Innovation, information, lobby and tort law under uncertainty

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Abstract

Recent environmental policies favor the 'pollutant-payer' Principle. This Principle points out the pollutant financial liability for eventual 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 authorization with the Regulator affairs, firms may develop specific strategies to exploit scientific uncertainty. They may produce favorable scientific findings. In case of accident, the firm having this type of behavior can be legally charged. We then analyze 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 she 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 behavior depends on its expected payoff, its level of research, and its belief being sentenced when she has chosen to adopt a lobby behavior. 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 she 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. *Ex ante* tool consists in requiring authorization before a public regulator for using new production processes and/or marketing new products: the firm has to provide the public regulator (say Regulator hereafter) with a risk assessment and, after checking methodology and results, the Regulator grants the authorization (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 she causes.[2]

Competition pushes the firms to innovate, by developing more cost-efficient processes and/or by developing new (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. 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 on the environment. So, in their efforts to obtain and/or to maintain a marketing authorization from the Regulator in the frame of the *ex ante* control, firms may develop specific strategies to exploit scientific uncertainty: they may produce favorable scientific findings and/or hide unfavorable findings. But in case of accident, the firm having this kind of behavior can be legally charged: penal liability can be stated to penalize a deviant behavior, and the firm can, by instance, be obliged to pay a fine (like in the VW diesel cheating scandal, see 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 undertake all "due diligence" in risk management. At the heart of concerns are the ability of public policy tools to provide the firms with incentives for making sufficient efforts in information research, and for pushing the firms to disclose to the Regulator all information on the dangerousness of the processes and/or products they want to use. Our paper aims at analyzing how (and in what extent) the *ex post* liability system, which combine civil and penal liability, helps the *ex ante* authorization 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. Acquiring 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

[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).

(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 Regulator. 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) analyze more deeply the interactions between the firms and the regulatory agencies, and study the conditions under which collusion 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 be a factor of implicit discipline to avoid collusion between firms and regulators ex ante. However, these studies do not consider the case of imperfectly known risks, for which additional information is expected. Moreover, the combined used of civil and penal liabilities is excluded. Immordino *et al.* (2011) provide a comparison between *ex ante* regulations and *ex post* fines in terms of incentives to develop a new product, and avoid 'regrettable substitution'. Both incentives to innovate and to not using dangerous processes are analyzed. 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 to affect the Regulator's decision-making[3]. In this paper, we provide an analysis in which *ex ante* marketing authorization 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.

From this model, we analyze the optimal firm's decisions. We find the conditions for which the firm will decide to stop or continue to sell its product. We obtain that its decision depends on the levels of precision of the exogenous and of the endogenous information she 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 study 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 behavior if: the amount of money she can recover by stopping selling its product increases, the financial cost when she continues to sell its product increases, the level of research increases, and its belief being sentenced when she has chosen to adopt a lobby behavior increases. On the other hand, she is more prone to adopt a lobby behavior: if the payoff by continuing to sell its product increases, the financial cost when she stops to sell 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, she does not see any interest to invest in research. On the other hand, if she perceives that the dangerousness

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

is high, she knows that the regulator will remove the authorization and then does not make a supplementary expense in investing in research. We also observe that when the uncertainty is the highest then the investment in research is the highest. The firm reduces the uncertainty on the dangerousness of its product. 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 behavior), the higher the investment in research. Indeed, if the firm adopts a lobbying behavior, the greater the probability of being caught, the more she 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 uncertainty 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 she 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 organized as follows. Section 2 introduces our model. Section 3 characterizes the regulators' optimal decision to maintain or suspend authorization, the firm's optimal decisions to adopt a lobby/non-lobbying behavior and to stop or continue the sale of its product. Section 4 presents the firm's optimal investment in research from simulation. We conclude in Section 5. All the proofs are in appendix.

