# WORKING PAPER SERIES

## Incentives to Innovate and Social Harm: Laissez-Faire, Authorization or Penalties?
### *Giovanni Immordino, Marco Pagano, Michele Polo*

**Working Paper n. 349**

**April 20, 2009**

# Incentives to Innovate and Social Harm: Laissez-Faire, Authorization or Penalties?

**Giovanni Immordino**
*Università di Salerno
and CSEF*

**Marco Pagano**
*Università di Napoli Federico II,
CSEF, EIEF and CEPR*

**Michele Polo**
*Università Bocconi
and IGIER*

April 20, 2009

**Abstract:** We analyze optimal policy design when firms' research activity may lead to socially harmful innovations. Public intervention, affecting the expected profitability of innovation, may both thwart the incentives to undertake research (average deterrence) and guide the use to which innovation is put (marginal deterrence). We show that public intervention should become increasingly stringent as the probability of social harm increases, switching first from *laissez-faire* to a penalty regime, then to a lenient authorization regime, and finally to a strict one. In contrast, absent innovative activity, regulation should rely only on authorizations, and *laissez-faire* is never optimal. Therefore, in innovative industries regulation should be softer.

**Keywords**: innovation, liability for harm, safety regulation, authorization.

**JEL classification**: D73, K21, K42, L51.

**Corresponding author**: Michele Polo, Università Bocconi, Via Sarfatti 25, 20136 Milan, Italy, michele.polo@unibocconi.it.

# 1 Introduction

It is generally recognized that when private actions generate harmful externalities, public intervention can improve welfare, if it appropriately trades off social harm reduction with enforcement costs[1] and if legal rules are designed and enforced so as to elicit the least damaging actions, thus achieving maximal "marginal deterrence" (Stigler, 1970; Shavell, 1992; Mookherjee and Png, 1994, among others).[2]. But it is less frequently acknowledged that public interventions may have yet another cost: that of stifling private sector innovations that open profit opportunities but may also entail risks for society. The idea that public intervention may thwart 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 both the risks and the benefits stemming from private innovative activity.

In this paper we investigate how public policies, including regulation and law enforcement, should be designed when they may affect firms' effort to discover new technologies, as well as their actual use once discovered. Central to our approach is the idea that research and development (R&D) often leads to innovations whose impact on welfare is initially unknown. In this perspective, uncertainty is pervasive: not only research may fail to produce workable results, but also when it succeeds the deployment of innovations may impact welfare unpredictably. Since in general public policies will treat ex-post socially harmful innovations differently from beneficial ones (e.g., it may authorize only the latter), a firm investing in R&D faces uncertainty as to how public policy will impinge on the results of its research. Indeed, if policy is expected to drastically reduce the expected profitability of innovation, the firm will refrain altogether from investing in research – a disincentive effect that we label "average deterrence". As we will see, public policies may differ in average deterrence – their research-thwarting effect – as well as in marginal deterrence – their ability to steer innovators towards less harmful implementation of their findings. We argue that precisely these differences dictate which is the best policy in each circumstance.

Uncertainty as to the social effects of innovations may arise in a variety of situations. An obvious example is that of scientific uncertainty in R&D: a biotech firm may either produce traditional seeds or research new genetically modified (GM) seeds that promise higher yields but may pose unknown risks to public health, for instance causing allergies to consumers.

---

[1] The literature on public intervention in the presence of market failures 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, 2008, among others).

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

A second example refers to the introduction of new products in an uncertain market environment. For instance, a software company may sell an established operating system and application packages or rather attempt to develop new applications tied to a new operating system. Depending on the circumstances prevailing when the innovation is marketed, the new software may raise consumer welfare (due to its greater ease of use) or induce market foreclosure. Which effect will prevail depends on the availability of alternative products on the market when the new software is introduced. Hence, apart from the initial strategic intentions of the software company about the possible effects of its new application, its actual market outcomes will also depend on random events outside of the developer's control when research is started.

Yet another class of cases may occur in financial markets: financial innovation, such as the introduction of new derivatives or markets, may open 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. The social harm that can ensue is well exemplified by the current financial crisis. In the words of Lloyd Blankfein, CEO of Goldman Sachs, one of the key lessons of the crisis is that the financial industry "let the growth in new instruments outstrip the operational capacity to manage them. As a result, operational risk increased dramatically and this had a direct effect on the overall stability of the financial system" (Blankfein, 2009, p. 7).

In each of these situations, a policy maker may adopt one of three different regulatory regimes: (i) *laissez faire*, (ii) a regime based on *authorization*, whereby innovations can be exploited commercially only if ex-ante authorized, and (iii) a regime based on *penalties*, where behavior is subject to legal rules and sanctioned ex post if found to be socially harmful. The difference between the two latter regimes does not lie only in the timing of the policy intervention – ex-ante scrutiny in the former *versus* ex-post evaluation in the latter – but also in their different degree of flexibility: authorization is a "yes-or-no" decision, and as such it admits no nuances, while penalties can be fine-tuned according to the severity and likelihood of social harm. But even an authorization regime can be made more lenient by authorizing firms when there is no decisive evidence that their innovations are harmful, or stricter by denying authorization in such circumstances, thus requiring evidence that innovations are beneficial.

