameters). Finally, according to the value of $\bar{M}$, we select the optimal level of investment which leads to the highest payoff. Figure 2 represents the firm's optimal investment in research for $M = 25$ and $p_J = 0.25$.

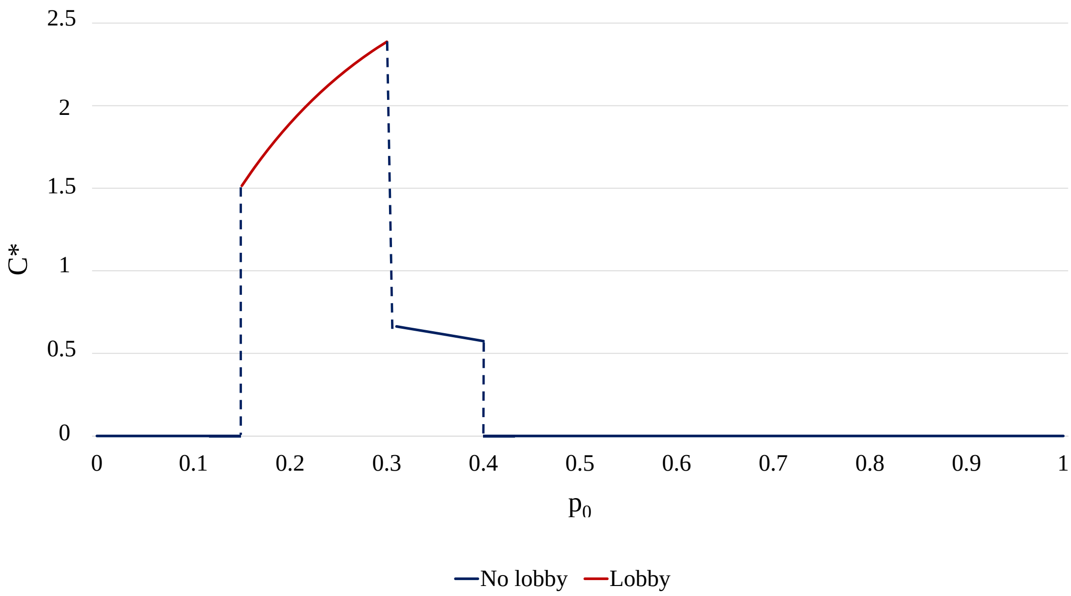

Figure 2: Firm's optimal investment in research, C^*. $M = 25$ and $p_J = 0.25$.

From Figure 2, we first note that for low and high levels of the prior belief being in the most dangerous state of the world, the firm does not invest in research.[10] Actually, if the firm perceives the dangerousness is low, it does not perceive any interest to invest in research. On the other hand, if it perceives that the dangerousness is high, it knows the agency will remove the authorisation and then does not make a supplementary expense in investing in research. We also observe that the company invests in research to reduce its uncertainty about the dangerousness of its product. But, first of all, it invests significantly and her investment believes with the perceived danger. At that time, it hides her results from the Agency to promote her own commercial interests. But when

[10]From $p_0 \in [0, 0.14]$, we have Case 1A, from $p_0 \in [0.15, 0.3]$, we have Case 2A, from $p_0 \in [0.31, 0.4]$, we have Case 3A, and from $p_0 \in [0.41, 0.5]$, we have Case 4A.

the acceptable threshold is close to being reached, it brutally reduces its investment in research which decreases with the perceived danger and transmits its results to convince the Agency not to withdraw its sales authorisation.

At that point, we want to examine the fine and the probability to pay a fine effects on the optimal investment in research. We vary the values of the probability to pay a fine $p_J \in \{0.25; 0.5; 0.75\}$ and of the level of the fine $M \in \{12.5; 25; 50; 100\}$.

