Norm Flexibility and Innovative Activity

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Abstract: Laws and enforcement may affect firms' innovative activity. We analyze optimal norm design when firms' innovation may be harmful to society. The legislator can set fines calibrated on social harm. Expected sanctions affect firms' choices among harmful actions (marginal deterrence) and/or stunt their innovative activity altogether (average deterrence). If enforcers are loyal, it is optimal to maximize the range of possible fines: the higher norm flexibility, the greater are both marginal and average deterrence. With unloyal enforcers, instead, a more rigid law is optimal, to prevent bribery and misreporting at the cost of reducing marginal deterrence and stunting innovation. The greater the potential corruption, the more rigid the optimal norms.

Keywords: norm design, innovative activity, enforcement, corruption.

JEL classification: D73, K21, K42, L51.

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1 Introduction

It is generally recognized that when private actions generate externalities, for instance in the form of diffuse social harm, public intervention can improve welfare. In this case, public policy must trade off the benefit of social harm reduction with enforcement and compliance costs, and possibly with the agency costs due to bureaucrats' self-serving behavior.

It is less frequently acknowledged that norms and their enforcement may have yet another cost: that of stifling private sector innovation that may open profit opportunities but entail risks for society, such as research and development (R&D) activity. The idea that public intervention may stifle valuable innovative activity dates back at least to the work of Friedrich Hayek (1935, 1940). But there is no formal analysis, to the best of our knowledge, of how the design and enforcement of norms should take into account the benefits and risks stemming from private innovative activity.

In this paper we inquire how the law should be designed when it may affect firms' effort to discover new technologies, as well as their actual use, once they are discovered. Uncertainty is a key aspect: not only innovative activity may fail, but even when successful its deployment may impact profits and welfare unpredictably. As a result, from the standpoint of a firm investing in innovation, the legal sanctions that it will eventually face are themselves uncertain. Regulators must take into account that the norm design and enforcement will affect both firms' initial research effort, and their subsequent choices if successful.

An obvious example arises in connection with R&D activity and scientific uncertainty: a biotech firm may either produce traditional seeds or research new genetically modified (GM) seeds that promise higher yields but pose unknown risks to public health, for instance causing allergies to consumers.

A second example refers to the introduction of new products in an uncertain market environment. For instance, a software developer may either market existing products or try to develop a new application tied to an operating system. Depending on the future market environment, the new software may benefit consumers (being more user-friendly) or induce market foreclosure. Which effect will prevail depends on the alternative products and firms that will be present on the market when the new software is introduced. Hence, apart from the strategic intentions of the software company regarding the possible effects of its new application, the actual effects of the innovation on market equilibrium will also depend on events that are out of the developer's control.

Yet another class of cases may occur in financial markets: financial innovation, such as the introduction of new instruments or markets, may create new profit opportunities for intermediaries as well as new hedging tools for investors, but may also create new dangers for uninformed investors who cannot master the information necessary to handle novel instruments or trade on new markets.

In each of these cases, public policy should design fines and enforcement so as to prevent the actions most harmful to society, while trying to preserve firms' incentives to innovate. The key instruments are the enforcement effort, that influences the probability of identifying illegal practices, and the fine schedule that relates fines to the social harm caused by such practices.

The expected sanctions will affect both firms' behavior if their research effort is successful, and the very resources that they invest in research. Otherwise stated, sanctions may induce firms to choose less harmful actions once they have innovated – the well-known *marginal deterrence* effect – and/or reduce the incentives to innovate, and thereby discourage any new action by the firm irrespective of its harmfulness – an effect that we label *average deterrence*. While marginal deterrence is always desirable and calls for more enforcement, average deterrence improves welfare only when social harm is sufficiently likely. When instead social harm is unlikely, average deterrence calls for lower enforcement, so as to avoid stifling innovation.

Indeed, we show that if the social risks stemming from private innovation are sufficiently remote, it is optimal to adopt a *laissez-faire* regime ("per-se legality rule"), where innovative activity is effectively free to unfold its effects. A *laissez-faire* regime is more likely to be optimal in this setting than in the traditional model where firms are not required to exert any learning effort before choosing their behavior. In this sense, when innovation is an important component of private activities, norms should be less interventionist.

Expected fines influence both marginal and average deterrence: the choice of an unlawful action depends on the shape of the fine schedule, and therefore on the range of feasible fines, while the expected fine determines the incentive to undertake innovative activity. In the extreme case of a *rigid* law that sanctions any unlawful action with the same fine, all marginal deterrence is lost, as successful innovators cannot be steered away from the most harmful actions. In this case, the law can bite only through its average deterrence, that is, by discouraging innovative activity per se. Conversely, if the law is *flexible* enough as to admit a wide range of fines, marginal deterrence can be extensively exploited by varying sanctions according to the harmfulness of unlawful behavior.

The optimal degree of flexibility of the law depends on the loyalty of enforcers. If enforcers can be trusted to be completely loyal, the legislator should choose the maximum degree of norm flexibility, so as to maximize marginal deterrence. When instead enforcers are unloyal and can be corrupted, the optimal design and enforcement of norms must take their incentives into account. Enforcement officials can extract a bribe from firms in exchange for misreporting their actions, leading to lower fines for noncompliers. In this case the legislator cannot simply rely on stiff fines to repress the most harmful actions, lest firms will circumvent them through bribes. In order to cope with bribery, the legislator must tolerate more harmful actions, leaving some rents to firms. This decreases marginal deterrence compared to the case where enforcers are loyal. To compensate this decrease in marginal deterrence, the legislator will have to rely more heavily on average deterrence by reducing the incentives to invest in innovative activity: when social harm is sufficiently likely, it is best to reduce flexibility, so as to discourage innovative activity altogether. Therefore, the more corruptible the enforcers, the more rigid the optimal norm: the range of fines decreases with the degree of enforcers' loyalty.

Our paper contributes to the literature on law enforcement, which concentrates on the marginal deterrence effect of enforcement (Stigler, 1970; Shavell, 1992; Mookherjee and Png, 1994, among others). As already mentioned, in our setting enforcement also has an average deterrence effect, insofar as it reduces the probability of innovation. This effect arises because in our model the set of possible actions is not exogenously given, as traditionally assumed, but depends on the private decision to innovate.[1] In this respect, our setting is reminiscent of the contract theory model by Aghion and Tirole (1997), where the effort of the principal depresses the initiative of the agent: similarly, in our setting enforcement by officials discourages innovation by firms. The difference is that in our model the principal's effort cannot directly substitute for the firm's innovative activity: the legislator cannot itself undertake R&D.

Our model also shares some elements with the "activity level" model of law enforcement (Shavell, 1980 and 2006; Polinsky and Shavell, 2000).[2] In this approach, private benefits and social harm depend on two different decisions by agents – an activity level (say, how long an individual drives a car) and a level of precaution (driving speed) – and the analysis typically compares the effects of different liability rules (strict versus fault-based liability). Innovative activity is reminiscent of the activity level, while the choice of new actions parallels the choice of precaution. But our information structure differs from that of these models: in our setting, innovative activity is chosen before the state of the world is known, so that uncertainty about the harmfulness of innovation plays an important role in the design of

[1] To our knowledge, Kaplow (1995) is the only other paper where the design of the law affects agents' learning decisions. In his setting, more complex rules allow better control over individual behaviour but are harder for people to understand ex ante and for courts to apply ex post. In his setting, individuals can choose not to learn, and take actions ignoring the associated effects (and fines). Our model differs from his in that new actions can be taken only upon learning. Moreover, our notion of norms' flexibility refers to the ability to fine-tune sanctions to actions, while Kaplow's notion of norms' complexity refers to the detail in the description of what is lawful or not.

[2] Seminal contributions on optimal law enforcement are Becker (1968), Becker and Stigler (1974), Polinsky and Shavell (2000 and 2001) and Shavell (1993).

norms and in enforcement activity; in contrast, in the "activity level" model uncertainty plays no role.

As argued above, we also address the issue of the optimal degree of flexibility of the law. This is a mute issue in the traditional analysis of enforcement, where maximum flexibility is always desirable, as it enhances marginal deterrence. We show that this result holds under loyal enforcement, while restricting flexibility may be efficient when there are agency problems in enforcement. This echoes another result in contract theory, namely the finding by Tirole (1986) that collusion blunts the principal's ability to discipline agents. In his analysis of a three-tier contracting relation between a principal, a supervisor and an agent, Tirole shows that the optimal contract offers low-powered incentives to the agent to prevent him from colluding with the supervisor. Laffont and Tirole (1993, Chapter 11) make a similar point in the context of the regulation of industry.

Finally, the paper contributes to the literature on public intervention in the presence of market failures, which highlights that intervention should be curtailed if its enforcement is very costly or generates bribery (Krueger, 1974; Rose-Ackerman, 1978; Banerjee, 1997; Acemoglu and Verdier, 2000; Glaeser and Shleifer, 2003; Immordino and Pagano, 2005, among others). However, this literature neglects the effect of norms on innovative activity.

Our paper is organized as follows. Section 2 presents the model. Section 3 analyzes the case of loyal officials, and Section 4 that of unloyal officials. Section 5 concludes.

2 The model

We consider a model with a profit-maximizing firm, a benevolent legislator and – for the time being – a loyal enforcer. The firm can either choose one among several known and lawful actions, or invest in learning how to carry out new actions, whose private and social effects are unknown *ex ante*. For instance, a biotech firm may either produce traditional seeds or experiment with a new GM seed that promises higher yields but poses unknown risks to public health.

The legislator may constrain the firm's operations by legal norms and associated penalties. To maximize social welfare, he must take into account the tradeoff between the social dividend arising from the firm's innovations (a larger harvest, in the previous example) and the potential social damage stemming from them (a public health hazard). The key issue that we wish to explore is how this tradeoff shapes the optimal design of legal norms and their enforcement.

The firm can choose the *status-quo* action a_0 (planting traditional seeds) with associated profits Π_0 and welfare W_0. Action a_0 is the most profitable of feasible legal actions.

Alternatively, the firm can consider a set of new actions $A = [\underline{a}, \overline{a}]$, with associated profit $\Pi(a) \in [\underline{\Pi}, \overline{\Pi}]$ that is differentiable, increasing and concave in $a \in A$.

Depending on the state of nature s, the social consequences of new actions are described by one of two different functions. With probability $1 - \beta$, a good state g occurs, where new actions improve welfare, according to an increasing function $W = W(a)$ such that $W(\underline{a}) \geqslant W_0$ and $W(\overline{a}) \equiv \overline{W}$. In this state, there is no conflict between private and social incentives, since $\Pi'(a) > 0$ and $W'(a) > 0$. With probability β, instead, a bad state b occurs, where new actions have a negative social externality and welfare is described by a decreasing function $W = w(a)$ such that $w(\underline{a}) \leqslant W_0$ and $w(\overline{a}) \equiv \underline{W} < \overline{W}$, with $w''(a) \leqslant 0$. In this case, private incentives conflict with social welfare since $\Pi'(a) > 0$ but $w'(a) < 0$. Nature chooses which state of the world occurs; hence, the probability β of the bad state is an *ex-ante* measure of the misalignment between public interest and firms' objectives.[3] In our example, β is the prior probability that the GM seeds will be hazardous to public health.