We show that the greater the social harm that innovations are expected to generate, the more cogent and blunter should be the chosen form of public intervention, namely the greater its average deterrence. Specifically, as expected social harm increases, the optimal intervention switches first from *laissez-faire* to a penalty regime, then to a lenient authorization regime, and finally to a strict one. This is precisely because the fines of a penalty

regime can be smoothly adapted to situations of moderate social harm, whereas the imperative nature of the authorization regime is more suited to situations where innovation is very likely to be socially harmful.

Interestingly, the principle that the regulatory regime should be attuned to the danger of social harm is tightly connected to the need to balance such harm with the benefits of innovation. Indeed, we show in the same setting that if the firm were able to implement its practices without a preliminary research phase, regulation should rely exclusively on authorizations (more or less lenient depending on the likelihood of social harm), and *laissez-faire* would be never optimal. The reason is that when the incentives to innovate are not an issue, the regulator simply wishes to deter actions that are expected to be socially harmful: since in our setting even maximal penalties would have limited deterrence, they are dominated by the authorization regime, where such actions can simply be banned. This also explains why *laissez faire* is optimal for innovative activities that are expected to raise welfare (even though marginal deterrence is forgone), while it is dominated when innovation is not part of the picture (and marginal deterrence is the only issue). This is an aspect of the general point that regulation should be softer in innovative industries.

It should be noticed that marginal deterrence, which is at the center of the traditional approach in law and economics, is present also in our penalty regime, where fines affect the choice among new actions that the firm takes if its research has been successful. However, this traditional effect is shown to interact with average deterrence that, by acting on the incentives to innovate, affects at the same rate the probability of taking any of the new actions. In the penalty regime marginal deterrence is always desirable, while average deterrence improves welfare only when social harm is sufficiently likely.

In the literature, our analysis is related to Shavell (1984), who analyzes four determinants of the choice between an authorization and a penalty regime, in his context respectively labeled as safety regulation and liability: (i) difference in risk knowledge; (ii) incentive or ability to enforce penalties; (iii) magnitude of administrative costs, and (iv) magnitude of maximal fines. In our analysis, we set factors (i) to (iii) equal across the two regimes, and assume maximal fines to equal the maximum profits in the penalty regime. These assumptions are made to focus attention on the role of innovation in the choice between the two regimes (and *laissez-faire*), eliminating other sources of differential effectiveness between them.[3]

---

[3] Our analysis is also related to Kaplow (1995), which is the only other paper where to our knowledge the design of the law affects agents' learning decisions. In his setting, more complex rules allow better control over individual behavior 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.

Our model also shares some features with the "activity level" model of law enforcement (Shavell, 1980 and 2007; Polinsky and Shavell, 2000). In that model, private benefits and social harm depend on two different decisions by agents – an activity level (say, how long an individual drives a car, or whether or how far a certain production is run) and a level of precaution (driving speed, or adopting safety measures in the production process) – and the analysis typically compares the effects of different liability rules (strict versus fault-based liability). Our innovative activity is reminiscent of the activity level, while the choice of new actions parallels the choice of precaution. But our timing and information structure differ from those of the standard activity model. There, agents typically choose activity and precaution simultaneously and knowing perfectly the effect of their actions on welfare and the rules that will apply to them; the design of these rules aims at steering their choices so as to minimize social harm. So the issue is only one of marginal deterrence. In contrast, in our model when firms choose their research effort, they still ignore whether they will produce a beneficial or a harmful innovation, and therefore consider the policies designed for both cases as potentially relevant to them. Through this veil of ignorance, policies devised to penalize socially harmful innovations may end up deterring from research even firms that would in fact produce beneficial innovations. That is why uncertainty is key to what we call average deterrence.

The model that comes closest to ours is that of Schwartzstein and Schleifer (2009), who investigate when and how the optimal policy combines ex-ante regulation and ex-post litigation in the activity model. They consider a setting where safe and unsafe firms decide whether to produce and may take precautions. Firms face uncertainty as to the liability for damages that will apply to them, due to the assumption that courts can make errors: a judge may mistake a safe firm for an unsafe one, which creates a disincentive effect for safe firms. If the regulator can identify safe firms ex ante (or at least is better at it than courts), it is optimal for regulation to set these firms free from liability for damages, since the social benefits of their activity exceeds the expected harm from taking too few precautions. This parallels our finding that regulation should be softer when social harm is unlikely. But our analysis differs from Schwartzstein and Schleifer's one, as it considers uncertainty as inherent to the social effects of firms' research activity, rather than as arising from judicial errors. As such, it applies uniformly to any form of policy intervention, and does not *per se* favor any regime over others.[4]

The paper is organized as follows. Section 2 presents the model. Section 3 presents two benchmark cases: the first best, where the regulator directly control firms' choices, and the

---

[4]The role of judicial errors in our setting is analyzed in Immordino and Polo (2008), who show that average deterrence determines new effects of errors in law enforcement compared to the traditional results in the law enforcement literature. This setting is also extended to include agency problems in enforcement arising from opportunistic enforcers and the potential for bribery, in Immordino, Pagano and Polo (2006).