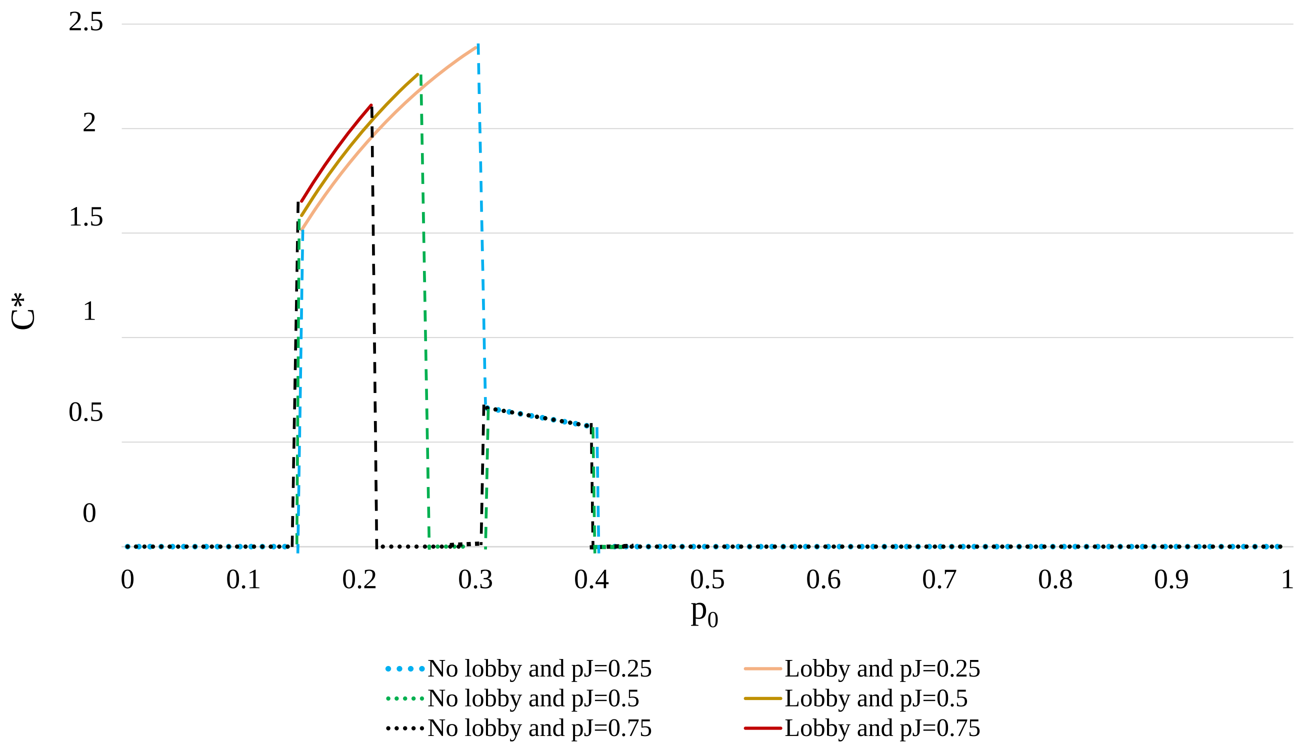

Figure 3: Firm's optimal investment in research, C^*. $M = 25$ is constant and p_J varies.