2 The model

We consider a three period model. At period 0, the Regulator grants the firm with an authorization to use 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 than state L, so:

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

At period 0, the Regulator and the firm have both the same prior belief p_0 on state H, and $1 - p_0$ on state L. The Regulator grants the marketing authorization when its belief on being in state H is below the threshold belief defined with the help of scientists as that associated with an acceptable risk to society, $\bar{p_0}$. We therefore have: $p_0 \leq \bar{p_0}$.

From independent scientific studies, new exogenous 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:

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

Still at period 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. This information is only observed by the firm. It is a private information that she may

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

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

reveal (to the Regulator) at its convenience. We define the precision of the signal as the probability the signal corresponds to the state. We represent it as an increasing and concave function $f_F(C)$ such that:

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

and

$$f_F(0) = \frac{1}{2} \text{ and } f_F'(+\infty) = 0.$$

Hence, the information precision depends on the amount C the firm has invested in information acquisition. If the firm does not invest, i.e., $C = 0$, then the signal is not informative. On the other hand, the higher the value of C, the higher the precision of the signal σ_F. We then define the exogenous combined with the endogenous information precision such that:[6]

$$\begin{gathered}
P((h,h)|H,C) = P((l,l)|L,C) = f f_F(C), P((l,l)|H,C) = P((h,h)|L,C) = (1-f)\,(1-f_F(C)) \\
P((h,l)|H,C) = P((l,h)|L,C) = f\,(1-f_F(C))\,, P((l,h)|H,C) = P((h,l)|L,C) = (1-f)\,f_F(C).
\end{gathered}$$

According to Bayes' rule, the probabilities of being in state H depending on signals (h and l) and C for the Regulator (i=R) and the firm (i=F) are, respectively:

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

At period 1, according to signal $\sigma \in \{l,h\}$ and $\sigma_F \in \{l,h\}$, we define $x^R_{\sigma,\sigma_F,C} \in \{0,1\}$ as the Regulator's decision to maintain the authorization ($x^R_{\sigma,\sigma_F,C} = 1$), or to remove it ($x^R_{\sigma,\sigma_F,C} = 0$). The Regulator maintains the authorization when its belief $P^R(H|(\sigma,\sigma_F),C)$ on state H is below the threshold belief defined by scientists as that associated with an acceptable risk to society, $\bar{p}_0$. $x^{R*}_{\sigma,\sigma_F,C} \in \{0,1\}$, which is the Regulator's optimal decision to maintain or to remove the authorization to the firm is as follows:

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

Always at the period 1, after receiving its private signal and updating its belief, we suppose that the firm has the possibility $t^F \in \{0,1\}$ to choose between two behaviors. $t^F = 1$ means the firm to behave as a "lobby". By doing so, the firm decides to not giving unfavorable information (i.e., a signal h) to the Regulator if such a signal leads the Regulator to withdraw the market authorization. The firm therefore hides information to the Regulator in order to still be authorized to market its product. In other words, if the firm adopts a lobby behavior, it will only send a signal to the Regulator when this signal is l. If the firm received a h signal, it does not send any message to the Regulator, as if $C = 0$. This implies that a necessary condition for the possibility of adopting a lobby behavior to exist is to satisfy both $P^R(H|(\sigma,l),0) \leq \bar{p}_0$ and $P^R(H|(\sigma,h),C) > \bar{p}_0$. If the firm chooses $t^F = 0$, it does not behave as a lobby and it provides all the available information to the Regulator. As a consequence, the firm and the Regulator have similar information and we have: $P^R(.|(.,.),C) = P^F(.|(.,.),C)$.

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

Of course, if the Regulator withdraws the market authorization, 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 $x^F_{\sigma,\sigma_F,C} \in \{0,1\}$ the firm's decision to remove by itself ($x^F_{\sigma,\sigma_F,C} = 0$), or not to remove ($x^F_{\sigma,\sigma_F,C} = 1$), 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 withdrew at period 1 (by the Regulator, or by the firm), the magnitude of harm is reduced: $K' > 0$ with $K' < K$.[7] Therefore, the payment the firm has to make for damages (through civil liability) is reduced to K'.