*laissez-faire* regime, where firms' actions are unrestricted. Section 4 analyzes the regime based on authorizations, Section 5 that based on penalties, Section 6 presents the overall optimal policy in the presence of innovative activity, and Section 7 compares it with the optimal policy in the absence of innovative activity. Section 8 concludes. All the proofs are in the Appendix.

## 2  Setup

We consider a profit-maximizing firm that must choose whether to invest in R&D activity or not. If the firm does not invest in such activity, it can select only among known actions, e.g. familiar technologies. If instead the firm invests and succeeds in its research effort, it expands its opportunity set. In many instances, the new actions made possible by innovation, though expected to be profitable, may have unknown social effects. For instance, a biotech firm may produce traditional seeds or experiment with new GM seeds that promise higher yields but pose unknown risks to public health.

To contain the potential hazards posed by innovative activity, public policy may constrain the actions of successful innovators either by subjecting them to an *ex-ante* notification and authorization requirement (*authorization*) or to an *ex-post* penalty enforcement regime (*penalty*). Under the authorization regime, the firm notifies to a public agency (such as the Food and Drugs Administration) the action it plans to undertake based on the results of its research (e.g., the marketing of a specific GM seed), and the agency decides whether the firm is allowed to do so or not, after carrying out an investigation on the potential implied harm. In contrast, under a penalty regime the firm is free to choose any new action made possible by its research findings (in our example, market any new GM seed), but may be liable *ex-post* to pay a fine if this action causes social harm. Public policies must trade off the social gains arising from the firm's innovations (a larger harvest) against their potential social harm (a public health hazard). The key issue to be explored is how this trade-off shapes the optimal design of both the authorization and the penalty regime, as well as the choice between the two.

In our analysis, the firm is assumed to know how to implement the *status-quo* action $a_0$ (selling traditional seeds), with associated profits $\Pi_0$ and welfare $W_0$, which are normalized to zero with no loss of generality: $\Pi_0 = W_0 = 0$. In contrast, carrying out a new action requires innovative activity (experiments with GM seeds). If the investment is unsuccessful, the firm must implement the *status-quo* action $a_0$. If it is successful, the firm discovers how to implement a set of new actions $A = (0, \overline{a}]$, with associated profits $\Pi = \pi a$, where $\pi > 0$. In this case, the firm is also assumed to learn the state of nature $s \in \{b, g\}$: in the bad state $b$, the innovation is socially harmful, whereas in the good state $g$ it is beneficial. 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.

Depending on the state of nature $s$, the social consequences of new actions are described by one of two different functions. In state $b$, which occurs with probability $\beta$, new actions decrease welfare according to $W_b = -\underline{w}a$, with $\underline{w} > 0$. In the bad state, private incentives conflict with social welfare since a new action $a$ yields profit $\pi a$ but reduces welfare by $\underline{w}a$. Hence, the probability $\beta$ measures the misalignment between public interest and firms' objectives: in our example, $\beta$ is the prior probability that GM seeds will pose a health hazard.[5] Instead, in the good state $g$, that occurs with probability $1 - \beta$, new actions raise welfare according to the function $W_g = \overline{w}a$. In this state, the social gains from innovation exceed private ones, that is, $\overline{w} > \pi$, or equivalently new actions increase consumer as well as producer surplus.[6]

The amount of resources $I$ that the firm invests in research determines its chances of success: for simplicity, $I$ is assumed to coincide with the firm's success probability, so that $I \in [0, 1]$. The cost of learning is increasing and convex in the firm's investment. For concreteness we assume

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

where $c > \pi$ ensures an internal solution for the choice of $I$. After choosing its investment $I$ in innovative activity and learning its outcome, the firm selects the profit-maximizing action among the feasible ones (which invariably include the *status-quo* action) under the constraints imposed by public policy.

# 3  Benchmarks: first best and *laissez faire*

As the opportunities created by innovation generate either positive or negative externalities, depending on the state of nature, public policy may be beneficial. To evaluate the benefits of public interventions, it is useful to benchmark them against the first-best outcome $(FB)$, which would obtain if the regulator could control firms' choices $I$ and $a$ directly, and a *laissez faire* regime $(LF)$, where firms are free to choose whichever action they like.