The firm knows from the beginning how to carry out the *status quo* action a_0. In contrast, carrying out any new action requires innovative activity (experiments with GM seeds). If the investment is successful, the firm will discover how to carry out the new actions $A = [\underline{a}, \overline{a}]$. In this case, the firm also learns the state of nature, that is whether its innovation is socially harmful. Proceeding with our example, the biotech company learns not only how to produce new GM seeds, but also the dangers that they pose to public health.

The amount of resources I that the firm invests in learning determines its chances of success: for simplicity, the firm's success probability $p(I)$ is assumed to be linear in I, i.e. $p(I) = I$ with $I \in (0, 1]$. The cost of learning is increasing and convex in the firm's investment. For concreteness we assume

$$c(I) = c\frac{I^2}{2}$$

with $c > \overline{\Pi} - \Pi_0$ to ensure an internal solution.

The design and enforcement of norms are chosen as follows. The legislator writes the norm, which specifies legal and unlawful actions and the fines to be inflicted. Enforcement officials seek evidence on noncomplying firms and report it to the judges (or authority commissioners) who apply the norm. Since we are assuming that judges never make errors, their decisions are completely dependent on the evidence that the officials report. Moreover, in the benchmark model we assume that officials are loyal and report all the collected

[3] A more complex setting can be imagined, in which social harm arises only over a subset of the new actions in A, so that even in the bad state not all the projects are socially harmful. This extension would complicate the analysis without adding any substantive result.

evidence. For this reason, in the benchmark model, norm design and enforcement are entirely chosen by the legislator, since neither officials nor judges have any real decision to take. However, in Section 4, the role of unloyal officials will be explicitly considered when we analyze the case in which they try to exploit their discretionary power.

The norm written by the legislator specifies how to distinguish between legal and illegal actions, and how the latter are punished. Technological constraints and social norms determine the maximum feasible range of fines, $[F_{\min}, F_{\max}]$, within which the legislator chooses a lower bound $\underline{F}$ and a higher bound $\overline{F}$.[4] The smaller the range of fines $\left[\underline{F}, \overline{F}\right]$ allowed by the law, the lower the flexibility in setting actual fines. The norm is assumed to be written as follows:

> The action $a \in A$ is illegal if it causes social harm relative to the *status quo*, $W_0 - w(a)$. Illegal actions are sanctioned according to a fine schedule $F(w(a))$ that is chosen in the interval $\left[\underline{F}, \overline{F}\right] \subset [F_{\min}, F_{\max}]$ and is non-decreasing in social harm.

Therefore, norms are effect-based, in that they punish only actions that are *ex-post* socially damaging and in proportion to the harm they cause.[5]

The legislator sets not only the level of fines but also the amount of resources E devoted to detecting non-complying firms (for instance, the budget allocated to the environmental or health protection agency). These resources determine the probability $q(E)$ that the enforcer correctly identifies the action chosen by the firm and learns its social consequences W, and therefore its lawfulness. For simplicity, we assume the probability $q(E)$ to be linear in E, namely $q(E) = E$. The cost of the enforcement effort is convex, implying decreasing returns to enforcement: $g' > 0$ and $g'' > 0$ for $E \in (0, 1]$, with $g(0) = g'(0) = 0$ and $\lim_{E \to 1} g(E) = \lim_{E \to 1} g'(E) = \infty$. With probability $1 - q(E)$, the authority's investigation does not unearth enough evidence to inflict any fine on the firm.

The timing of the model is described in Figure 1. At time 1, the legislator writes the norm, which determines the lower bound $\underline{F} \in \left[F_{\min}, \overline{F}\right]$, the higher bound $\overline{F} \in [\underline{F}, F_{\max}]$, and the fine schedule $F(a) \in \left[\underline{F}, \overline{F}\right]$. It also allocates the resources E to enforcement.

[4] The common wisdom among lawyers is that $F_{\min} > 0$, meaning that illegal actions must be punished. But in principle the legislator may wish to abstain from punishing or subsidize certain illegal actions, as in the case of leniency programs for "whistleblowers" in antitrust enforcement (Motta and Polo, 2003).

[5] For a discussion on an effect-based interpretation of antitrust norms, see Gual *et al.* (2005). Throughout the paper we adopt a notion of illegality based on *ex-post* social harm. All our results, however, can be obtained even assuming a more formalistic definition of unlawfulness, as for instance when an action is recognized as illegal only if a certain contingency is observed. For instance, a certain GM seed is prohibited if it contains genes from animal species. This setting would be equivalent to ours provided the elements that identify unlawful actions are not yet observed when innovative investment is chosen.

At time 2, the firm, knowing the norm and the enforcement level, chooses its innovative activity I and learns the state of the world and the technology to carry out new actions with probability $p(I) = I$. At time 3, the firm chooses an action, conditional on what it learnt in the previous stage. Finally, at time 4 actions produce their private payoffs Π and their social effects W; enforcement officials collect evidence with probability $q(E) = E$ and report it to judges, who set the actual fines.

[Insert Figure 1]

Finally, we assume the following ranking among payoffs:

$$\overline{W} - W_0 > \overline{\Pi} - \Pi_0 > F_{\max}. \tag{1}$$

The first inequality implies that in the good state, social gains exceed private ones, or, equivalently, that new actions in good state increase consumer surplus as well as producer surplus. The last inequality says that the maximum payoff from innovative activity exceeds the maximum feasible fine even when this is inflicted with certainty. According to this assumption, we focus our analysis on the case of incomplete deterrence, that is, firms always prefer to take some unlawful action if they learn how to take it.

3 Loyal officials

We now proceed to analyze the equilibrium of the game in the benchmark case where enforcement officials are loyal in reporting the collected evidence. We solve the game backwards, starting from the last stage, in which the firm chooses its action.

3.1 Firm actions

The choice of actions at stage 3 depends on whether the firm's innovative activity is successful or not, and on the fine schedule $F(a)$ designed by the legislator.[6] When the innovative activity is unsuccessful, under our assumptions the firm is unable to implement any new action and therefore chooses the *status-quo* action a_0. When instead the innovative activity is successful, the firm can take new actions $a \in A$. If these are not socially harmful ($s = g$), all of them are lawful, so that the firm chooses the profit-maximising action $\overline{a}$, which also yields the maximum welfare $\overline{W}$. If instead the new actions produce a negative externality ($s = b$), and therefore are unlawful, under the incomplete deterrence assumption (1) the firm chooses the unlawful action that maximizes its profits, net of the expected fine.

[6] With a slight abuse of notation, from here onwards we replace $F(w(a))$ with $F(a)$.

Then, given the fine schedule $F(a)$, the firm will select the action

$$\widehat{a} = \arg\max_{a \in A} [\Pi(a) - EF(a)]$$

The features of the optimal fine schedule will be analyzed later on, when optimal policy design will be considered. We summarize the above discussion in the following Lemma:

Lemma 1 (Optimal actions) *At stage* 3*, given* E *and* $F(a)$*, the firm chooses:*

- a_0 *if learning is unsuccessful;*
- $\overline{a}$ *if learning is successful and new actions are not socially harmful (*$s = g$*);*
- $\widehat{a}$ *if learning is successful and new actions are socially harmful (*$s = b$*).*

3.2 Firm innovative activity

At stage 2 the firm chooses its innovative activity I so as to maximize its expected profits, given the optimal actions that it will select at stage 3. In terms of our example, the biotech firm decides how much to invest in R&D on GM seeds, taking into account which seeds it will produce and market if its R&D effort is successful. Its expected profits at this stage are:

$$\mathrm{E}(\Pi) = \Pi_0 + I \left\{ \beta[\Pi(\widehat{a}) - EF(\widehat{a})] + (1-\beta)\Pi(\overline{a}) - \Pi_0 \right\} - c\frac{I^2}{2}, \tag{2}$$

where the first term is the *status-quo* profit, the second is the expected gain from innovative activity (net of expected fines) and the third is the cost of innovative activity.[7] Therefore:

Lemma 2 (Optimal innovative activity) *At stage* 2*, given* E *and* $F(a)$*, the optimal level of innovative activity is:*

$$\widehat{I} = (\beta[\Pi(\widehat{a}) - EF(\widehat{a})] + (1-\beta)\Pi(\overline{a}) - \Pi_0)/c.$$

Proof. The result follows immediately from the first order condition:

$$\beta[\Pi(\widehat{a}) - EF(\widehat{a})] + (1-\beta)\Pi(\overline{a}) - \Pi_0 - c\widehat{I} = 0, \tag{3}$$

where the second order condition is obviously satisfied. ■

[7] The second term is always positive, by equation (1): incomplete deterrence implies that the firm always gains from initiative.

3.3 Norm design

We now turn to the analysis of the design and enforcement of norms at stage 1. In our setting, judges do not make errors given the evidence provided, and enforcement officials are loyal, reporting all the evidence they obtain. Hence, enforcement depends only on the resources E that the legislator assigns and on the available evidence, with no discretionary role for judges and officials. The focus of the analysis is therefore on the legislator's choices.

The legislator influences the firm's behavior in two ways: by affecting the selection of the action a in case of successful learning, and by influencing the incentives to pursue innovative activity I. The first effect, well known in the literature on law enforcement, captures *marginal deterrence*, that is, the law's ability to guide private choices among unlawful actions.[8] The second effect, which is not considered in traditional models of law enforcement, derives from the impact of norms on innovative activity and therefore on the probability that any new action a will be taken. We label this second effect *average deterrence*. The legislator sets the policy parameters considering both effects on private choices and, ultimately, on welfare.

Starting with the marginal deterrence problem, the legislator will set the fine schedule so as to elicit the lowest possible $\widehat{a}$, since in general $w(\widehat{a}) \geqslant \underline{W}$ and $w' < 0$. For instance, the environmental agency will induce firms to opt for the safest type of GM seeds among those that they are willing to produce. Since the profit function $\Pi(a)$ is increasing, it is easy to show that, within the non-decreasing fine schedules, one can focus on stepwise functions such as:

$$F(a) = \begin{cases} \underline{F} & \text{if } a \leqslant \widetilde{a} \\ \overline{F} & \text{if } a > \widetilde{a} \end{cases}$$

We rely on Figure 2 to illustrate this point. The function $F(a)$ shifts the profit function $\Pi(a)$ downward by $\underline{F}$ to the left of point $\widetilde{a}$, and by $\overline{F}$ to its right, creating a local maximum at $\widetilde{a}$. The legislator wants to induce the firm to choose $\widetilde{a}$, by making it a global maximum of the profit function, i.e. $\widetilde{a} = \widehat{a}$. This requires:

$$\Pi(\widetilde{a}) - E\underline{F} \geqslant \Pi(\overline{a}) - E\overline{F}.$$

Moreover, among the global maxima $\widehat{a}$ the legislator will pick the lowest action $\underline{\widehat{a}}$, in order to minimize social harm. Therefore $\underline{\widehat{a}}$ is the implemented action, implicitly defined by

$$\Pi(\underline{\widehat{a}}) - E\underline{F} = \Pi(\overline{a}) - E\overline{F}, \tag{4}$$

or

$$\underline{\widehat{a}} = \Pi^{-1}[\Pi(\overline{a}) - E(\overline{F} - \underline{F})], \tag{5}$$

[8] See the seminal work by Stigler (1970) and, for a more general treatment, Mookherjee and Png (1994).

as illustrated by Figure 2.