Moreover, in the case where the firm has chosen to behave as a lobby, it may be penalized for having such a deviant behavior. 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 Regulator. If the judge discovers that this is not the case (i.e., the firm has adopted a lobby behavior), it enforces penal liability and sentenced the firm to pay a fine $M > 0$. We suppose that the 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:

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

We consider that the firm depreciates each following period with a discount rate $\beta \leq 1$. So, if signal σ, and σ_F have been perceived, expected payoffs of the firm at period 2 may be expressed as follows.

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

Likewise, expected payoffs of the firm at period 1 is:

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

[7] We assume that if the firm removes its product, the use and exposure will be shorter and therefore the magnitude of harm is lower.

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

$$\begin{aligned}
V_0(t^F, x^R, x^F, C) &= -C + (\beta/2) \\
&[[p_0 f f_F(C) + (1-p_0)(1-f)(1-f_F(C))]t^F V_1(t^F, x^R_{hh,0}, x^F_{hh,C}, h, h, C) \\
&+[p_0 f f_F(C) + (1-p_0)(1-f)(1-f_F(C))](1-t^F)V_1(t^F, x^R_{hh,C}, x^F_{hh,C}, h, h, C) \\
&+[p_0(1-f)(1-f_F(C)) + (1-p_0) f f_F(C)]V_1(t^F, x^R_{ll,C}, x^F_{ll,C}, l, l, C) \\
&+[p_0 f(1-f_F(C)) + (1-p_0)(1-f) f_F(C)]V_1(t^F, x^R_{hl,C}, x^F_{hl,C}, h, l, C) \\
&+[p_0(1-f) f_F(C) + (1-p_0) f(1-f_F(C))]t^F V_1(t^F, x^R_{lh,0}, x^F_{lh,C}, l, h, C) \\
&+[p_0(1-f) f_F(C) + (1-p_0) f(1-f_F(C))](1-t^F)V_1(t^F, x^R_{lh,C}, x^F_{lh,C}, l, h, C)].
\end{aligned}$$

Finally, by assumption, we consider that if there is no exogenous nor endogenous information, the firm is authorized by the Regulator to sell its product and will always continue to sell it (until period 2). Therefore, we have:

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

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 Regulator has to decide between maintaining the authorization and removing it. The Regulator maintains the authorization when its belief $P^R(H|(\sigma, \sigma_F), C)$ on state H is below the threshold belief defined by scientists as that associated with an acceptable risk to society, $\bar{p_0}$.

Lemma 1 *For all $C \geq 0$,*

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

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

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

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

From Lemma 1, we understand that the Regulator always maintains the authorization when it receives two signals l, that is $x^{R*}_{l,l,C} = 1$. 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 summarize the Regulator's decisions in Table 1.

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 Regulator has not withdrew the market authorization). 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:

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

Lemma 2 *For all $C \geq 0$,*

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

Case	$x^{R*}_{h,h,C}$	$x^{R*}_{h,h,0}$	$x^{R*}_{l,h,C}$	$x^{R*}_{l,h,0}$	$x^{R*}_{h,l,C}$	$x^{R*}_{l,l,C}$	Conditions
1	1	1	1	1	1	1	$P^R(h,h,C) \leq \bar{p}_0$
2	0	1	1	1	1	1	$P^R(h,h,0) \leq \bar{p}_0$ *and* $P^R(h,h,C) > \bar{p}_0$
3	0	0	1	1	1	1	$P^R(l,h,C) \leq \bar{p}_0, P^R(h,h,0) > \bar{p}_0$ *and* $f_F(C) > f$ or $P^R(h,l,C) \leq \bar{p}_0, P^R(h,h,0) > \bar{p}_0$ *and* $f_F(C) < f$ or $P^R(l,h,C) = P^R(l,h,0) = P^R(h,l,C) = P^R(h,l,0) = p_0 \leq \bar{p}_0, P^R(h,h,0) > \bar{p}_0$ *and* $f_F(C) = f$
4	0	0	0	1	1	1	$P^R(l,h,0) \leq \bar{p}_0, P^R(l,h,C) > \bar{p}_0$ *and* $f_F(C) > f$
5	0	0	0	0	1	1	$P^R(h,l,C) \leq \bar{p}_0, P^R(l,h,0) > \bar{p}_0$ *and* $f_F(C) > f$
6	0	0	1	1	0	1	$P^R(l,h,C) \leq \bar{p}_0, P^R(h,l,C) > \bar{p}_0$ *and* $f_F(C) < f$
7	0	0	0	1	0	1	$P^R(l,h,0) \leq \bar{p}_0, P^R(l,h,C) > \bar{p}_0$ *and* $f_F(C) < f$
8	0	0	0	0	0	1	$P^R(l,l,C) \leq \bar{p}_0, P^R(l,h,0) > \bar{p}_0$ *and* $f_F(C) > f$ or $P^R(l,l,C) \leq \bar{p}_0, P^R(h,l,C) > \bar{p}_0$ *and* $f_F(C) < f$ or $P^R(l,l,C) \leq \bar{p}_0, P^R(l,h,C) = P^R(l,h,0) = P^R(h,l,C) = P^R(h,l,0) = p_0 > \bar{p}_0$ *and* $f_F(C) = f$
9	0	0	0	0	0	0	$P^R(l,l,C) > \bar{p}_0$

Table 1: Regulators' optimal decision to maintain or suspend authorization, $x^{R*}_{\sigma,\sigma_F,C}$.

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

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

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

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

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

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 $x^{F*}_{l,l,C} = 1$. When she receives other signals, we observe that its decision depends on the levels of precision of the exogenous and of the endogenous information she 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 she has received the signal h, and the more it is prone to maintain its product when she has receive the signal l. Finally, a higher discount rate β provide incentives to maintain the product.

Still at period 1, depending on the signals $\sigma \in \{l,h\}$ and $\sigma_F \in \{l,h\}$ and for given decisions $x^R_{\sigma,\sigma_F,C} \in \{0,1\}$ and $x^F_{\sigma,\sigma_F,C} \in \{0,1\}$, the firm has to decide whether to behave as a lobby, or not. Recall that adopting a lobby behavior consists in hiding any $\sigma_F = h$ signal that could lead the Regulator to withdraw the market authorization[8]. The firm

[8]That is, if the Regulator had knowledge of this signal, she would choose to withdraw the market authorization. However, if she has not this information, she still maintain the market authorization.

chooses to adopt a lobby behavior if its expected payoff by doing so is higher than when it does not. That is:

$$V_1(0, x^R_{\sigma,\sigma_F,C}, x^F_{\sigma,\sigma_F,C}, \sigma, \sigma_F, C) < V_1(1, x^R_{\sigma,\sigma_F,C}, x^F_{\sigma,\sigma_F,C}, \sigma, \sigma_F, C).$$

We then summarize the firm's optimal decision to stop or continue the sale of its product in Table 2.

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

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

Conditions under which the firm chooses to adopt a "lobby" behavior or a "non-lobby" behavior are given by the following proposition. We note

$$\bar{M} = \frac{x^F_{\sigma,h,C}(x^R_{\sigma,h,C} - x^R_{\sigma,h,0})(D - \beta(R_2 - E(\theta|(\sigma,h),C)(K - K'))}{\beta E(\theta|(\sigma,h),C)p_J}.$$

Proposition 2 *For $\sigma \in \{l,h\}$, $x^R_{\sigma,\sigma_F,C} \in \{0,1\}$, $x^F_{\sigma,\sigma_F,C} \in \{0,1\}$, and $C \geq 0$:*