Unconstrained welfare maximization calls for action $\overline{a}$ in the good state and action $a_0$

---

[5] 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.

[6] The assumption that profits and welfare are linear in actions allows us to compare analytically the authorization and liability regime. Without linearity, this comparison could only be effected via numerical simulations.

in the bad state, so that the first-best expected welfare is

$$\mathrm{E}(W_{FB}) = I(1 - \beta)\overline{wa} - c\frac{I^2}{2}. \tag{1}$$

The first-order condition with respect to $I$ yields the corresponding investment level

$$I_{FB} = \frac{(1 - \beta)\overline{wa}}{c}, \tag{2}$$

which is increasing in the likelihood of the good state $1 - \beta$ and in the associated welfare gain $\overline{wa}$, and decreasing in the marginal cost of innovative activity $c$.

In the polar opposite scenario of *laissez faire*, firms will opt for action $\overline{a}$ whenever their research efforts have been successful, irrespective of the state. Therefore, their expected profits from innovation are $\mathrm{E}(\Pi) = I\pi\overline{a} - cI^2/2$, implying an optimal level of innovative activity

$$I_{LF} = \frac{\pi\overline{a}}{c}, \tag{3}$$

which can exceed the first-best level in (2) or fall short of it, depending on the likelihood $1 - \beta$ of the good state. The welfare level associated with the *laissez-faire* level of investment is

$$\mathrm{E}(W_{LF}) = I_{LF}\left[(1 - \beta)\overline{wa} - \beta\underline{w}\overline{a}\right] - c\frac{I_{LF}^2}{2} = \frac{\pi\overline{a}^2}{c}\left(Ew - \frac{\pi}{2}\right), \tag{4}$$

where in the second step we denote the expected marginal welfare of action $\overline{a}$ by $Ew \equiv (1 - \beta)\overline{w} - \beta\underline{w}$ .

In what follows, the policy maker is assumed not to control firms' choices directly, but to influence them either via authorizations or via penalties. In the authorization regime, public intervention occurs *ex ante*, as firms cannot implement their preferred action unless a public agency agrees to it. In contrast, in the penalty regime firms are free to implement their preferred action, but are aware that public intervention may occur *ex post* in the form of fines, whenever social harm is recognized to have occurred.

We assume policy makers to be benevolent, in the sense that public policies are designed and enforced so as to maximize social welfare. Since at any stage and under any regime public decisions are taken according to this goal, we can avoid to define precisely the institutional framework in which the public policies are designed and enforced. In our analysis we just refer to an "agency", which might be a legislator, a regulator, an authority or a judge depending on the relevant regime.

## 4   Authorization

In the authorization regime, after a firm notifies the action that it wishes to undertake, the authorizing agency investigates whether the action is socially harmful or not, and obtains

decisive evidence about its social effects with probability $p$, while it finds no evidence in either direction with probability $1 - p$. If the evidence is decisive, the authorization is given if and only if the evidence is favorable. If the evidence is indecisive, instead, the agency can opt for one of two rules: a "lenient authorization" ($LA$) rule whereby when in doubt the firm is authorized, or a "strict authorization" rule ($SA$) whereby in such circumstances the authorization is denied. Hence, under the $LA$ regime the firm is authorized as long as no social harm is proved, while under the $SA$ rule new actions are permitted only if proved to be socially beneficial. When the authorization is denied, the firm must take the *status-quo* action $a_0$.

The timing of the game is illustrated in Figure 1. At $t = 0$ the agency chooses between regime $LA$, $SA$ and *laissez faire ($LF$).*[7] At $t = 1$ the firm chooses its innovative activity $I$ and with probability $I$ discovers the set of new actions $A$ and the state of nature $s$. At $t = 2$, in regimes $LA$ and $SA$ the firm notifies the agency of the new action it wishes to undertake. At $t = 3$ the agency obtains with probability $p$ evidence on the social effects of the proposed action, and decides whether to authorize it or not. At $t = 4$ the firm carries out the authorized action (if any), and the corresponding private and social payoffs are realized. Under the $LF$ regime, one moves directly from $t = 1$ to the final stage $t = 4$, and the firm is free to implement any action it wants.

[Insert Figure 1]

Since by assumption the new actions in $A$ are more profitable than the *status-quo* action $a_0$, if research is successful the firm always applies to be authorized to carry out the highest (most profitable) new action $\overline{a}$.[8] In the $LA$ regime, the firm anticipates that the agency will always authorize it in the good state (whether it uncovers favorable evidence or not), and will authorize it only with probability $1 - p$ in the bad state (that is, only if no decisive evidence is uncovered). Therefore, in this regime the firm will take action $\overline{a}$ with probability $(1 - \beta) + \beta(1 - p)$, and its expected profits are

$$\mathrm{E}(\Pi_{LA}) = I\left[(1 - \beta) + \beta(1 - p)\right]\pi\overline{a} - c\frac{I^2}{2},$$

so that its optimal innovative activity is

$$I_{LA} = \frac{(1 - p\beta)\pi\overline{a}}{c}. \tag{5}$$

---

[7] In all cases, it commits to such regime for the entire game.