[Insert Figure 2]

The figure also helps understanding why there is not a unique non-decreasing fine schedule $F(a)$ capable of inducing the action $\underline{\widehat{a}}$: any such function that penalizes action $\underline{\widehat{a}}$ with $\underline{F}$ and action $\overline{a}$ with $\overline{F}$ will induce the same choice. For example, this is also true of a schedule that punishes actions below $\underline{\widehat{a}}$ with $\underline{F}$ and those above it with a penalty that makes expected profits constant.

Equation (5) shows that the marginal deterrence of the law can be increased both by enforcement and by norm flexibility, as measured by the permitted range of fines: higher enforcement E allows the legislator to implement a less damaging action $\underline{\widehat{a}}$:

$$\frac{\partial \underline{\widehat{a}}}{\partial E} = -\Pi^{-1\prime}[.](\overline{F} - \underline{F}) \leqslant 0, \tag{6}$$

and so does a wider range of fines:

$$\frac{\partial \underline{\widehat{a}}}{\partial \underline{F}} = \Pi^{-1\prime}[.]E \geqslant 0, \qquad \frac{\partial \underline{\widehat{a}}}{\partial \overline{F}} = -\Pi^{-1\prime}[.]E \leqslant 0. \tag{7}$$

Substituting equation (4) in expression (2) yields the profit that the firm expects to earn at stage 2:

$$\mathrm{E}(\Pi) = \Pi_0 + I[\overline{\Pi} - \Pi_0 - \beta E\overline{F}] - c\frac{I^2}{2}.$$

From this, the optimal investment in innovation is seen to be:

$$\widehat{I} = \frac{\overline{\Pi} - \Pi_0 - \beta E\overline{F}}{c}, \tag{8}$$

which is decreasing both in the enforcement effort E and in the higher bound $\overline{F}$:

$$\frac{\partial \widehat{I}}{\partial E} = -\frac{\beta\overline{F}}{c} \leqslant 0, \quad \frac{\partial \widehat{I}}{\partial \overline{F}} = -\frac{\beta E}{c} \leqslant 0.$$

This is reminiscent of a result in contract theory proved by Aghion and Tirole (1997): the effort of the principal is a strategic substitute for that of the agent, if both efforts can concur to the solution of a decision problem. Likewise, here enforcement by officials depresses innovative activity by firms. Differently from Aghion and Tirole (1997), in our setting enforcement effort cannot directly substitute for the firm's innovative activity.

To characterize optimal norm design and enforcement, we proceed through three steps: (i) how enforcement E affects welfare; (ii) how the legislator chooses the optimal fines $\overline{F}$ and $\underline{F}$; and (iii) how the optimal policy changes in response to a variation in the likelihood of social harm, β.

Expected welfare, conditional on the firm choosing the optimal innovative activity and implementable action, is

$$\mathrm{E}(W) = W_0 + \widehat{I}(E, \overline{F})[\beta w(\underline{\widehat{a}}(E, \overline{F}, \underline{F})) + (1-\beta)\overline{W} - W_0] - [g(E) + c(\widehat{I}(E, \overline{F}))],$$

where the first term is the *status-quo* welfare level, the second term

$$\Delta\mathrm{E}(\widehat{W}) \equiv \beta w(\underline{\widehat{a}}) + (1-\beta)\overline{W} - W_0$$

is the expected welfare gain (or loss) stemming from innovative activity, and the last term captures the public and private costs of innovative activity. The optimal enforcement E^* is given by the legislator's first-order condition:[9]

$$\frac{\partial \mathrm{E}(W)}{\partial E} = \underbrace{[\Delta\mathrm{E}(\widehat{W}) - c\widehat{I}]\frac{\partial \widehat{I}}{\partial E}}_{\text{average deterrence } (+/-)} + \underbrace{\widehat{I}\beta w' \frac{\partial \underline{\widehat{a}}}{\partial E}}_{\text{marginal deterrence } (+)} - g' = 0. \quad (9)$$

This derivative has a nice interpretation. The first term captures the *average deterrence* of enforcement – the extent to which E discourages innovative activity and reduces the probability of any new action, irrespective of its social harmfulness. Indeed, this effect can be positive or negative, depending on whether innovative activity has a positive or negative marginal social value $\Delta\mathrm{E}(\widehat{W}) - c\widehat{I}$.[10]

The second effect, instead, captures the *marginal deterrence* of enforcement – the extent to which enforcement affects the specific choice of actions when the latter are socially harmful (which occurs with probability $\widehat{I}\beta$). In contrast with average deterrence, the effect of marginal deterrence is always positive, because in the bad state welfare is assumed to be decreasing in the firm's actions ($w' < 0$) and the latter are curtailed by enforcement activity ($\partial\underline{\widehat{a}}/\partial E < 0$).

The last term of condition (9) is the marginal cost of deterrence. In an interior solution the optimal enforcement level equates the sum of average and marginal deterrence to its marginal cost. When innovative activity is socially valuable, i.e. $\Delta\mathrm{E}(\widehat{W}) - c\widehat{I} > 0$, average deterrence calls for lower enforcement while marginal deterrence calls for higher enforcement.

[9] The second derivative is negative:

$$\frac{\partial^2 \mathrm{E}(W)}{\partial E^2} = -c\left(\frac{\partial \widehat{I}}{\partial E}\right)^2 + 2\beta w' \frac{\partial \underline{\widehat{a}}}{\partial E}\frac{\partial \widehat{I}}{\partial E} + \widehat{I}\beta w' \frac{\partial \underline{\widehat{a}}^2}{\partial E^2} + \widehat{I}\beta w'' \frac{\partial \underline{\widehat{a}}^2}{\partial E^2} - g'' < 0.$$

In fact $w' < 0$ and $w'' \leqslant 0$ when the externality arises and $\frac{\partial \underline{\widehat{a}}^2}{\partial E^2} \geqslant 0$ thanks to $\Pi'' \leqslant 0$.

[10] If $\beta = 0$, then $\Delta\mathrm{E}(\widehat{W}) - c\widehat{I} = \overline{W} - W_0 - (\overline{\Pi} - \Pi_0) > 0$ by assumption (1). If instead $\beta = 1$, then $\Delta\mathrm{E}(\widehat{W}) - c\widehat{I} = w(\underline{\widehat{a}}) - W_0 - c\widehat{I} < 0$, because even the least damaging action $\underline{a}$ reduces welfare below the *status quo*: $w(\underline{a}) \leqslant W_0$ by assumption.

When instead innovative activity is socially valuable, i.e. $\Delta\mathrm{E}(\widehat{W}) - c\widehat{I} < 0$, the enforcer faces a tradeoff: in setting the enforcement effort, the benefit of innovative activity must be balanced with the risk it entails. This is reminiscent of the Hayekian idea that if innovation is expected to be welfare-enhancing, public intervention must be moderated to preserve private incentives.[11] When instead innovative activity is socially harmful, both average and marginal deterrence require higher enforcement.

We now turn to the second step of our normative analysis. The following Lemma (proved in the Appendix) identifies the optimal fines:

Lemma 3 (Maximum flexibility) *The optimal fines are* $\underline{F} = F_{\min}$ *and* $\overline{F} = F_{\max}$.

Choosing the widest possible range of fees $[\underline{F}, \overline{F}]$ is optimal as it maximizes marginal deterrence: according to (5), the implementable action $\widehat{\underline{a}}$ depends on $E(\overline{F} - \underline{F})$. This does not come at the expense of average deterrence: as shown by (8), the innovative effort $\widehat{I}$ depends on $E\overline{F}$. When enforcement E^* is positive, the legislator will always set the lower and higher bounds of the fine schedule at the extreme feasible levels, so as to achieve marginal deterrence with minimum enforcement. This allows the legislator to save on resources devoted to enforcement, as in Becker (1968). Average deterrence, instead, is unaffected by changes in the low penalty $\underline{F}$.[12] It may appear surprising that, when the marginal social value of innovative activity is positive, it is optimal to set the maximum fine at the highest possible level. This apparent paradox is explained by the legislator's ability to correct the disincentive effect of a larger fine with a lower enforcement intensity E^*.

We conclude the normative analysis by considering how the optimal policy changes with β, the probability that innovation is socially harmful. To this purpose, denote by β_0 the probability that calls for no enforcement ($E^* = 0$):

$$\beta_0(E = 0, \underline{F} = F_{\min}, \overline{F} = F_{\max}) : -[\Delta E(\widehat{W}) - c'(\widehat{I})]\frac{\partial \widehat{I}}{\partial E} = \widehat{I}\beta_0 w' \frac{\partial \widehat{\underline{a}}}{\partial E}. \tag{10}$$

Then, as shown in the Appendix:

[11] Intuitively, the tradeoff arises from the fact that the regulator has too few instruments to influence firm's choices of innovation and actions: indeed one can show that the tradeoff disappears if the regulator is free to subsidize socially beneficial actions beside punishing socially harmful ones. (We thank Franck Portier for raising this point.) In our setting, we assume that such subsidies are unavailable either because of their budgetary costs or because they might create incentive for corrupt behavior by enforcers.

[12] To understand why changes in the low fine leave average deterrence unaffected, consider that if the lower bound $\underline{F}$ is changed the implemented action $\widehat{\underline{a}}$ adjusts, leaving the innovating firm's expected profits unchanged (and equal to its "outside option" $\overline{\Pi} - E\overline{F}$). Hence, reducing the lower bound $\underline{F}$ comes together with a less profitable (lower) implemented action $\widehat{\underline{a}}$, leaving net expected profits and the incentives to exert initiative unchanged.

Lemma 4 (Optimal enforcement) *The optimal enforcement level E^* is zero if $\beta \in [0, \beta_0]$ and it is positive if $\beta \in (\beta_0, 1]$.*

When social harm is very unlikely, i.e. $\beta \in [0, \beta_0]$, even if welfare-reducing actions in A were outlawed, it would be optimal not to enforce their prohibition: $E^* = 0$. Anticipating this, it is optimal to treat any action in A as legal ("laissez faire" or "per-se legality rule"). When instead the innovation is sufficiently likely to be harmful to society ($\beta \in (\beta_0, 1]$), then enforcement must be positive: $E^* > 0$.