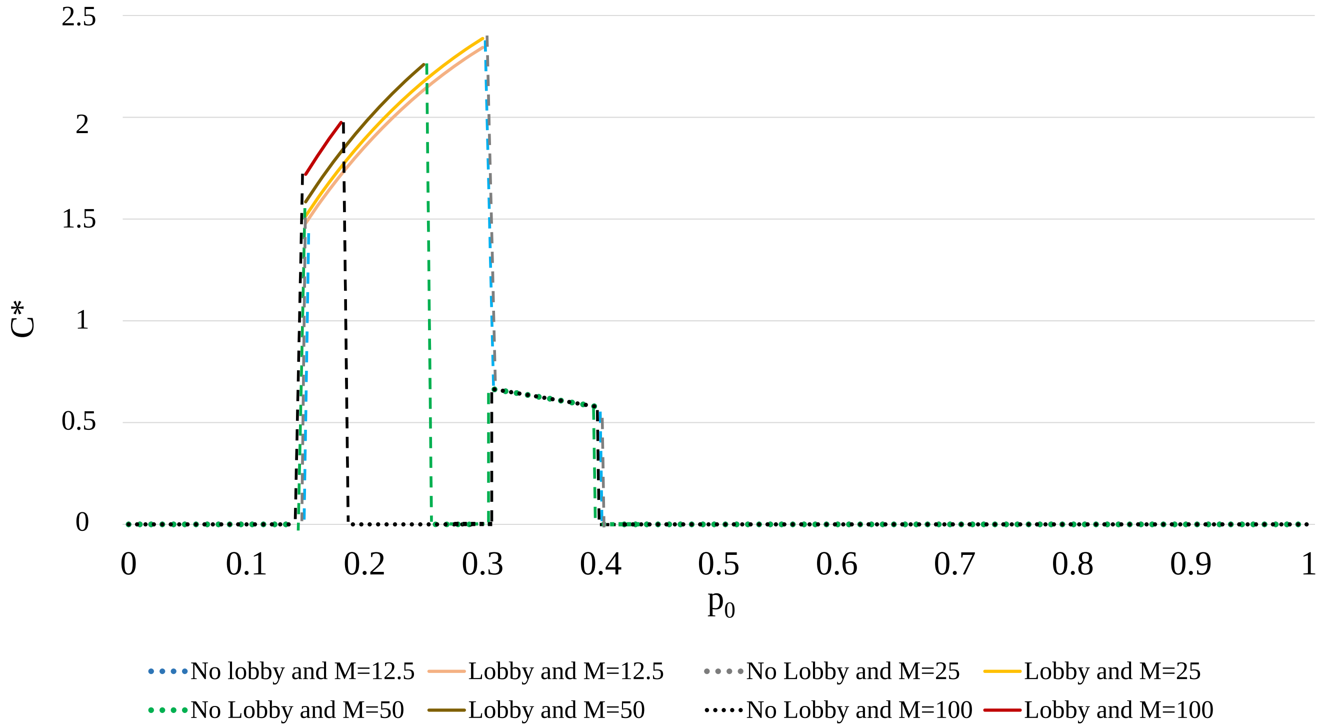

Figure 4: Firm's optimal investment in research, C^*. $P_J = 0.25$ is constant and M varies.

From Figures 3 and 4, we recognize that when the firm adopts a lobbying behaviour the higher the probability of paying a fine and the higher the level of the fine (in the case where the firm adopts a lobby behaviour), the higher the investment in research.[11] Indeed, when the firm adopts a lobbying behaviour, the greater the probability of being caught and the greater the level of the fine, the more it will seek to obtain a better signal precision to reduce its own uncertainty. Actually, the firm increases its investment in research to reduce its own uncertainty about the dangerousness of its product and be able to withdraw. It tries to reassure itself and have enough confidence in its results to avoid being fined. In addition, we observe that when the firm adopts a lobbying behaviour, the greater the probability of being caught and the greater the level of the fine, more the firm will stop investing in research earlier. In addition, it will also hide her results less from the agency because it wants to avoid the fine that would lower her profit. Ultimately, we note that whatever the level of the fine and the level of the probability, the firm always invests in research in the same proportion and transfers its results to the Agency, when the acceptable threshold is close to be reached.

Now, we want to analyse the impacts of the threshold of the acceptable risks on the investment in research and the level of the information precision. We vary the values of the threshold belief defined with the help of scientists as associated with an acceptable risk to society $\bar{p_0} \in \{0.3; 0.5; 0.7\}$, and the level of precision of the exogenous information $f \in \{0.55; 0.7; 0.9\}$.