[8] In the present setting it is equivalent for the firm to require an authorization on all the new actions $A$ or just for the selected action $\overline{a}$.

The corresponding level of expected welfare is

$$\text{E}(W_{LA}) = I_{LA}\left[(1-\beta)\overline{wa} - \beta(1-p)\underline{w}\overline{a}\right] - c\frac{I_{LA}^2}{2} = \frac{\pi\overline{a}^2}{c}(1-p\beta)\left[Ew - \frac{\pi}{2} + p\beta(\frac{\pi}{2} + \underline{w})\right].$$

(6)

Under the $SA$ regime, instead, the agency will authorize action $\overline{a}$ only if it uncovers favorable evidence, which happens exclusively in the good state. Hence action $\overline{a}$ will be authorized with probability $(1-\beta)p$, and the firm's expected profits are

$$\text{E}(\Pi_{SA}) = I(1-\beta)p\pi\overline{a} - c\frac{I^2}{2},$$

so that its optimal innovative activity is

$$I_{SA} = \frac{(1-\beta)p\pi\overline{a}}{c}.$$

(7)

Clearly, the lenient rule is associated with greater investment in innovation than the strict one ($I_{LA} > I_{SA}$), because it leaves greater expected profits to innovators. The welfare level associated with the $SA$ regime is

$$\text{E}(W_{SA}) = I_{SA}(1-\beta)p\overline{wa} - c\frac{I_{SA}^2}{2} = \frac{\pi\overline{a}^2}{c}(1-\beta)^2p^2(\overline{w} - \frac{\pi}{2}).$$

(8)

The following lemma establishes that the lenient rule – being more permissive towards innovators – is optimal if and only if innovation is sufficiently unlikely to cause social harm:

**Lemma 1 (Optimal authorization)** *There exists a value $\widetilde{\beta} \in (0,1)$ such that the lenient authorization regime is preferred to the strict one iff $\beta \leqslant \widetilde{\beta}$.*

## 5   Penalties

In the penalty regime, successful innovators can implement their preferred action $\overline{a}$ but anticipate that they may be liable to pay a fine if the action is found to have caused social harm. This occurs when the agency obtains definite evidence that the chosen action was socially harmful, which happens with probability $p$ as in the authorization regime.[9] In this regime, an action $a \in A$ that causes social harm relative to the *status quo* $(-\underline{w}a < 0)$ is punished according to a fine schedule $f(a)$ chosen in the interval $[0, F]$ and non-decreasing in social harm. This legal rule, that in our example would prohibit to commercialize hazardous

---

[9] As argued in the introduction, the assumption that in both regimes law enforcers obtain decisive evidence with the same probability is made to avoid biasing the comparison between them with assumptions regarding the relative efficiency of enforcement.

GM seeds, is effect-based, as it punishes only actions that are *ex-post* socially damaging and does so in proportion to the harm caused.[10]

Fines are assumed to have limited deterrence: they cannot exceed the profits that successful innovators can earn from their preferred action, that is, $F = \pi\bar{a}$.[11] This is the interesting case, since if the maximum fine $F$ were unbounded, the penalty regime would always dominate the authorization regime: by inflicting sufficiently high fines, an agency could prevent the firm from taking new actions if socially damaging, while still allowing them if beneficial.

The timing of the game for the penalty regime is illustrated in Figure 2. At $t = 0$ the agency chooses between the penalty regime $P$ and *laissez faire* $LF$. In the former case, it sets a fine schedule $f(a)$. At $t = 1$, the firm chooses innovative activity $I$ and with probability $I$ discovers the set of new actions $A$ and the state of nature $s$. At $t = 2$ it decides which action $a$ to take. At time $t = 3$ the private and social payoffs are realized. At time $t = 4$ the agency investigates the action $a$, finds decisive evidence about its social effects with probability $p$ and, if it does, levies the fine $f(a)$. Of course, this enforcement stage only occurs if *laissez faire* was not chosen at $t = 0$.

[Insert Figure 2]

The choice of actions at $t = 2$ depends on the outcome of the firm's innovative activity at $t = 1$ and on the fine schedule $f(a)$ designed by the agency at $t = 0$. When innovative activity is unsuccessful, the firm carries out the *status-quo* action $a_0$. Instead, when successful the firm can take new actions $a \in A$. If these are socially beneficial, all of them are lawful, so that the firm picks the highest action $\bar{a}$. If instead the new actions are socially harmful, they are illegal but cannot be completely deterred by fines (since $F = \pi\bar{a}$). The firm chooses the unlawful action $\hat{a}$ that maximizes its profits, net of the expected fine:

$$\hat{a} = \arg\max_{a \in A}[\pi a - pf(a)]$$

Referring again to our example, if innovative activity is unsuccessful, the firm sells traditional seeds, while if successful the biotech firm markets the most profitable type of seeds if it does

---

[10] For a discussion on an effect-based interpretation of antitrust rules, see Gual *et al.* (2005). Here we adopt a notion of illegality based on *ex-post* social harm. All our results regarding the penalty regime, however, are robust to a more formalistic definition of illegality, whereby an action is deemed to be illegal based on its characteristics rather than on its effects. The key point in this case is that at least some of the characteristics of the action that make it ex-post unlawful are not observed ex-ante, when the innovative activity is exerted.