The following proposition summarizes the optimal design of norms characterized so far:

Proposition 1 (Optimal policy) *If $\beta \in [0, \beta_0]$, laissez faire is optimal: $E^* = 0$. If social harm is more likely ($\beta \in (\beta_0, 1]$), then the legislator must choose the most flexible fine schedule ($\underline{F} = F_{\min}, \overline{F} = F_{\max}$) and enforcement $E^* > 0$, so as to implement the action $\widehat{\underline{a}} \in (\underline{a}, \overline{a})$.*

3.4 Comparison with the first best

The first-best outcome provides a useful benchmark for the previous results. In the first best, the legislator would control firms' choices directly without bearing enforcement costs ($E = 0$). The welfare-maximizing action is $\overline{a}$ in the good state and a_0 in the bad state, so that expected welfare is

$$\mathrm{E}(W) = W_0 + I(1-\beta)(\overline{W} - W_0) - c\frac{I^2}{2}.$$

The first-order condition with respect to I yields the first-best investment

$$\widehat{I}^{FB} = \frac{(1-\beta)(\overline{W} - W_0)}{c}, \tag{11}$$

which exceeds the equilibrium investment $\widehat{I}(E, \overline{F})$ derived in (8) if the bad state is very unlikely (β close to 0).[13] The reason is that firms disregard the social benefits of innovative activity, which in this case exceed its private ones. By the same token, if the bad state is very likely (β close to 1) we obtain overinvestment: $\widehat{I}^{FB} < \widehat{I}$, since in this case social benefits are below private ones. Hence, our model produces underinvestment or overinvestment depending on the likelihood of social harm.

3.5 Comparison with the traditional model

It is interesting to compare the results obtained so far with a setting where firms could implement the actions in A without any investment in learning, as in the traditional model of

[13] To show this, recall that $\overline{W} - W_0 > \overline{\Pi} - \Pi_0 > \overline{F}$ by assumption.

law enforcement, where the choice between actions requires no previous innovative activity. Such a firm would choose the same actions that, according to Lemma 1, it chooses under successful learning: $\underline{\widehat{a}}$ if the innovation is socially harmful and $\overline{a}$ otherwise. In this setting, social welfare would be

$$\mathrm{E}(W) = [\beta w(\underline{\widehat{a}}(E, \underline{F}, \overline{F})) + (1-\beta)\overline{W}] - g(E),$$

and therefore optimal enforcement would be given by[14]

$$\frac{\partial \mathrm{E}(W)}{\partial E} = \underbrace{\beta w' \frac{\partial \underline{\widehat{a}}}{\partial E}}_{\text{marginal deterrence } (+)} - g' = 0.$$

In this case regulation affects private incentives only through marginal deterrence, and enforcement is always positive if the probability β of a social harm is positive: since $g'(0) = 0$, it is evident that $E^* > 0$ for $\beta \in (0, 1]$. Moreover, maximum flexibility is optimal also in this case: $\underline{F} = F_{\min}$ and $\overline{F} = F_{\max}$, because

$$\frac{\partial \mathrm{E}(W)}{\partial \overline{F}} = \widehat{I}\beta w' \frac{\partial \underline{\widehat{a}}}{\partial \overline{F}} > 0$$

and

$$\frac{\partial \mathrm{E}(W)}{\partial \underline{F}} = \widehat{I}\beta w' \frac{\partial \underline{\widehat{a}}}{\partial \underline{F}} < 0.$$

The following Lemma states the different scope of "per-se legality rules" in the two cases:

Lemma 5 (Optimality of laissez faire) *If the new actions A can be chosen without exerting any innovative activity, then laissez-faire is optimal only if no social harm can occur ($\beta = 0$). If instead new actions require innovative activity, then laissez-faire is optimal also when social harm occurs with a positive although small probability ($\beta \in [0, \beta_0]$).*

[Insert Figure 3]

Figure 3 summarizes how the optimal policy changes with the probability of the bad state, β, in our model and in the traditional one. The comparison helps to understand the role of innovative activity in shaping public intervention: when private investment in learning and innovation is an important piece of the story, it is optimal to limit the intervention by opting for *laissez-faire* in a wider set of circumstances ($\beta \in [0, \beta_0]$). When innovative activity is sufficiently likely to lead to a social gain, it is worth forgoing marginal deterrence so as to encourage it.

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[14] The second derivative is negative:

$$\frac{\partial^2 \mathrm{E}(W)}{\partial E^2} = \alpha w' \frac{\partial \underline{\widehat{a}}^2}{\partial E^2} + \alpha w'' \frac{\partial \underline{\widehat{a}}}{\partial E} - g'' < 0.$$

In fact $w' < 0$ and $w'' \leqslant 0$ when the externality arises and $\frac{\partial \underline{\widehat{a}}^2}{\partial E^2} \geqslant 0$ thanks to $\Pi'' \leqslant 0$.

4 Unloyal officials

In the setting considered so far, enforcement officials collect evidence on the firms' conduct and on the welfare effects of their actions, truthfully reporting these facts to a judge who decides on the penalty according to a given fine schedule. Since enforcement officials can always be trusted to report their evidence truthfully, we have analyzed policy design without distinguishing between legislator and enforcers.

In this section, instead, we consider the agency problems that may arise in enforcement, by exploring how the design and enforcement of norms is affected when enforcement officials are self-interested and uncommitted to truthful reporting. We denote the official's report on the firm's action by $r = r(a) \in A$. We maintain the previous setup, assuming that the legislator chooses both the enforcement effort E (the resources of the agency), the range of fines $\left[\underline{F}, \overline{F}\right]$ within the admissible range $[F_{\min}, F_{\max}]$ and a (weakly) increasing fine schedule. The fine inflicted to the firm depends on the reported action r, that is $F(r) \in \left[\underline{F}, \overline{F}\right]$. This notation encompasses the case of loyal officials examined in previous sections as a special case where $r = a$, so that $F = F(a)$.

When officials are self-interested, they may extract rents from firms to misreport evidence about their conduct. By misreporting the firms' true actions, they can let the firm pay a lower fine than the statutory one in exchange for a bribe. More specifically, we assume that while the judge can directly recognize the lawful action a_0, he cannot distinguish among the new actions $a \in A$ and has to rely on the report r by the enforcement official. The latter cannot misreport the true state of nature s, but only the action taken by the firm: in other words, the enforcer can lie on the finer pieces of information but not on the bolder ones. Moreover, we assume that he cannot submit a false report $r \neq a$ that damages the firm: if he did, the firm would be able to rebut the false report by providing counter evidence. This "no blackmail" assumption implies that, if there is social harm, the official cannot report an offence that is more serious than the real one, i.e. an action $r > a$.

He can however report information that is more favorable to the firm. When he discovers that the firm's innovation is socially harmful, the official reports an action $r < a$ (less severely sanctioned than the actual one) if he is offered a bribe B greater than a minimum bribe $\underline{B} \geqslant 0$. Otherwise, he reports truthfully. The "reservation bribe" $\underline{B}$, which will turn out to be a key parameter in the analysis, can be regarded as a measure of the honesty of the official. We shall concentrate on the interesting case where $\underline{B} \leqslant F_{\max} - F_{\min}$: if this restriction were not to hold, $\underline{B}$ would be so large that officials could never be bribed, and we would be back to the benchmark case of loyal officials.

The new timing of the model is as follows: at time 1 the legislator writes the norm, specifies the lower bound $\underline{F} \in \left[F_{\min}, \overline{F}\right]$ and the higher bound $\overline{F} \in [\underline{F}, F_{\max}]$, sets the enforcement effort E and designs the fine schedule $F(r)$. At time 2 the official sets the bribe B to be requested from firms when innovations are socially harmful in exchange for the report $r(a)$. At time 3 the firm undertakes innovative activity I. At time 4 it takes the action, given the outcome of its learning process. Finally, at time 5 actions produce their private payoffs Π and their social consequences W; the official obtains evidence with probability E, files a report r and possibly takes a bribe B in exchange for misreporting; conditioning on the official's report, the judge levies the fine $F(r)$.[15]

4.1 Firm actions

As in the benchmark model, we proceed by solving the game backwards, starting from stage 4 in which the firm chooses its action. When the new actions are harmful to society ($s = b$), the firm has the following alternatives:

(i) not paying the bribe, so that the official reports truthfully ($r = a$), and choose the most profitable action $\widehat{a}^{nb}$, defined by

$$\widehat{a}^{nb} = \arg\max_{a \in A} [\Pi(a) - EF(a)], \tag{12}$$

(ii) paying the bribe B (so that the official reports $r(a) < a$) and select the most profitable action $\widehat{a}^b$ such that

$$\widehat{a}^b = \arg\max_{a \in A} \left\{ \Pi(a) - E\left[F(r(a)) + B\right] \right\}.$$

If the firm chooses the first course of action, its anticipated profits are net of the expected fine. If it chooses the second, they are also net of the expected bribe. The following Lemma characterizes the optimal actions chosen in each contingency:

Lemma 6 (Optimal actions) *At stage 4, given E, $F(r)$, $r(a)$ and B, the firm:*

- *chooses action a_0 if innovative activity is unsuccessful;*
- *chooses action $\overline{a}$ and does not pay any bribe if innovative activity is successful and new actions are not socially harmful ($s = g$);*
- *chooses action $\widehat{a}^b$ and pays bribe B if innovative activity is successful, new actions are socially harmful ($s = b$) and* $\Pi(\widehat{a}^{nb}) - EF(\widehat{a}^{nb}) < \Pi(\widehat{a}^b) - E\left[F(r(\widehat{a}^b)) + B\right]$;

[15] This timing implicitly assumes that at stage 2 the official commits to a given bribe B before the choices of the firm are made. However, it can be shown that the results of this section would be qualitatively unchanged if the bribe were set after the firm moves, provided the firm has some bargaining power in negotiating the bribe.

- *chooses action* $\widehat{a}^{nb}$ *and does not pay any bribe if learning is successful, new actions are socially harmful* ($s = b$) *and* $\Pi(\widehat{a}^{nb}) - EF(\widehat{a}^{nb}) \geqslant \Pi(\widehat{a}^{b}) - E\left[F(r(\widehat{a}^{b})) + B\right]$.

Therefore, it is only when new actions are socially harmful that the firm's behavior differs from that analyzed in the previous sections (see Lemma 1). In the present case, the firm's choice of action does not depend only on the policy variables $F(r)$ and E, as in the benchmark model, but also on the possibility of paying the bribe B to the official in exchange for his report $r(a)$.

4.2 Firm innovative activity

At stage 3 the firm chooses its innovative activity, given the optimal actions to be chosen at stage 4, the enforcement policy $F(r)$ and E chosen by the legislator, and the bribe B and the reporting schedule $r(a)$ chosen by the official. The firm's expected profits are:

$$\mathrm{E}(\Pi) = \Pi_0 + I\left\{\beta \max\left[\Pi(\widehat{a}^{nb}) - EF(\widehat{a}^{nb}),\ \Pi(\widehat{a}^{b}) - E\left(F(r(\widehat{a}^{b})) + B\right)\right] + (1-\beta)\overline{\Pi} - \Pi_0\right\} - c\frac{I^2}{2}. \tag{13}$$

This expression differs from the earlier expression (2) only by the term in square brackets, which is the payoff obtained when the innovative activity is successful and the new actions are socially harmful. In this case, the firm must choose between the best action that it can pick without bribing the official and its best action conditional on bribing the official.