[11]Figure 3: when $p_J = 0.5$, from $p_0 \in [0, 0.14]$, we have Case 1A, from $p_0 \in [0.15, 0.25]$, we have Case 2A, from $p_0 \in [0.26, 0.3]$, we have Case 1A, from $p_0 \in [0.31, 0.4]$, we have Case 3A, and from $p_0 \in [0.41, 0.5]$, we have Case 4A; when $p_J = 0.75$, from $p_0 \in [0, 0.14]$, we have Case 1A, from $p_0 \in [0.15, 0.21]$, we have Case 2A, from $p_0 \in [0.22, 0.3]$, we have Case 1A, from $p_0 \in [0.31, 0.4]$, we have Case 3A, and from $p_0 \in [0.41, 0.5]$, we have Case 4A. Figure 4: : when $M = 12.5$, from $p_0 \in [0, 0.14]$, we have Case 1A, from $p_0 \in [0.15, 0.3]$, we have Case 2A, from $p_0 \in [0.31, 0.4]$, we have Case 3A, and from $p_0 \in [0.41, 0.5]$, we have Case 4A; when $M = 50$, from $p_0 \in [0, 0.14]$, we have Case 1A, from $p_0 \in [0.15, 0.25]$, we have Case 2A, from $p_0 \in [0.23, 0.3]$, we have Case 1A, from $p_0 \in [0.31, 0.4]$, we have Case 3A, and from $p_0 \in [0.41, 0.5]$, we have Case 4A; when $M = 100$, from $p_0 \in [0, 0.14]$, we have Case 1A, from $p_0 \in [0.15, 0.18]$, we have Case 2A, from $p_0 \in [0.19, 0.3]$, we have Case 1A, from $p_0 \in [0.31, 0.4]$, we have Case 3A, and from $p_0 \in [0.41, 0.5]$, we have Case 4A.

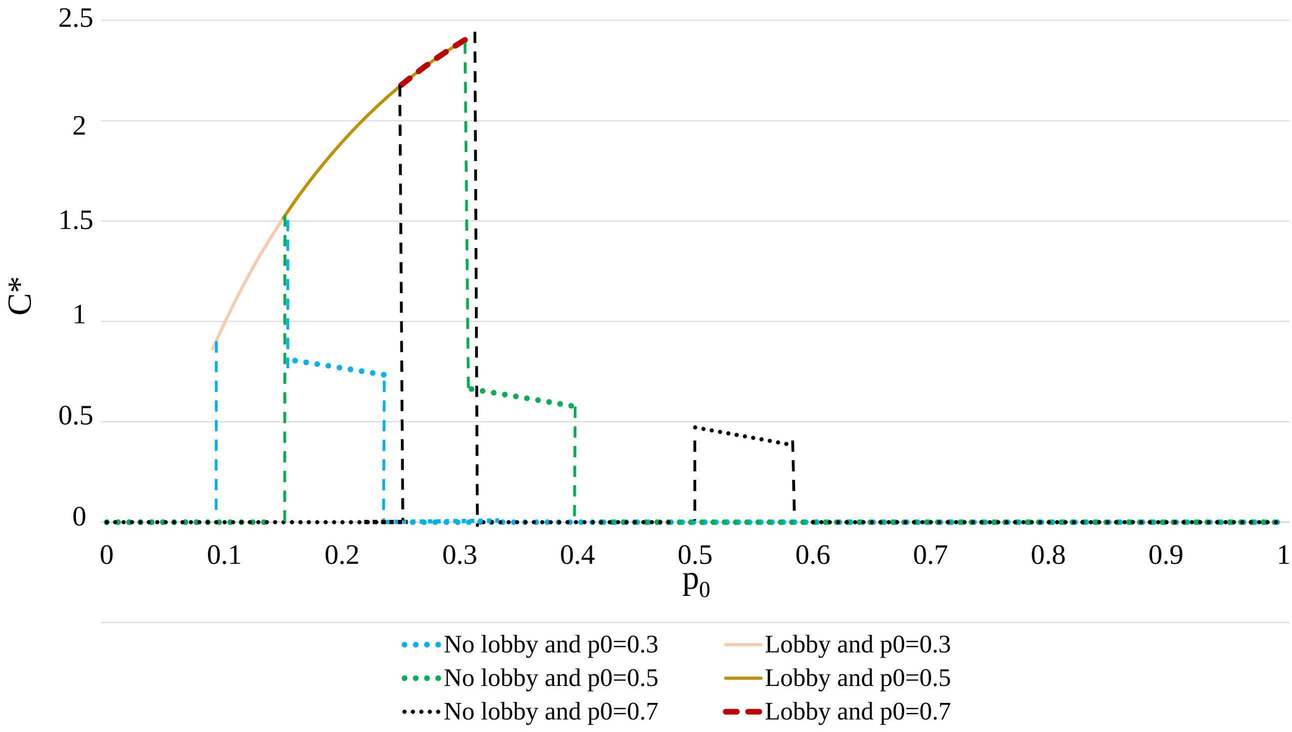

Figure 5: Firm's optimal investment in research, C^*. $M = 25$, $p_J = 0.25$ and $\bar{p_0}$ varies.