[11] This condition reflect the idea that the firm has no other wealth to be seized by authorities, and that its owners are protected by limited liability.

not pose any concern for public health, or a less profitable variety if it is dangerous, taking into account the corresponding fines it may be called to pay. We summarize this discussion as follows:

**Lemma 2 (Actions)** *At stage* 2, *given the fine schedule* $f(a)$, *the firm chooses (i)* $a_0$ *if the innovative activity is unsuccessful; (ii)* $\overline{a}$ *if it is successful and the new actions are socially beneficial; (iii)* $\widehat{a}$ *if it is successful and the new actions are socially harmful.*

At stage 1 the firm chooses the innovative activity $I$ so as to maximize its expected profits, anticipating the optimal actions to be taken at stage 2. In terms of our example, the biotech firm chooses its investment in R&D, taking into account which GM seeds it will market if successful. Its expected profits at this stage are:

$$\mathrm{E}(\Pi_P) = I\left[(1-\beta)\pi\overline{a} + \beta(\pi\widehat{a} - pf(\widehat{a}))\right] - c\frac{I^2}{2}, \tag{9}$$

where the subscript $P$ indicates that this expression refers to the penalty regime. The expression in square brackets is the expected gain from innovative activity, net of expected fines. Due to incomplete deterrence, this expression is always positive, implying that the firm will always perform some innovative activity. Notice that, since when $I$ is chosen the firm does not yet know whether the innovations will be socially beneficial (lawful) or harmful (unlawful), it mixes up the legal treatment of the two cases according to the likelihood of each state of the world.

Maximizing (9) with respect to $I$ yields:

**Lemma 3 (Innovative activity)** *At stage* 1, *given the fine schedule* $f(a)$, *the optimal level of innovative activity is*

$$I_P = \frac{(1-\beta)\pi\overline{a} + \beta[\pi\widehat{a} - pf(\widehat{a})]}{c}.$$

We now turn to the design of the fine schedule at stage 0. The influence of law enforcement and penalties on firms' behavior is twofold: it affects both the choice of the action $a$ when innovation succeeds, and the incentives to pursue innovative activity $I$ in the first place. The first role of fines is known in the literature on law enforcement as *marginal deterrence*, that is, the ability of fines to guide private choices among unlawful actions.[12] The second role, which is absent in standard models, stems from the impact of fines on innovative activity, and therefore on the probability that any new action $a$ will be taken. For this reason we label this second effect *average deterrence*. The legislator sets the policy parameters considering both effects on private choices and, ultimately on welfare.

---

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

The fine schedule must be designed so as to elicit the lowest possible $\widehat{a}$. For instance, an environmental agency must 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 set of non-decreasing fine schedules, one can focus on the stepwise function

$$f(a) = \begin{cases} \underline{f} \geqslant 0 & \text{if } a \leqslant \widetilde{a} \\ \overline{f} \leqslant F & \text{if } a > \widetilde{a} \end{cases} \tag{10}$$

We rely on Figure 3 to illustrate this point. The function (10) shifts the profit function $\pi a$ downward by $\underline{f}$ to the left of point $\widetilde{a}$, and by $\overline{f} > \underline{f}$ to its right, creating a local maximum at $\widetilde{a}$. To induce the firm to choose $\widetilde{a}$, this must however be a global maximum of the profit function, requiring

$$\pi \widetilde{a} - p\underline{f} \geqslant \pi \overline{a} - p\overline{f}.$$

Being a global maximum, this action corresponds to that chosen by the firm, that is $\widetilde{a} = \widehat{a}$ according to our previous notation. Moreover, the lowest action that satisfies this weak inequality is the welfare maximizing one. This action $\widehat{a}$ is implicitly defined by

$$\pi \widehat{a} - p\underline{f} = \pi \overline{a} - p\overline{f}, \tag{11}$$

so that

$$\widehat{a}(\overline{f}, \underline{f}) = \overline{a} - \frac{p(\overline{f} - \underline{f})}{\pi}. \tag{12}$$

Therefore, action $\widehat{a}(\overline{f}, \underline{f})$ is decreasing in $\overline{f}$ and increasing in $\underline{f}$, so that a wider range of fines allows the agency to implement a less damaging action $\widehat{a}$, that is, raise marginal deterrence.[13]

**[Insert Figure 3]**

Substituting equation (11) in expression (9) yields the profit that the firm expects to earn as of stage 1:

$$\mathrm{E}(\Pi_P) = I\left[\pi \overline{a} - \beta p\overline{f}\right] - c\frac{I^2}{2}.$$

From this, the optimal investment is seen to be

$$I_P(\overline{f}) = \frac{\pi \overline{a} - \beta p\overline{f}}{c}, \tag{13}$$

which is decreasing in the highest possible fine $\overline{f}$.