The optimal innovative activity $\widehat{I}^c$, where the superscript c refers to corruption, is described in the following Lemma.

Lemma 7 (Optimal innovative activity) *At stage* 3*, given* E , $F(r)$, $r(a)$ *and* B*, the optimal level of innovative activity is*

$$\widehat{I}^c = \frac{\beta \max\left[\Pi(\widehat{a}^{nb}) - EF(\widehat{a}^{nb}),\ \Pi(\widehat{a}^{b}) - E\left(F(r(\widehat{a}^{b})) + B\right)\right] + (1-\beta)\overline{\Pi} - \Pi_0}{c}.$$

Proof. The result follows immediately from the first order condition. ■

4.3 Bribe and official's report

At stage 2 the official sets the bribe requested in exchange for misreporting, that is for reporting an action $r(a) < a$, given the policy variables set by the legislator. Clearly, for misreporting not to be detectable, the misreported action must be the same as the action optimally chosen by the firm in the absence of bribing: $r(\widehat{a}^{b}) = r(\widehat{a}^{nb}) = \widehat{a}^{nb}$. We assume that the equilibrium bribe $\widehat{B}$ is determined as the outcome of Nash bargaining between the firm and the official, where the firm's and the official's bargaining power are γ and $1-\gamma$, respectively. The following Lemma identifies the optimal bribe $\widehat{B}$ and reporting $\widehat{r}(a)$:

Lemma 8 (Optimal bribe) *Given E and $F(a)$, an official takes a bribe*

$$\widehat{B} = \underline{B} + (1-\gamma)\left[\frac{\overline{\Pi} - \Pi(\widehat{a}^{nb})}{E} - \underline{B}\right] > \underline{B} \tag{14}$$

in exchange for reporting $r(a) = \widehat{a}^{nb}$ for any $a > \widehat{a}^{nb}$. He does not take any bribe and reports truthfully if $\widehat{B} \leqslant \underline{B}$.

Proof. The Nash bargaining problem for B is:

$$\max_B \left[\Pi(\widehat{a}^b) - \Pi(\widehat{a}^{nb}) - E\left(F(r(\widehat{a}^b)) - F(\widehat{a}^{nb}) + B\right)\right]^\gamma [EB - E\underline{B}]^{1-\gamma},$$

which is solved by

$$\widehat{B} = \gamma\underline{B} + (1-\gamma)\left\{\frac{\Pi(\widehat{a}^b) - \Pi(\widehat{a}^{nb})}{E} - \left[F(r(\widehat{a}^b)) - F(\widehat{a}^{nb})\right]\right\}.$$

Taking into account that $r(\widehat{a}^b) = r(\widehat{a}^{nb}) = \widehat{a}^{nb}$, the solution becomes

$$\widehat{B} = \gamma\underline{B} + (1-\gamma)\frac{\Pi(\widehat{a}^b) - \Pi(\widehat{a}^{nb})}{E}.$$

The official will accept the bribe $\widehat{B}$ if it exceeds $\underline{B}$. Moreover, to maximize his bribe, the official will be ready to misreport any action above $\widehat{a}^{nb}$. By doing so, he will induce the firm to choose the worst possible action, that is, $\widehat{a}^b = \overline{a}$, since this pushes its profit $\Pi(\widehat{a}^b)$ to the maximal level $\overline{\Pi}$. By using this fact and rearranging, one obtains (14). ■

Note that the misreporting schedule optimally chosen by the official when he takes the bribe induces the firm to choose the worst possible action $\overline{a}$, since this is the action that maximizes the gains from corruption.

The equilibrium bribe (14) has a simple interpretation: to misreport, the official must obtain a premium over and above his reservation bribe $\underline{B}$, and this premium is a share $1-\gamma$ (his bargaining power) of the net increase in the joint net surplus that the two parties derive from misreporting (the expression in square brackets).[16] For the inequality in (14) to hold, this premium must be positive: in other words, bribing occurs only if

$$\overline{\Pi} - \Pi(\widehat{a}^{nb}) - E\underline{B} > 0. \tag{15}$$

It is up to the legislator to prevent this condition from being met, by implementing the appropriate action $\widehat{a}^{nb}$ through the design of the fine schedule. This leads us to stage 1 of the game.

[16] This joint net surplus is the increase in the firm's profits minus the disutility incurred by the official when misreporting ($-\underline{B}$).

4.4 Norm design

At stage 1, the legislator sets policy variables so as to maximize welfare, taking into account that officials will behave opportunistically. He anticipates that changing the implementable action $\widehat{a}^{nb}$ modifies the maximum bribe that the official will be able to request for misreporting. More precisely, according to (14), by implementing through the fine schedule a slightly worse action $\widehat{a}^{nb}$, the legislator reduces the firm's relative gain from paying the bribe and choosing $\overline{a}$. This reduces the maximum bribe the firm is willing to pay. Since the official takes a bribe as long as it is above his reservation level $\underline{B}$, the legislator can deter bribing by setting $\widehat{a}^{nb}$ at a level that eliminates all surplus from bribery. Bribe deterrence is always optimal for the legislator, since the action $\widehat{a}^{nb}$ is less harmful to society than $\widehat{a}^{b} = \overline{a}$.

As in the benchmark model, we can restrict our analysis to stepwise fine schedules: the implemented action will occur at the point of discontinuity in the schedule, so that less harmful actions are sanctioned with the lowest fine $\underline{F}$ and more harmful ones with the highest fine $\overline{F}$. The optimal implementable action $\widehat{a}^{nb} = \widehat{\underline{a}}^{c}$ is the lowest action that makes the bribe unattractive, that is, induces inequality (15) to fail:

$$\overline{\Pi} - \Pi(\widehat{\underline{a}}^{c}) = E\underline{B}, \tag{16}$$

which implies

$$\widehat{\underline{a}}^{c} = \Pi^{-1}\left[\overline{\Pi} - E\underline{B}\right]. \tag{17}$$

Notice that the implementable action is determined by the reservation bribe and the enforcement effort. A greater enforcement E and a higher reservation bribe $\underline{B}$ allow the legislator to implement a less harmful action:

$$\frac{\partial \widehat{\underline{a}}^{c}}{\partial E} = -\Pi^{-1\prime}[.]\underline{B} \leqslant 0 \text{ and } \frac{\partial \widehat{\underline{a}}^{c}}{\partial \underline{B}} = -\Pi^{-1\prime}[.]E \leqslant 0. \tag{18}$$

As shown by equation (17), if officials are corruptible the optimal implementable action $\widehat{\underline{a}}^{c}$ does not depend either on the minimum fine $\underline{F}$ (which is paid regardless of whether the firm pays the bribe) or on the relative bargaining power γ (which only affects the split of the surplus from misreporting, not its total size). In the limiting case where $\underline{B} = 0$, i.e. if the official is so dishonest as to misreport even for a negligible bribe, then $\widehat{\underline{a}}^{c} = \Pi^{-1}\left[\overline{\Pi}\right] = \overline{a}$, implying that only the worst possible action is implementable, since marginal deterrence is completely lost.

The optimal fine schedule that leads the firm to prefer action $\widehat{\underline{a}}^{c}$ (without paying any bribe) to action $\overline{a}$ (when paying the bribe), implicitly excludes that the firm might prefer a third option: choosing the most profitable illegal action $\overline{a}$ and, if caught, instead of paying the bribe, paying the full fine $\overline{F}$. The firm will never take this option, since equation (12) defines $\widehat{a}^{nb}$ as the action that gives the highest net profits, i.e. $\Pi(\widehat{a}^{nb}) - E\underline{F} \geqslant \overline{\Pi} - E\overline{F}$.

Although the implementable action depends on the reservation bribe, equation (16) implies a restriction on the range of fines that the legislator can use in designing the optimal fine schedule. We can see that upon subtracting $E\underline{F}$ from both sides and rearranging, equation (16) can be rewritten as

$$\Pi(\widehat{\underline{a}}^c) - E\underline{F} = \overline{\Pi} - E(\underline{F} + \underline{B}),$$

which equates the net profits when paying and not paying the bribe. This equality, jointly with the condition $\Pi(\widehat{a}^{nb}) - E\underline{F} \geqslant \overline{\Pi} - E\overline{F}$, yields

$$\Pi(\widehat{\underline{a}}^c) - E\underline{F} = \overline{\Pi} - E(\underline{F} + \underline{B}) \geqslant \overline{\Pi} - E\overline{F},$$

implying

$$\underline{B} \leqslant \overline{F} - \underline{F}. \tag{19}$$

So the official's reservation bribe $\underline{B}$ determines the range of fines (19) consistent with the incentive constraint, as well as marginal deterrence (as shown by (17)). Recalling that $\overline{F} - \underline{F} \leqslant F_{\max} - F_{\min}$, the assumption that $\underline{B} \leqslant F_{\max} - F_{\min}$ guarantees that the legislator can choose the range of fines (19).

The expected profits (13) can be simplified by using the equilibrium values $F(\widehat{a}^{nb}) = F(r(\widehat{a}^b)) = \underline{F}$, $\Pi(\widehat{a}^b) = \overline{\Pi}$, $\Pi(\widehat{a}^{nb}) = \Pi(\widehat{\underline{a}}^c)$ and exploiting the equality in (16):

$$\mathrm{E}(\Pi) = \Pi_0 + I[\overline{\Pi} - \beta E(\underline{F} + \underline{B}) - \Pi_0] - c\frac{I^2}{2},$$

yielding the following expression for the optimal innovative activity chosen by the firm:

$$\widehat{I}^c = \frac{\overline{\Pi} - \Pi_0 - \beta E(\underline{F} + \underline{B})}{c}.$$

Hence, the optimal innovative activity trades off the maximum profits from innovation with its expected cost, and it is decreasing in enforcement E, in the minimum fine $\underline{F}$ and in the reservation bribe $\underline{B}$. An increase in the reservation bribe has a similar effect to that of an increase in enforcement or fines: if officials are more honest, so that they would require a larger bribe to lie, firms can reap lower net profits from innovation and therefore will invest less in innovative activity.

As in the model with loyal officials, the optimal norm design and enforcement is analyzed in three steps: (i) how enforcement E affects welfare; (ii) how the legislator chooses the optimal fines $\overline{F}$ and $\underline{F}$; and finally (iii) how the optimal policy changes responds to changes in the likelihood of social harm and in the reservation bribe $\underline{B}$.