Figure 5 indicates that even if the acceptability threshold is low the firm will still invest in research to acquire information and reduce its uncertainty on the level of dangerousness of its project.[12] Moreover, we note that higher the threshold is, more the firm invests in research when it decides to hide the results. Indeed, when the risk of accident is low, the firm seeks to obtain more precision from its research to reassure itself and be ready to stop its project. On the other hand, when the firm transfers information to the Agency, its level of investment in research is lower and it performs this just before the threshold is reached. Actually, if the risk of accident is great, it prefers decreasing its investment to avoid additional costs while it or that the agency will tend to stop production.

[12] When $\bar{p_0} = 0.3$, from $p_0 \in [0, 0.08]$, we have Case 1A, from $p_0 \in [0.09, 0.15]$, we have Case 2A, from $p_0 \in [0.16, 0.24]$, we have Case 3A, from $p_0 \in [0.25, 0.3]$, we have Case 4A; When $\bar{p_0} = 0.7$, from $p_0 \in [0, 0.24]$, we have Case 1A, from $p_0 \in [0.25, 0.31]$, we have Case 2A, from $p_0 \in [0.32, 0.49]$, we have Case 1A, from $p_0 \in [0.5, 0.58]$, we have Case 3A, from $p_0 \in [0.59, 0.68]$, we have Case 4A, from $p_0 \in [0.69, 0.7]$, we have Case 4D.