1. *If $\sigma_F = l$, the firm always chooses to not adopt a lobby behavior, 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 not adopt a lobby behavior, i.e., $t^{F*} = 0$; if $M < \bar{M}$, then the firm always chooses to adopt a lobby behavior, 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, $P^R(H|(h,h),C)$ and $P^R(H|(l,h),C)$ are increasing with C, therefore $x^R_{\sigma,h,C} \leq x^R_{\sigma,h,0}$, that is $x^R_{\sigma,h,C} - x^R_{\sigma,h,0} \in \{-1,0\}$. A firm is therefore less prone to adopt a lobby behavior if: the amount of money, D, she can recover by stopping selling its product increases, the financial cost, K, when she continues to sell its product increases, the level of research, C, increases, and its belief being sentenced when she has chosen to adopt a lobby behavior, p_J, increases. On the other hand, she is more prone to adopt a lobby behavior: if the payoff, R_2, by continuing to sell its product increases, the financial cost, K', when she stops to sell its product increases, and the discount rate, β, increases.

In addition, Point 2 of Proposition 2 implies that the firm always chooses to not adopt a lobby behavior, i.e., $t^{F*} = 0$, for $\sigma = l$ under cases 1, 2, 3, 5, 6, 8, 9 and C, and for $\sigma = h$ under cases 1, 3, 4, 5, 6, 7, 8, 9, B, C and D. In all other the cases, this will depend on the value of M.

Finally, at period 0, the firm chooses the magnitude of the investment $C \geq 0$ that she will make for acquiring information. She chooses the level of C to maximize its expected payoff at period 0, that is:

$$\max_{C \geq 0} V_0(t^{F*}, x^{R*}, x^{F*}, C).$$

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.

4 Numerical Simulation

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 exogenous information precision f.

Parameter	*Value*
θ^H	0.8
θ^L	0.2
R_2	180
K	150
K'	20
D	80
β	0.9
f	0.75

From these specifications, we then obtain $\frac{\beta R_2 - D}{\beta(K-K')} \approx 0.7$. We consider that the firm's precision of the signal is represented by:

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

Then 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 $M \in \{50; 100; 150\}$. We first consider that the threshold belief defined with the help of scientists as associated with an acceptable risk to society is at $\bar{p_0} = 0.7$.

The determination of the private optimal investment C^* in research for information follows this process: first, among the different cases introduced in Table 1 and Table 2, we have to isolate the relevant cases (which depend on the values of exogenous parameters). Then, for each relevant case, we have to calculate the optimal level of investment. Finally, the optimal level of investment C^* is the one which provides the firm with the highest expected payoff V_0. Figures 1 and 2 represent the firm's optimal investment in research.