Expected welfare, conditional on the optimal implementable action $\widehat{\underline{a}}^c$ and innovative activity $\widehat{I}^c$, is:

$$\mathrm{E}(W^c) = W_0 + \widehat{I}^c(E, \underline{F}, \underline{B})[\beta w(\widehat{\underline{a}}^c(E, \underline{B})) + (1-\beta)\overline{W} - W_0] - [g(E) + c(\widehat{I}^c(E, \underline{F}, \underline{B}))].$$

Therefore, the optimal level of enforcement is implicitly defined by:[17]

$$\frac{\partial \mathrm{E}(W^c)}{\partial E} = \underbrace{[\Delta \mathrm{E}(\widehat{W}^c) - c\widehat{I}^c]\frac{\partial \widehat{I}^c}{\partial E}}_{\text{average deterrence } (\,+\,/\,-\,)} + \underbrace{\widehat{I}^c \beta w' \frac{\partial \underline{\widehat{a}}^c}{\partial E}}_{\text{marginal deterrence } (+)} - g' = 0, \tag{20}$$

where $\Delta \mathrm{E}(\widehat{W}^c) \equiv \beta w(\underline{\widehat{a}}^c) + (1-\beta)\overline{W} - W_0$ is the expected change in welfare relative to the *status quo* if the innovative activity is successful, while the term in square brackets measures the marginal social value of innovative activity. The first term of equation (20) captures average deterrence, and as before it can be negative or positive, depending on whether innovative activity has positive or negative marginal social value. The second term corresponds to the marginal deterrence effect, and it is positive if $\underline{B} > 0$, since a higher enforcement effort E allows to implement a lower action, i.e. a socially better one.

To identify how the optimal policy responds to changes in the probability β of the bad state, as in the benchmark model, we denote by β_0^c the probability that requires no enforcement ($E^c = 0$), i.e. such that the first two terms in (20) cancel out. When this occurs, the marginal social value of innovative activity must be positive, since $\partial \widehat{I}^c / \partial E < 0$. In addition, we define a second threshold level, $\underline{\beta}_0^c$, such that the marginal social value of innovative activity is zero, that is, $\Delta \mathrm{E}(\widehat{W}^c) - c\widehat{I}^c = 0$. The following Lemma (proved in the Appendix) establishes the relationship between these two thresholds:

Lemma 9 (Threshold probabilities) $0 < \beta_0^c < \underline{\beta}_0^c < 1$.

Equipped with these two thresholds, we can analyze the fines chosen within the available range $[F_{\min}, F_{\max}]$. Recall that the lower bound $\underline{F}$ influences the level of innovative activity $\widehat{I}^c$ but not the implementable action $\underline{\widehat{a}}^c$. Hence, the lower bound affects average deterrence but not marginal deterrence. Indeed, we have

$$\frac{\partial \mathrm{E}(W^c)}{\partial \underline{F}} = \underbrace{[\Delta \mathrm{E}(\widehat{W}^c) - c\widehat{I}^c]\frac{\partial \widehat{I}^c}{\partial \underline{F}}}_{\text{average deterrence } (\,+\,/\,-\,)}$$

If the marginal social value of innovative activity and the optimal enforcement E are positive, i.e. in the interval $\beta \in \left(\beta_0^c, \underline{\beta}_0^c\right]$, this derivative is negative and it is optimal to set $\underline{F} = F_{\min}$.This, together with the constraint (19), defines an interval for the maximum fine: $\overline{F} \in [F_{\min} + \underline{B}, F_{\max}]$.

[17] The second derivative is negative:

$$\frac{\partial^2 \mathrm{E}(W^c)}{\partial E^2} = -c\left(\frac{\partial \widehat{I}^c}{\partial E}\right)^2 + 2\beta w' \frac{\partial \underline{\widehat{a}}^c}{\partial E}\frac{\partial \widehat{I}^c}{\partial E} + \widehat{I}^c \beta w' \frac{\partial \underline{\widehat{a}}^{c2}}{\partial E^2} + \widehat{I}^c \beta w'' \frac{\partial \underline{\widehat{a}}^{c2}}{\partial E^2} - g'' < 0.$$

In fact $w' < 0$ and $w'' \leqslant 0$ when the externality arises and $\frac{\partial \underline{\widehat{a}}^{c2}}{\partial E^2} \geqslant 0$ thanks to $\Pi'' \leqslant 0$.

For higher values of the probability of the bad state, i.e. for $\beta > \underline{\beta}_0^c$, we have $\Delta \mathrm{E}(\widehat{W}^c) - c\widehat{I}^c < 0$, implying $\frac{\partial \mathrm{E}(W^c)}{\partial \underline{F}} > 0$. In this case the legislator will want to raise the lower bound $\underline{F}$ as much as possible, in order to discourage innovative activity. Since $\underline{F} \leqslant \overline{F} - \underline{B}$ in order to prevent bribing (see inequality 19) this requires to set the higher bound $\overline{F}$ as large as possible, i.e. $\overline{F} = F_{\max}$. Then, we obtain the optimal lower bound $\underline{F} = F_{\max} - \underline{B}$. These fines, and the actions that they induce, are illustrated in Figure 4. The figure shows that, for given enforcement, the corruptibility of enforcers weakens the effectiveness of the law, as the action implemented with unloyal officials, $\underline{\widehat{a}}^c$, exceeds that implemented with loyal officials, $\underline{\widehat{a}}$, and therefore reduces the welfare level that the legislator can hope to achieve.

[Insert Figure 4]

We summarize this discussion in the following proposition, which is illustrated in Figure 5:

Proposition 2 (Optimal policy with unloyal enforcers) *If $\beta \in [0, \beta_0^c]$ laissez faire is optimal:$E^* = 0$. If social harm is more likely ($\beta \in \left(\beta_0^c, \underline{\beta}_0^c\right]$), then the legislator must choose the most flexible fine schedule ($\underline{F} = F_{\min}, \overline{F} = F_{\max}$) and enforcement $E^* > 0$, so as to implement the action $\underline{\widehat{a}}^c \in (\underline{\widehat{a}}, \overline{a})$. When social harm is even more likely ($\beta \in \left(\underline{\beta}_0^c, 1\right]$), the legislator must reduce the flexibility of the norm by setting $\overline{F} = F_{\max}$ and $\underline{F} = F_{\max} - \underline{B} > F_{\min}$.*

[Insert Figure 5]

This proposition highlights that the corruptibility of enforcers affects the design of the law only if innovation is very likely to result in social harm ($\beta > \underline{\beta}_0^c$): in this case, to compensate the reduction in marginal deterrence arising from the risk of bribery, the law must rely more heavily on average deterrence, in the sense that the lower bound must be raised so as to discourage innovative activity. In the presence of corruption the lower bound is $F_{\max} - \underline{B} > F_{\min}$, whereas with loyal enforcers it would be set at the lower level $F_{\min}$. In other words, corruption reduces the flexibility of the law. Notice that this result could not occur in the traditional approach, where a reduction in the flexibility of the law has no benefits in terms of average deterrence, as in our model. Instead, our result echoes the finding by Tirole (1986) that to deter collusion between an agent and a supervisor, a principal must offer low-powered incentives to the agent, compared to a situation where collusion is not possible.

An immediate implication of the previous proposition is that:

Corollary (Effects of greater enforcers' loyalty) *A decrease in enforcers' loyalty* $\underline{B}$ *raises the lower bound of the fine schedule* $\underline{F} = F_{\max} - \underline{B}$ *and reduces the norm's flexibility* $(\overline{F} - \underline{F} = \underline{B})$*.*

Therefore, greater corruptibility of enforcers calls for more rigid laws. This also results in a worse implementable action $\widehat{\underline{a}}^c$, due to the loss of marginal deterrence.

Finally, a natural question is whether corruption makes *laissez faire* more or less desirable compared to the benchmark case. The following proposition (proved in the Appendix) compares the boundaries of the *laissez faire* regions in the two cases:

Proposition 3 (Laisser faire region) *Whenever* $F_{\min} > 0$, *laissez-faire is chosen for a wider range of* β*'s when officials are unloyal than when they are loyal.*

The intuitive rationale of this result is that the corruptibility of enforcers renders enforcement of the law a blunter instrument, insofar as it can exploit marginal deterrence less effectively than in the benchmark case, which widens the region where government intervention is inefficient.

5 Conclusion

The literature on law enforcement has disregarded that norms may affect the decision to invest in innovative activity. To fill this gap, we present a model of law design and enforcement where firms can invest in such an activity (e.g., R&D) and then, contingent upon success, undertake new types of production that can prove either beneficial or harmful to society.

The analysis is first conducted under the assumption that law enforcers are loyal. In this case, when the new actions made possible by innovation can be harmful to society, it is optimal to design the structure of fines and enforcement so as to deter firms from choosing the most harmful actions (marginal deterrence). Enforcement also reduces the firms' expected profit from innovation, and thereby discourages their research effort, irrespective of its actual outcome (average deterrence).

If innovative activity is likely to cause social harm, the legislator should maximize the flexibility of the norm, by choosing the widest possible range of fines, so as to sharpen marginal deterrence without reducing average deterrence. If instead innovative activity is expected to be socially beneficial, greater enforcement enhances social welfare via its marginal deterrence but tends to reduce it through its average deterrence, that is, discouraging innovative investment even when beneficial. Indeed the legislator should chooses *laissez* *faire* if social harm is sufficiently unlikely. This contrasts with the more interventionist prescription of the traditional model, which neglects the disincentive effect of the law on innovative activity.

When enforcers can misreport observed actions in exchange for a bribe, the marginal deterrence of enforcement is reduced. If social harm is sufficiently likely, in order to prevent bribery, the legislator must become less ambitious in designing regulation: he cannot prevent more socially damaging actions compared to the case of loyal officials, weakening marginal deterrence. Another consequence of corruption is that the legislator must compress the fine schedule by increasing its lower bound, thereby reducing both the flexibility of the law and the private incentives to innovate.

Appendix

Proof of Lemma 3. The first order conditions in the complete optimal policy program are:

$$\frac{\partial \mathrm{E}(W)}{\partial \overline{F}} = [\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}]\frac{\partial \widehat{I}}{\partial \overline{\overline{F}}} + \widehat{I}\beta w' \frac{\partial \widehat{\underline{a}}}{\partial \overline{\overline{F}}} \geqslant 0 \tag{21}$$

$$\frac{\partial \mathrm{E}(W)}{\partial \underline{F}} = \widehat{I}\beta w' \frac{\partial \widehat{\underline{a}}}{\partial \underline{F}} < 0 \tag{22}$$

$$\frac{\partial \mathrm{E}(W)}{\partial E} = [\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}]\frac{\partial \widehat{I}}{\partial E} + \widehat{I}\beta w' \frac{\partial \widehat{\underline{a}}}{\partial E} - g' \leqslant 0 \tag{23}$$

Recall that: $\frac{\partial \widehat{\underline{a}}}{\partial E} = -\Pi^{-1\prime}[.](\overline{F} - \underline{F}) \leqslant 0$, $\frac{\partial \widehat{\underline{a}}}{\partial \underline{F}} = \Pi^{-1\prime}[.]E \geqslant 0$, $\frac{\partial \widehat{\underline{a}}}{\partial \overline{\overline{F}}} = -\Pi^{-1\prime}[.]E \leqslant 0$, $\frac{\partial \widehat{I}}{\partial E} = -\frac{\beta \overline{F}}{c} \leqslant 0$, $\frac{\partial \widehat{I}}{\partial \overline{\overline{F}}} = -\frac{\beta E}{c} \leqslant 0$.