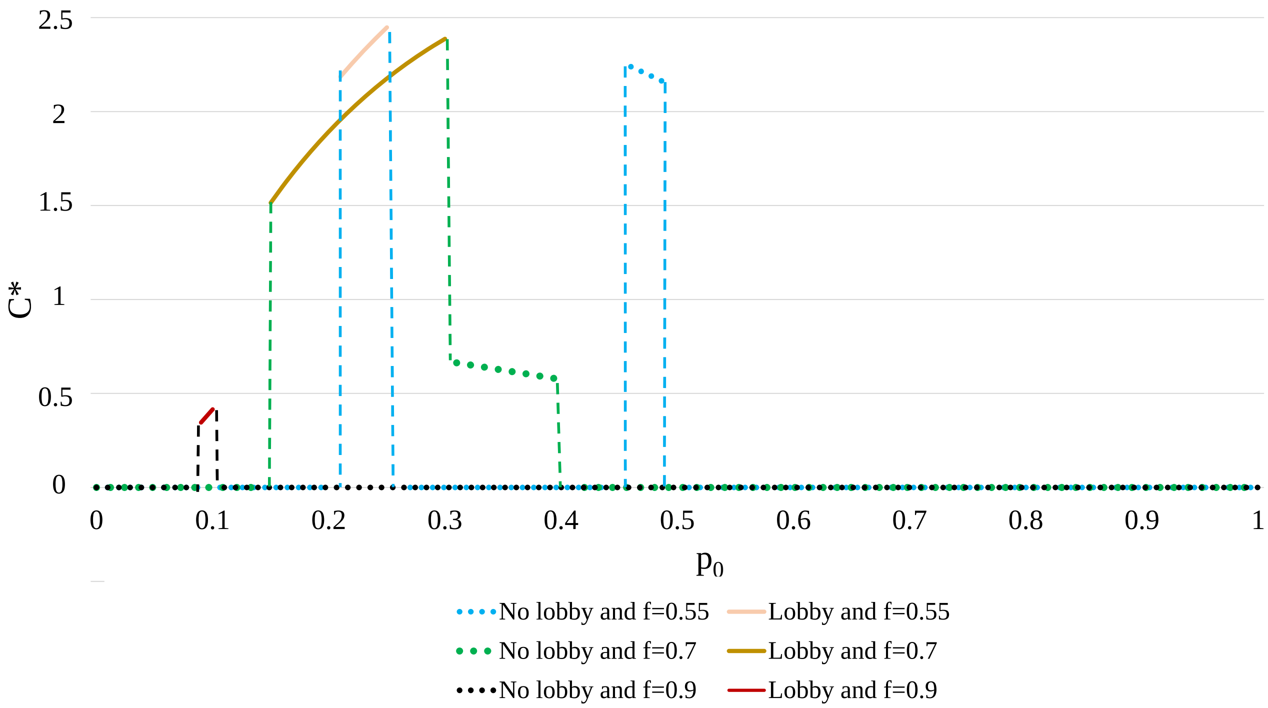

Figure 6: Firm's optimal investment in research.C^*. $M = 25$, $p_J = 0.25$ and f varies.

Figure 6 shows that the investment in research decreases with the level of the public information precision.[13] Then, when the level of precision of public information is high ($f = 0.9$), the firm does not have any interest in investing in research because it benefits from public information for free. If it carries out research, it knows (as shown in the Figure 7) that its precision is not as good as that of public research and therefore will not send it to the Agency to convince it but will keep it for itself to reassure itself and stop its project if necessary. On the other hand, when the level of precision of public information is low ($f = 0.55$), the firm will strongly invest in research and will hide information for low levels of the prior belief being in the most dangerous state of the world, while it will transfer it for high levels for having an influence on Agency decision. Therefore, we could note that for low and high level of public information precision, public and private information are substitute otherwise they are complementary.

[13]When $f = 0.55$, from $p_0 \in [0, 0.2]$, we have Case 1A, from $p_0 \in [0.21, 0.25]$, we have Case 2A, from $p_0 \in [0.26, 0.45]$, we have Case 1A, from $p_0 \in [0.46, 0.5]$, we have Case 5A; When $f = 0.9$, from $p_0 \in [0, 0.08]$, we have Case 1A, from $p_0 \in [0.09, 0.1]$, we have Case 2A, from $p_0 \in [0.11, 0.35]$, we have Case 4A, from $p_0 \in [0.36, 0.5]$, we have Case 4D.