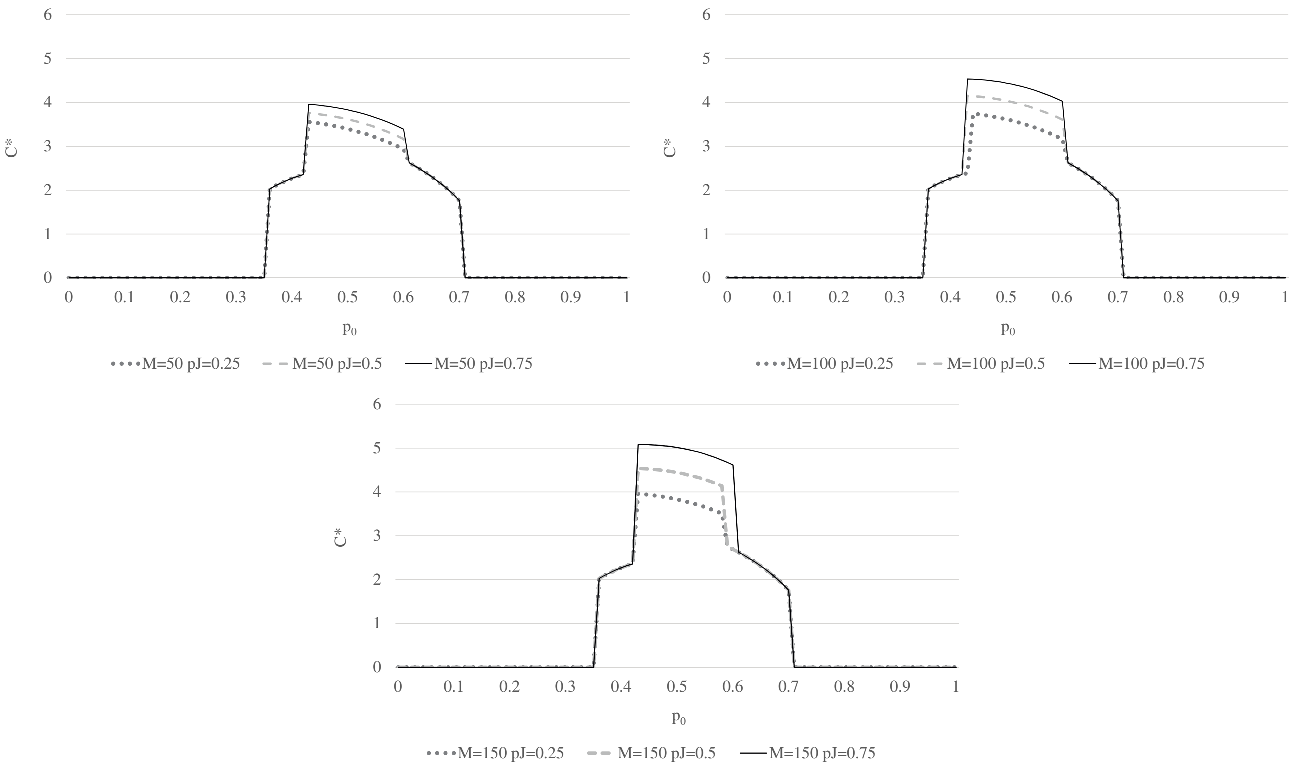

Figure 1: Firm's optimal investment in research, C^*. M is constant and p_J varies.

From Figure 1, we understand that the higher the probability of paying a fine (in the case where the firm adopts a lobby behavior), the higher the investment in research. Indeed, if the firm adopts a lobbying behavior, the greater the probability of being caught, the more she will seek to obtain a better signal precision to reduce its own uncertainty.