If $E = 0$ $\frac{\partial \widehat{I}}{\partial \overline{\overline{F}}} = \frac{\partial \widehat{\underline{a}}}{\partial \overline{\overline{F}}} = \frac{\partial \widehat{\underline{a}}}{\partial \underline{F}} = 0$ then $\overline{F}$ and $\underline{F}$ are indeterminate.

We want to check if for values of β such that $E^* > 0$ $\overline{F}$ and $\underline{F}$ can assume interior values.

i) For $\underline{F}$, this is false, given that the first order condition with respect to $\underline{F}$ is always negative.

ii) For $\overline{F}$, substitute $\frac{\partial \widehat{I}}{\partial \overline{\overline{F}}}$, $\frac{\partial \widehat{\underline{a}}}{\partial \overline{\overline{F}}}$, $\frac{\partial \widehat{I}}{\partial E}$ and $\frac{\partial \widehat{\underline{a}}}{\partial E}$in the first order conditions to get:

$$\frac{\partial \mathrm{E}(W)}{\partial \overline{F}} = [\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}]\left(-\frac{\beta E}{c}\right) + \widehat{I}\beta w'\left(-\Pi^{-1\prime}[.]E\right) \geqslant 0 \tag{24}$$

$$\frac{\partial \mathrm{E}(W)}{\partial E} = [\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}]\left(-\frac{\beta \overline{F}}{c}\right) + \widehat{I}\beta w'\left(-\Pi^{-1\prime}[.](\overline{F})\right) - g' = 0 \tag{25}$$

where both conditions are evaluated at the same $\widehat{I}$, $\widehat{\underline{a}}$, $\underline{F} = 0$, E^* and $\overline{F}$.

Rewrite the first-order conditions to get:

$$\frac{\partial \mathrm{E}(W)}{\partial \overline{F}} = E\left\{[\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}]\left(-\frac{\beta}{c}\right) + \widehat{I}\beta w'\left(-\Pi^{-1\prime}[.]\right)\right\} \geqslant 0 \tag{26}$$

$$\frac{\partial \mathrm{E}(W)}{\partial E} = \overline{F}\left\{[\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}]\left(-\frac{\beta}{c}\right) + \widehat{I}\beta w'\left(-\Pi^{-1\prime}[.]\right)\right\} - g' \leqslant 0 \tag{27}$$

Assume $E^* > 0$. Then $g' = \overline{F}\left\{[\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}]\left(-\frac{\beta}{c}\right) + \widehat{I}\beta w'\left(-\Pi^{-1\prime}[.]\right)\right\}$. For $E^* > 0$ we have $g' > 0$ and this, together with $\overline{F} > 0$, implies $\left\{[\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}]\left(-\frac{\beta}{c}\right) + \widehat{I}\beta w'\left(-\Pi^{-1\prime}[.]\right)\right\} > 0$. Next, $E^* > 0$ and $\left\{[\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}]\left(-\frac{\beta}{c}\right) + \widehat{I}\beta w'\left(-\Pi^{-1\prime}[.]\right)\right\} > 0$ imply $\frac{\partial \mathrm{E}(W)}{\partial \overline{F}} > 0$. In other words, $\overline{F}$ is always equal to $F_{\max}$ when $E^* > 0$.

Finally, since the only interior solution in the program is for E^*, the second order conditions are satisfied given $\frac{\partial^2 \mathrm{E}(W)}{\partial E^2} < 0$. ■

Proof of Lemma 4. When $\beta = 0$ the first term in (9) is negative, given (1); the second term is zero and the third is negative. Hence, we have a corner solution at $E^* = 0$. When $\beta = 1$, then both the first and second terms of (9) are positive, and the third must therefore be negative. Hence, $\partial \mathrm{E}(W)/\partial E = 0$ implies an interior solution with $E^* > 0$.

Notice that given the definition of β_0, when $E = 0$ and the fines are optimally set at $\underline{F} = F_{\min}, \overline{F} = F_{\max}$ the first two terms in (9) cancel out and, given that $g'(0) = 0$ by assumption, $\partial \mathrm{E}(W)/\partial E = 0$ at $E^* = 0$. In other words, β_0 is defined consistently with the optimal policy program, which implies at β_0 an interior solution with $E^* = 0$.

Next, we want to show that β_0 is unique. First, since we have just shown that $E^* = 0$ for $\beta = 0$ and $E^* > 0$ for $\beta = 1$, then a unique interior β_0 would feature $\left.\frac{dE^*}{d\beta}\right|_{\beta_0} > 0$. If instead there were multiple β_0's, we would obtain an internal solution $E^* = 0$ for each of these different β_0's. But if this were true, then $\left.\frac{dE^*}{d\beta}\right|_{\beta_0} < 0$ for at least some β_0. Now remember that

$$\frac{dE^*}{d\beta} = -\frac{\frac{\partial^2 \mathrm{E}(W)}{\partial E \partial \beta}}{\frac{\partial^2 \mathrm{E}(W)}{\partial E^2}}.$$

Since $\frac{\partial^2 \mathrm{E}(W)}{\partial E^2} < 0$ due to the second order conditions, $sign \frac{dE^*}{d\beta} = sign \frac{\partial^2 \mathrm{E}(W)}{\partial E \partial \beta}$. Note that, evaluated at $E = 0$, the latter derivative is

$$\frac{\partial^2 \mathrm{E}(W)}{\partial E \partial \beta} = \frac{\partial [\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}(0)]}{\partial \beta} \frac{\partial \widehat{I}(0)}{\partial E} + (\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}(0)) \frac{\partial^2 \widehat{I}(0)}{\partial E \partial \beta} + \widehat{I}(0) w' \frac{\partial \widehat{a}}{\partial E}. \qquad (28)$$

From the definition of β_0, the last term in the derivative equals

$$\widehat{I}(0) w' \frac{\partial \widehat{a}}{\partial E} = -[\Delta E(\widehat{W}) - c\widehat{I}(0)] \frac{\partial \widehat{I}(0)}{\partial E} / \beta.$$

Moreover,

$$\frac{\partial \widehat{I}(0)}{\partial E} = -\frac{\beta \overline{F}}{c} \text{ and } \frac{\partial^2 \widehat{I}(0)}{\partial E \partial \beta} = -\frac{\overline{F}}{c}.$$

Substituting the last two expressions into (28), the last two terms of (28) cancel out, yielding

$$\frac{\partial^2 \mathrm{E}(W)}{\partial E \partial \beta} = \frac{\partial [\Delta \mathrm{E}(\widehat{W}) - c\widehat{I}(0)]}{\partial \beta} \frac{\partial \widehat{I}(0)}{\partial E} = (\widehat{W} - \overline{W}) \frac{\partial \widehat{I}(0)}{\partial E} > 0.$$

Hence, we have shown that

$$\left.\frac{dE^*}{d\beta}\right|_{\beta_0} > 0,$$

that is, at β_0 the optimal enforcement is always increasing in β. Therefore, this single crossing argument implies that there cannot be multiple values of β such that the optimal enforcement is zero as an internal solution. Summarizing, the optimal policy program implies an unique interior solution with $E^* = 0$ at $\beta = \beta_0$, positive levels of enforcement for $\beta > \beta_0$, and a corner solution with $E^* = 0$ for $\beta < \beta_0$. ■

Proof of Lemma 9. The first threshold β_0^c is defined by:

$$\beta_0^c(E^c=0,\underline{F}=F_{\min},\overline{F}\geqslant F_{\min}+\underline{B}):-[\Delta \mathrm{E}(\widehat{W}^c)-c\widehat{I}^c]\frac{\partial \widehat{I}^c}{\partial E}=\widehat{I}^c\beta w'\frac{\partial \widehat{\underline{a}}^c}{\partial E}. \qquad (29)$$

Borrowing from the analysis of the benchmark case, we know that if $\left.\frac{\partial^2 E(W^c)}{\partial E \partial \beta}\right|_{\beta=\beta_0^c}>0$, then the optimal enforcement E^* is zero for $\beta\in[0,\beta_0^c]$ and positive for $\beta>\beta_0^c$. Hence, β_0^c is unique. Moreover, notice that at β_0^c the marginal social value of innovative activity is positive, i.e. $\Delta \mathrm{E}(\widehat{W}^c)-c\widehat{I}^c>0$.

The second threshold $\underline{\beta}_0^c$ is defined by:

$$\underline{\beta}_0^c(E=E^*>0,\underline{F}=F_{\max}-\underline{B},\overline{F}=F_{\max}):\Delta \mathrm{E}(\widehat{W}^c)-c\widehat{I}^c=0.$$

From the definition of $\underline{\beta}_0^c$ we know that at $\beta=\underline{\beta}_0^c$ the first term in (20) is zero, the second is positive and the third is negative. Since $g'(E)>0$ for $E>0$ by assumption, we conclude that $E^*>0$ at $\beta=\underline{\beta}_0^c$. Then, it must be that $\beta_0^c<\underline{\beta}_0^c$. ∎

Proof of Proposition 3. Recall that β_0 is defined, in the case of loyal officials, as the value of β such that the optimal policy is $(E=0,\underline{F}=F_{\min},\overline{F}=F_{\max})$ and that β_0^c is such that the optimal policy in case of selfish officials is $(E=0,\underline{F}=F_{\min},\overline{F}\geqslant F_{\min}+\underline{B})$. It is straightforward to see that the relevant functions, when evaluated at these optimal policies, are: i) $\widehat{\underline{a}}=\widehat{\underline{a}}^c=\overline{a}$; ii) $\widehat{I}=\widehat{I}^c=\frac{\overline{\Pi}-\Pi_0}{c}$; iii) $\frac{\partial \widehat{I}}{\partial E}=-\frac{\beta_0 F_{\max}}{c}$; iv) $\frac{\partial \widehat{I}^c}{\partial E}=-\frac{\beta_0^c(F_{\min}+\underline{B})}{c}$; v) $\frac{\partial \widehat{\underline{a}}}{\partial E}=-\Pi^{-1\prime}[\Pi(\overline{a})](F_{\max}-F_{\min})$; vi) $\frac{\partial \widehat{\underline{a}}^c}{\partial E}=-\Pi^{-1\prime}[\Pi(\overline{a})]\underline{B}$. Notice that, in absolute terms, the derivatives of the innovative investment and of the implemented action are higher under loyal officials than with selfish ones, i.e. the impact of enforcement is larger when there are no agency costs. Hence, upon substituting these functions in equations (10) and (29) and simplifying, we obtain the following expressions for β_0 and β_0^c:

$$\beta_0=\frac{\left(\overline{W}-W_0-\overline{\Pi}+\Pi_0\right)}{\overline{W}-w(\overline{a})}+\frac{\left(\overline{\Pi}-\Pi_0\right)w'\Pi^{-1\prime}[\Pi(\overline{a})](F_{\max}-F_{\min})}{\left[\overline{W}-w(\overline{a})\right]F_{\max}}$$

and

$$\beta_0^c=\frac{\left(\overline{W}-W_0-\overline{\Pi}+\Pi_0\right)}{\overline{W}-w(\overline{a})}+\frac{\left(\overline{\Pi}-\Pi_0\right)w'\Pi^{-1\prime}[\Pi(\overline{a})]\underline{B}}{\left[\overline{W}-w(\overline{a})\right](F_{\min}+\underline{B})}.$$