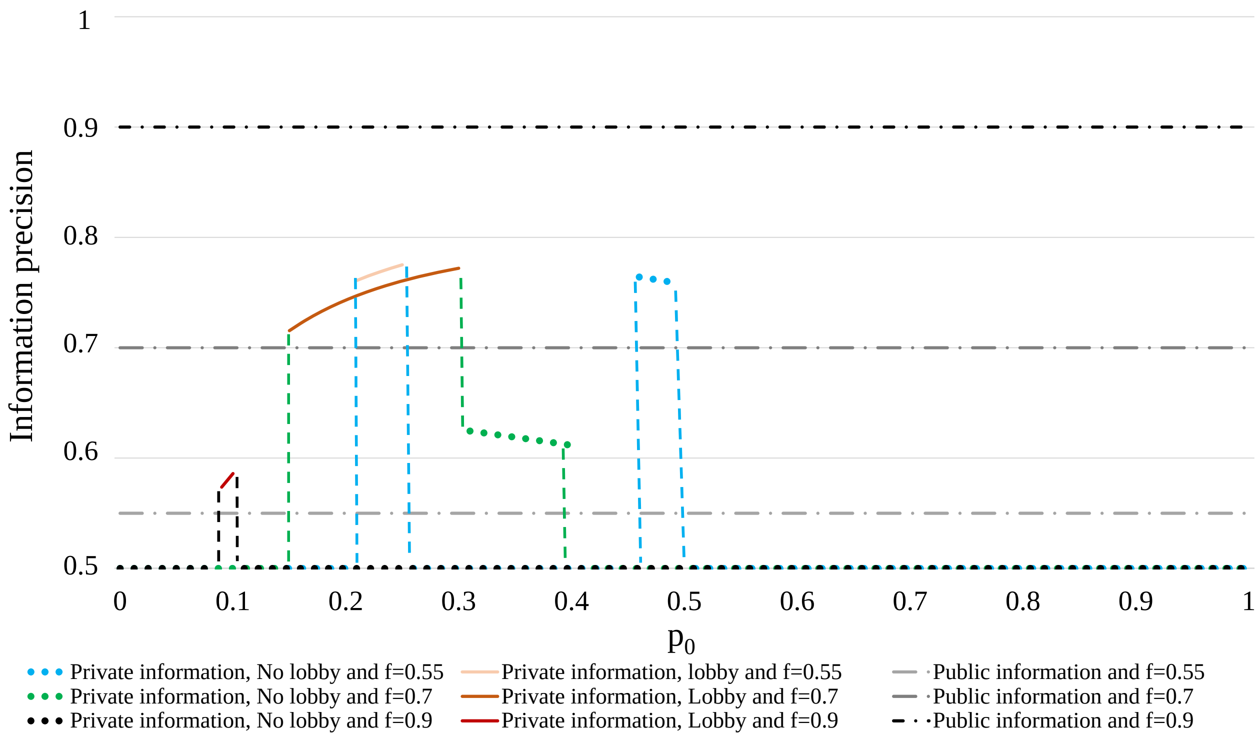

Figure 7: Precision of public and private information according to the firm's behaviour, f and $f_F(C^*)$. $M = 25$ and $p_J = 0.25$.

	Research investment			
Parameter	C1	C2	C3	C4
β	+	+	+	+
f	-		-	-
R_2	-	-		-
K	+	+	+	+
K'	-	-		-
D	+	+		+
θ^H	+	+	+	+
θ^L	-	-	-	-
p_0	-	-	-	+
q	-	-	-	-
M			+	+
p_J			+	+

Table 5: Static comparison.

5 Conclusion

In this paper, we analyse the optimal agency's and firm's decisions. We obtain the conditions for which the agency decides to maintain or remove the authorisation to sell a product, and for which the firm will decide to behave (or not) as a lobby and to stop or continue to sell its product. Then, we examine the optimal firm's investment in research to obtain more information on the dangerousness of the production. To be specific, we clarify the effect of the penal liability on the firm's investment in research decision. Finally, this allows us to discuss about the role of the combination of the authorisation process with civil and penal liabilities on the firm's decisions and the uncertainty reduction.

We find that although the firm has a research and development programme, the possibility of losing its approval to sell its product on the market motivates it to acquire the information to have a precision allowing him to convince the agency not to withdraw its authorisation. Private research and public research are therefore in competition. It can therefore be worrying to reduce public research budgets. This would risk leaving control to industrial lobbies over authorisations for innovative products. This is reminiscent of the case of glyphosate. In addition, the possibility a significant cost will be added in the event of an accident penalised by the civil liability encourages the firm to invest more to acquire information and reduce uncertainty as to the dangerousness of its production. It therefore seems significant that the polluter pays principle be introduced through corporate civil liability. Indeed, this obliges companies to take into account the potential damage that their production can cause on health and the environment. It also forces them to try to reduce uncertainty about their product to avoid exorbitant costs in the event of an accident.

Moreover, in a context of scientific uncertainty, the firm may adopt both illegal and dangerous behaviour for health and the environment to prevent its product from being withdrawn from the market. Hence, the civil and penal liabilities demotivate the firm from adopting this type of behaviour. The level of the sanction as well as the success to prove the fault of the firm must be carefully set. The civil and penal consequences on Servier with the Mediator or Monsanto with Roundup can be dissuasive for firms from hiding their results from public agencies.

Finally, this revives the discussion in French law of punitive damages. In the United States, punitive damages consider a jurisprudential or legal origin depending on the states concerned. In the state of California, they are set. The Pilliod case (the decision of the Oakland Superior Court, Pilliod against Monsanto, on May 13, 2019) illustrates this. After using Roundup, the Pilliod spouses developed critical illnesses. The jury considered the exposure to this product was the cause and that Monsanto had failed in its obligation to prevent the danger. The jury also believed that the firm had acted maliciously (or fraud) and should be punished for its behaviour. The Oakland jury ordered in favour of the spouses the payment of 45 million dollars in compensatory damages and 2 billion dollars for punitive damages. At the end of July 2019, a Californian judge considerably reduced these convictions, the punitive damages thus passing to 69.3 million dollars. However, French law has always been reserved on punitive damages since it pursues an objective of compensation and not punishment.