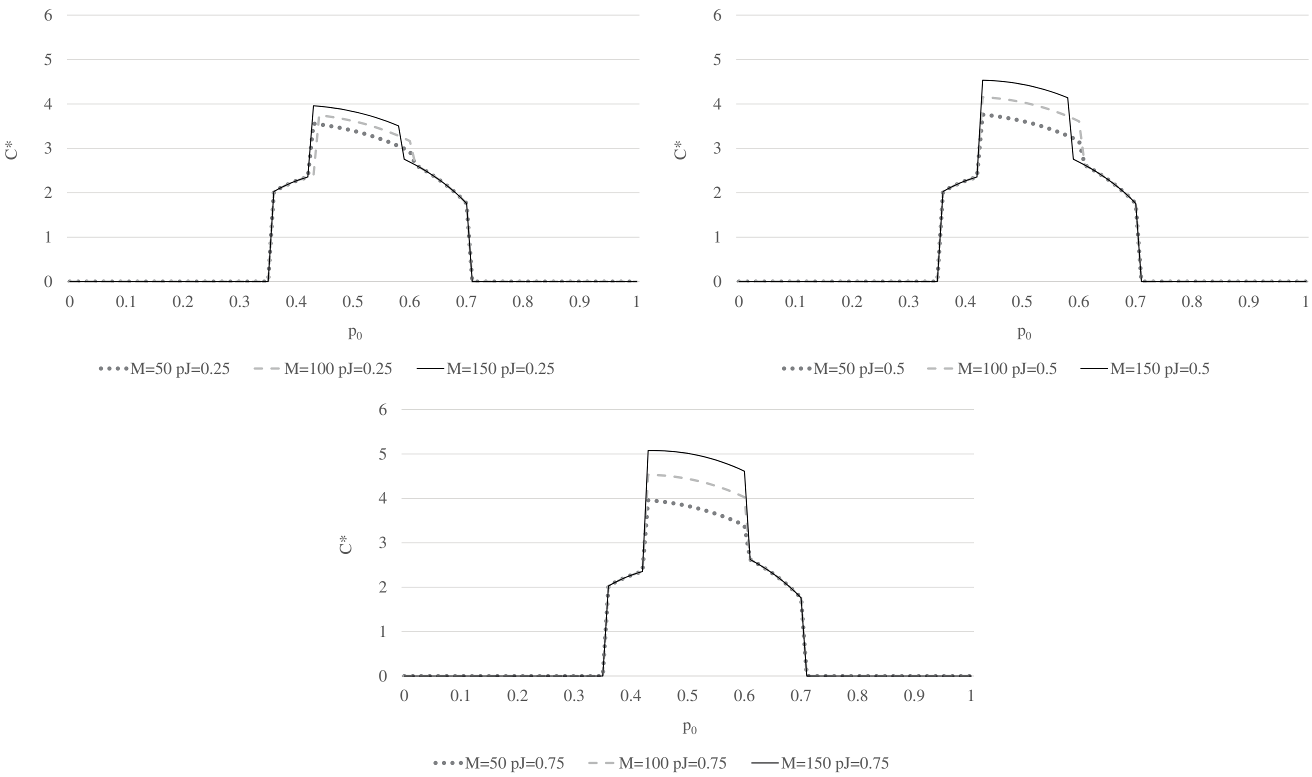

Figure 2: Firm's optimal investment in research, C^*. P_J is constant and M varies.

From Figures 1 and 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. Actually, if the firm perceives that the dangerousness is low, she does not see any interest to invest in research. On the other hand, if she perceives that the dangerousness is high, she knows that the regulator will remove the authorization and then does not make a supplementary expense in investing in research. We also observe that when the uncertainty is the highest, that p_0 is closed to 0.5, then the investment in research is the highest. The firm reduces the uncertainty on the dangerousness of its product.

Moreover, we can see that increasing the level expected fine (the level of the probability to pay a fine in case of lobby in Figure 1, the level of fine in Figure 2) leads the firm to increase its level of investment in research for information, for prior beliefs close to 0.5. Recall that the fine is paid only after an accident, in the case where it is proved that the firm has hidden a signal h. Hence, the highest the penalty for such a behavior, the highest the firm has an interest in reducing the uncertainty 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 she 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.

5 Conclusion

In this paper, we analyze the optimal regulator's and firm's decisions. We find the conditions for which the regulator decide to maintain or remove the authorization 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 study the optimal firm's investment in research to obtain more information on the dangerousness of the production. In particular, we clarify the effect of the penal liability on the firm's investment in research decision. Finally, this allow us to discuss about the role of the combination of the authorization process with civil and penal liabilities on the firm's decisions and the uncertainty reduction.

For further research, it would be interesting to analyze which cases are selected by the firm, when varying some parameters (and especially parameters which are decided by the public regulator: K', K and M. It also would have an interest to compare the endogenous and exogenous information precision (private and public research). Finally, introducing a solvability constraint for the firm would also be a track. 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.

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

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

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

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

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

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

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

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

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

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

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

■

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

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

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

The firm removes its product from the market if:

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

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

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

■

Proof of Proposition 2.

For $\sigma \in \{l, h\}$, $x^R_{\sigma,\sigma_F,C} \in \{0, 1\}$, $x^F_{\sigma,\sigma_F,C} \in \{0, 1\}$, and $C \geq 0$:

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

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

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

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

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

We note $\bar{M} = \frac{x^F_{\sigma,h,C}(x^R_{\sigma,h,C} - x^R_{\sigma,h,0})(D - \beta(R_2 - E(\theta|(\sigma,h),C)(K-K'))}{\beta E(\theta|(\sigma,h),C) p_J}$, 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 not adopt a lobby behavior, i.e., $t^{F*} = 0$; if $M < \bar{M}$, then the firm always chooses to adopt a lobby behavior, 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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