Comparing these two expressions, we find that

$$\beta_0\leqslant\beta_0^c\Leftrightarrow\frac{F_{\max}-F_{\min}}{F_{\max}}\geqslant\frac{\underline{B}}{F_{\min}+\underline{B}}\Leftrightarrow F_{\max}-F_{\min}\geqslant\underline{B}.$$

Since the last inequality is true by assumption, the result that $\beta_0\leqslant\beta_0^c$ follows. ∎

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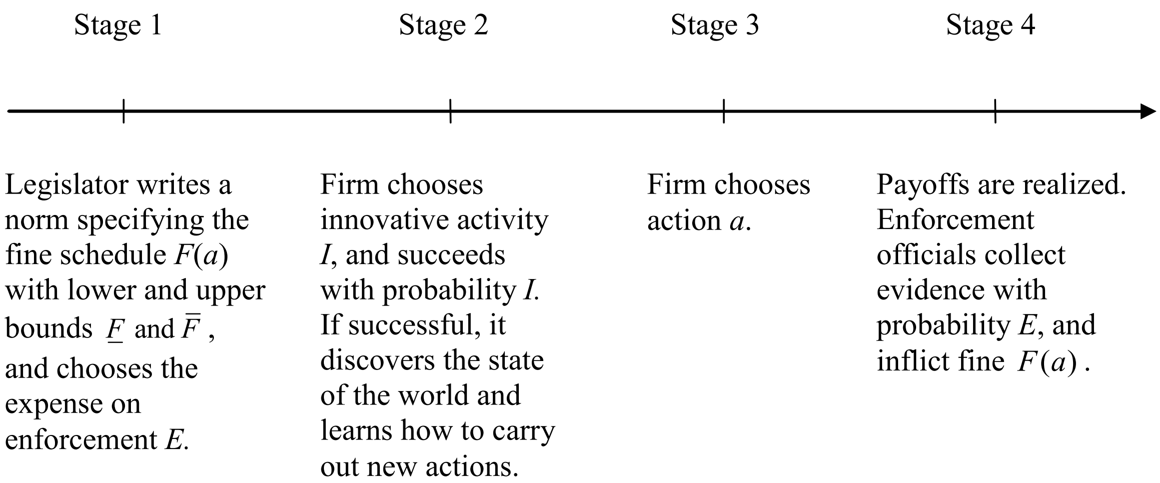

Figure 1: Time line

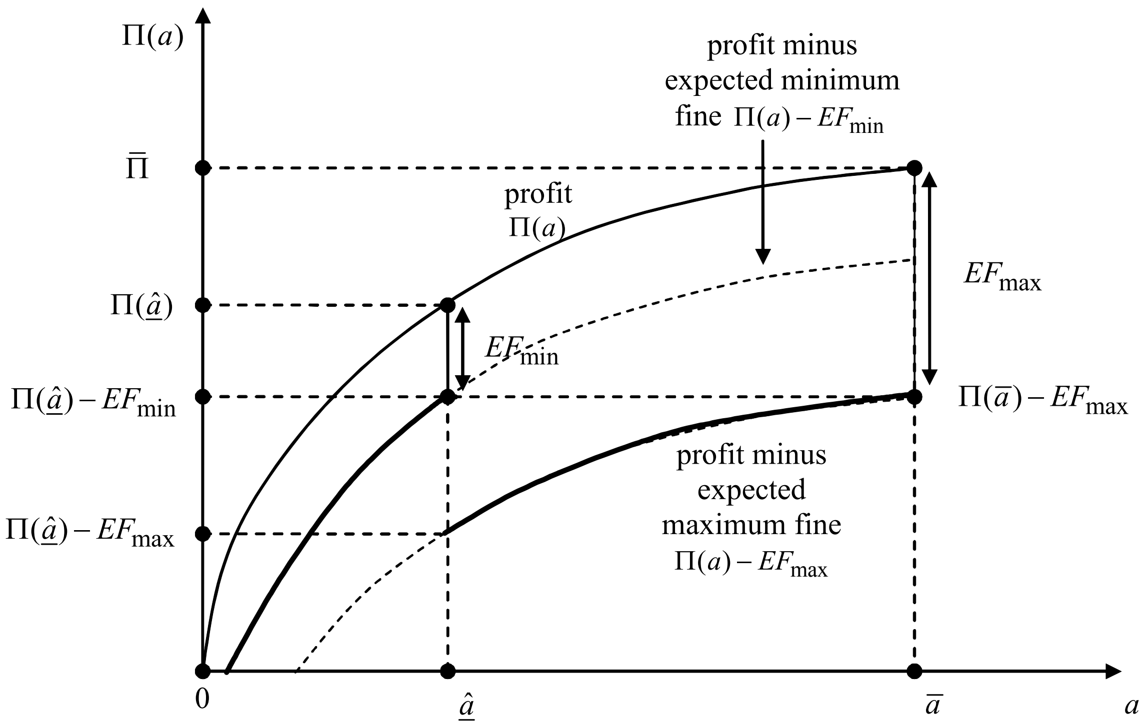

Figure 2: Actions, profits and fines

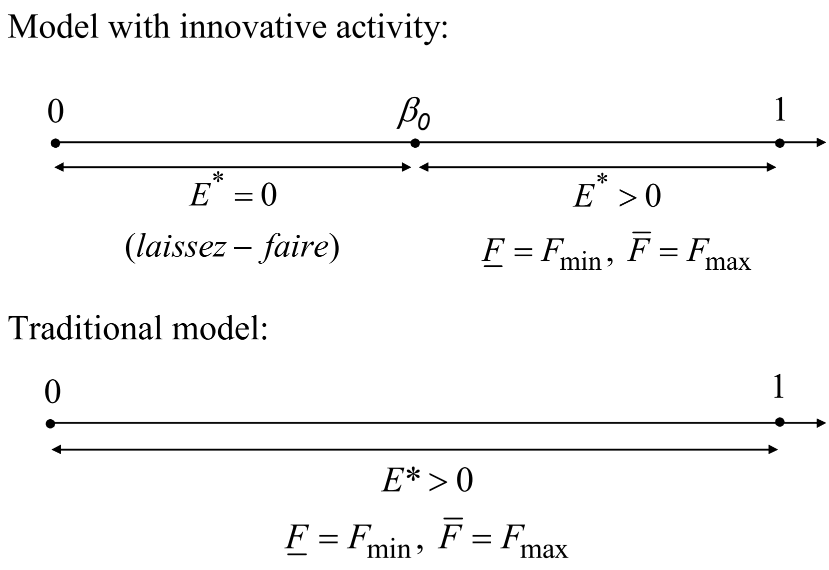

Figure 3: Optimal policy and innovative activity

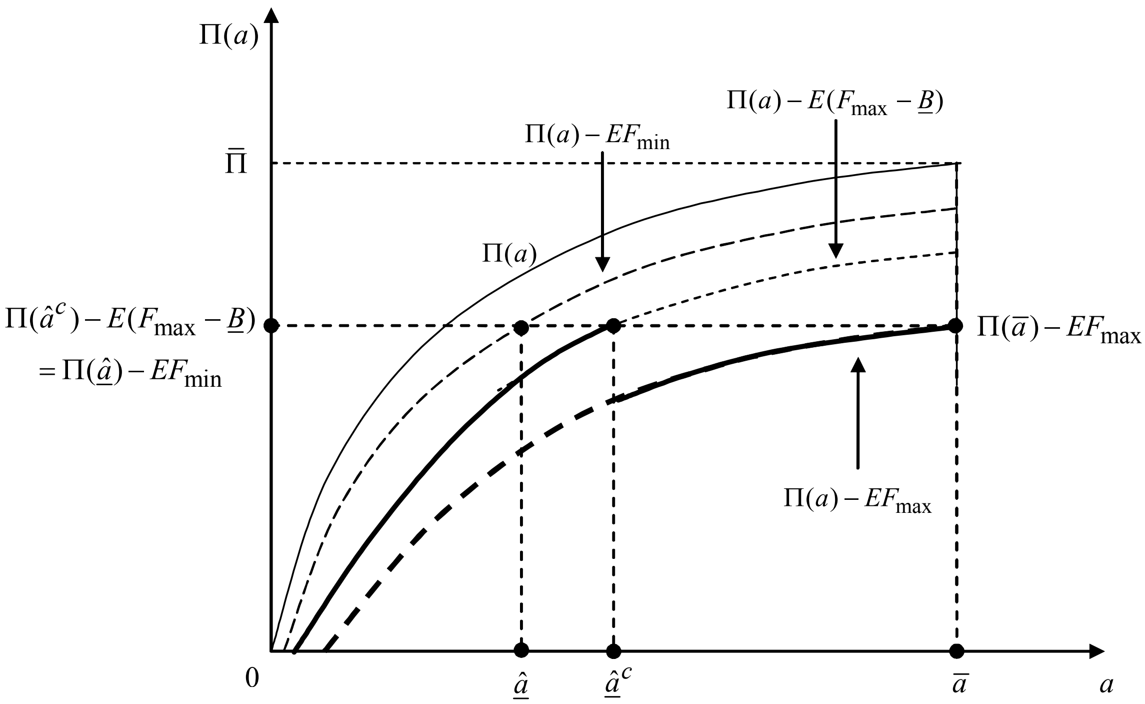

Figure 4: Actions, profits and fines with unloyal officials

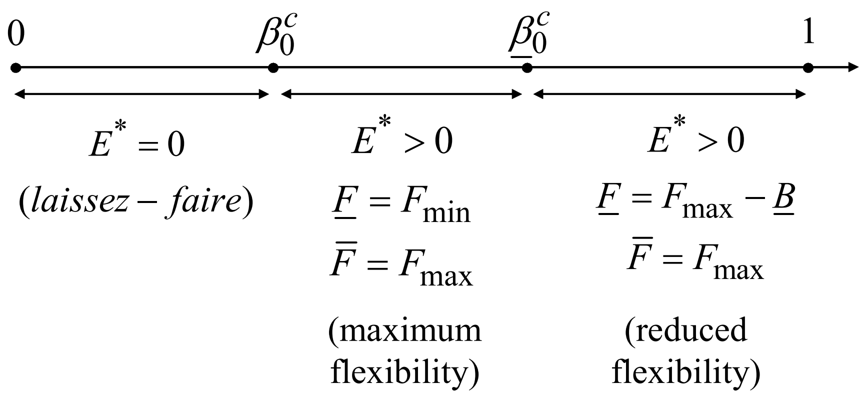

Figure 5: Optimal policy with unloyal officials