For further research, it would be intriguing to introduce a solvability constraint for the firm. Indeed, the effect of the probability to pay a fine p_J and the amount of the fine M could be different in such a case.

6 Appendix

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 Lemma 2.
From Lemma 1, the proof is easily deduced.
■

Proof of Proposition 1.
The firm continues to sell its product if:

$V_1(t^F, x^A_{\sigma,\sigma_F,f_F(C)}, 0, \sigma, \sigma_F) < V_1(t^F, x^A_{\sigma,\sigma_F,f_F(f_F(C))}, 1, \sigma, \sigma_F)$
$\Leftrightarrow x^A_{\sigma,\sigma_F,f_F(C)}D < \beta\left(V_2(t^F, x^A_{\sigma,\sigma_F,f_F(C)}, 1, \sigma, \sigma_F) - V_2(t^F, x^A_{\sigma,\sigma_F,f_F(C)}, 0, \sigma, \sigma_F)\right)$
$\Leftrightarrow x^A_{\sigma,\sigma_F,f_F(C)}D < \beta x^A_{\sigma,\sigma_F,f_F(C)}\left(R_2(K-K')\right)$
$\Leftrightarrow E^F(\theta|(\sigma,\sigma_F), f_F(C)) < \frac{\beta R_2 - D}{\beta(K-K')}.$

The firm removes its product from the market if:

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

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

$V_1(t^F, x^A_{\sigma,\sigma_F,f_F(C)}, 0, \sigma, \sigma_F) = V_1(t^F, x^A_{\sigma,\sigma_F,f_F(C)}, 1, \sigma, \sigma_F) \Leftrightarrow E^F(\theta|(\sigma,\sigma_F), f_F(C)) = \frac{\beta R_2 - D}{\beta(K-K')}$.

■

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 $C \geq 0$:

1. If $\sigma_F = l$, then the firm does not adopt a lobby behaviour when:

$$V_1(1, x^A_{\sigma,l,f_F(C)}, x^F_{\sigma,l,f_F(C)}, \sigma, \sigma_F) < V_1(0, x^A_{\sigma,l,f_F(C)}, x^F_{\sigma,l,f_F(C)}, \sigma, l) \Leftrightarrow \\ E^F(\theta|(\sigma,l), f_F(C))p_J M > 0.$$

Since $E^F(\theta|(\sigma,l), f_F(C))p_J M > 0$ is always true, if $\sigma_F = l$ then the firm always chooses not to adopt a lobby behaviour, i.e., $t^{F*} = 0$.

2. If $\sigma_F = h$, then the firm does not adopt a lobby behaviour when:

$$V_1(1, x^A_{\sigma,h,\frac{1}{2}}, x^F_{\sigma,h,f_F(C)}, \sigma, h, f_F(C)) < V_1(0, x^A_{\sigma,h,f_F(C)}, x^F_{\sigma,h,f_F(C)}, \sigma, h) \Leftrightarrow \\ \frac{x^F_{\sigma,h,f_F(C)}(x^A_{\sigma,h,f_F(C)} - x^A_{\sigma,h,\frac{1}{2}})(D - \beta(R_2 - E(\theta|(\sigma,h), f_F(C))(K-K'))}{\beta E(\theta|(\sigma,h), f_F(C))p_J} < M.$$

We note $\bar{M} = \frac{x^F_{\sigma,h,f_F(C)}(x^A_{\sigma,h,f_F(f_F(C))} - x^A_{\sigma,h,\frac{1}{2}})(D - \beta(R_2 - E(\theta|(\sigma,h), f_F(C))(K-K'))}{\beta E(\theta|(\sigma,h), f_F(C))p_J}$, 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 not to adopt a lobby behaviour, i.e., $t^{F*} = 0$; if $M < \bar{M}$, then the firm always chooses to adopt a lobby behaviour, i.e., $t^{F*} = 1$; if $M = \bar{M}$, then the firm is indifferent between adopting a lobby or not adopting it, i.e., $t^{F*} \in \{0,1\}$. ■

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