---

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

As explained above, the fine schedule, and in particular its parameters $\underline{f} \geqslant 0$ and $\overline{f} \leqslant F$, must be designed taking into account their effect not only on the choice of the action $\widehat{a}(\overline{f}, \underline{f})$ (marginal deterrence) but also on the choice of the innovative activity $I_P(\overline{f})$ (average deterrence). The expected welfare is

$$\mathrm{E}(W_P) = I_P(\overline{f}) \left[ (1 - \beta)\overline{wa} - \beta \underline{w}\widehat{a}(\overline{f}, \underline{f}) \right] - c\frac{I_P^2(\overline{f})}{2}. \tag{14}$$

Increasing the lowest fine $\underline{f}$ only affects marginal deterrence, and invariably lowers welfare:

$$\frac{\partial \mathrm{E}(W_P)}{\partial \underline{f}} = -I_P(.)\beta \underline{w}\frac{\partial \widehat{a}}{\partial \underline{f}} < 0,$$

so that $\underline{f}$ is optimally set at its lower bound, i.e. $\underline{f} = 0$. The welfare effect of the highest fine $\overline{f}$ is instead described by a more complex expression:

$$\frac{\partial \mathrm{E}(W_P)}{\partial \overline{f}} = \underbrace{[\Delta EW - cI_P(\cdot)] \frac{\partial I_P}{\partial \overline{f}}}_{\text{average deterrence } (+/-)} \underbrace{-I_P(\cdot)\beta \underline{w}\frac{\partial \widehat{a}}{\partial \overline{f}}}_{\text{marginal deterrence } (+)}, \tag{15}$$

where $\Delta EW = (1 - \beta)\overline{wa} - \beta \underline{w}\widehat{a}(\cdot)$ is the expected welfare from the innovative activity and the term in squared brackets is its marginal social value. The first term in the derivative captures the average deterrence of $\overline{f}$ and the second its marginal deterrence. The average deterrence effect of the highest fine $\overline{f}$ depends on the marginal social value of innovative activity, $\Delta EW - cI_P$. If this is negative, a higher fine $\overline{f}$ raises social welfare by discouraging undesirable innovations (since $\partial I_P/\partial \overline{f} < 0$); if positive, instead, a higher fine would be socially detrimental. In contrast, the marginal deterrence effect of a higher $\overline{f}$ invariably raises welfare, as it allows to implement less damaging actions in the bad state ($\partial \widehat{a}/\partial \overline{f} < 0$). This is reflected by the fact that the second term of the derivative is unambiguously positive.

As a result, three different cases may arise, for different values of the probability $\beta$ of the bad state. If this state is very unlikely, that is, $\beta$ is below the lower bound

$$\beta_0 \equiv \max\left\{ \frac{\overline{w} - \underline{w} - \pi}{\overline{w} + \underline{w}}, 0 \right\}, \tag{16}$$

then the first term in (15) is negative and can be shown to determine the sign of the derivative. In this case, it is optimal to set $\overline{f} = 0$, which is equivalent to the *laissez-faire* regime $LF$. In the opposite case where social harm is very likely ($\beta$ close to 1), then average deterrence enhances welfare (or mildly reduces it), and the derivative (15) becomes positive: in this case, it is optimal to set the highest fine at its largest admissible value so as to discourage innovative activity: $\overline{f} = F = \pi\overline{a}$. This applies for $\beta$ above the upper bound

$$\beta_1 \equiv \max\left\{ \frac{\overline{w} - \underline{w} - \pi}{(\overline{w} + \underline{w}) - p(\pi + 2\underline{w})}, 0 \right\}. \tag{17}$$

Notice that $\beta_1 > \beta_0 > 0$ only if $\pi < \overline{w} - \underline{w}$, that is, if private incentives to innovate are not too strong. If so, for values of $\beta$ comprised in the interval between $\beta_0$ and $\beta_1$ we have an internal solution:[14]

$$\overline{f}(\beta) = \frac{\pi \overline{a} \left[ \underline{w}(1+\beta) - \overline{w}(1-\beta) + \pi \right]}{\beta p (2\underline{w} + \pi)}. \tag{18}$$

If instead $\pi \geqslant \overline{w} - \underline{w}$, then $\beta_0 = \beta_1 = 0$, so that it is optimal to set the fine $\overline{f}$ at its maximal level $F$ for any $\beta$. To summarize:

**Lemma 4 (Optimal fines)** *If $\pi < \overline{w} - \underline{w}$, for $\beta \leqslant \beta_0$ the optimal policy is laissez faire LF ($\underline{f} = \overline{f} = 0$); for $\beta_0 < \beta \leqslant \beta_1$, the optimal fines are*

$$f(a) = \begin{cases} 0 & \text{if } a \leqslant \widehat{\underline{a}}, \\ \overline{f}(\beta) & \text{if } a > \widehat{\underline{a}} \end{cases} \tag{19}$$

*where $\overline{f}(\beta)$ is given by (18) and is increasing in $\beta$; for $\beta_1 < \beta \leqslant 1$, they are*

$$f(a) = \begin{cases} 0 & \text{if } a \leqslant \widehat{\underline{a}}, \\ F & \text{if } a > \widehat{\underline{a}}. \end{cases} \tag{20}$$

*If instead $\pi \geqslant \overline{w} - \underline{w}$ the optimal policy entails (20) for $\beta \in (0, 1]$.*

Therefore, as the probability of social harm $\beta$ increases, the optimal fine becomes gradually stiffer, from 0 to $\overline{f}(\beta)$ and finally to $F$. Thereby it induces successful innovators to carry out less extreme actions in the bad state, i.e. a lower $\widehat{\underline{a}}$:

$$\widehat{\underline{a}} = \begin{cases} \overline{a} & \text{for } \beta \in [0, \beta_0), \\ \overline{a} - \frac{p \overline{f}(\beta)}{\pi} & \text{for } \beta \in [\beta_0, \beta_1], \\ \overline{a} - \frac{pF}{\pi} = \overline{a}(1-p) & \text{for } \beta \in (\beta_1, 1]. \end{cases}$$

Even though the optimal policy just derived tends to counter the social harm associated with the bad state, expected welfare can be shown to be decreasing in the probability of social harm $\beta$:

$$\mathrm{E}(W_P) = \begin{cases} \frac{\pi \overline{a}^2}{c} \left[ Ew - \frac{\pi}{2} \right] & \text{for } \beta \in [0, \beta_0), \\ \frac{\pi \overline{a}^2}{c} \frac{(1-\beta)^2 (\overline{w}+\underline{w})^2}{2(\pi + 2\underline{w})} & \text{for } \beta \in [\beta_0, \beta_1], \\ \frac{\pi \overline{a}^2}{c}(1 - p\beta) \left[ Ew - \frac{\pi}{2} + p\beta(\frac{\pi}{2} + \underline{w}) \right] & \text{for } \beta \in (\beta_1, 1], \end{cases} \tag{21}$$

where $Ew \equiv (1 - \beta)\overline{w} - \beta \underline{w}$. This expression is continuous across the three regions, it is linear in $\beta$ for $\beta \in [0, \beta_0)$ and convex for $\beta \in [\beta_0, 1]$. Note that, if $\pi \geqslant \overline{w} - \underline{w}$, so that $\beta_0 = \beta_1 = 0$, expected welfare is given by the expression on the third line for any $\beta$.

---

[14] The second order condition clearly holds:

$$\frac{\partial^2 \mathrm{E}(W_P)}{\partial \overline{f}^2} = -\frac{\beta E(2\underline{w} + \pi)}{\pi} < 0.$$

# 6 Optimal policy

We are now equipped to derive the optimal policy regime, by comparing social welfare (21) in the penalty regime with the corresponding expression (4) obtained under *laissez faire* and with expressions (6) and (8) for the authorization regimes. Our first step requires to find out which of the two authorization regimes is to be compared to the penalty regime for each possible value of $\beta$. To this purpose, it is useful to note that

$$\beta_0 < \beta_1 < \widetilde{\beta}, \tag{22}$$

as shown in the Appendix. Therefore, lenient authorization – which dominates strict authorization for $\beta \leqslant \widetilde{\beta}$ – must be evaluated against the regime with penalties and against *laissez faire*. Only for $\beta > \widetilde{\beta}$ strict authorization is to be compared with the penalty regime. We are now ready to compare the various regimes:

**Proposition 1 (Optimal policy)** *The optimal regime requires:*[15]

> *(i) laissez faire for $0 \leqslant \beta \leqslant \beta_0$;*
>
> *(ii) positive and increasing penalties for $\beta_0 < \beta \leqslant \beta_1$;*
>
> *(iii) indifferently, the maximum penalty or lenient authorization for $\beta_1 < \beta \leqslant \widetilde{\beta}$;*
>
> *(iv) strict authorization for $\widetilde{\beta} < \beta \leqslant 1$.*

Therefore, public intervention becomes increasingly stringent as the danger of social harm increases: as $\beta$ goes up, the optimal policy changes from *laissez-faire* to a penalty regime, then to a lenient authorization regime and finally to a strict one. The comparison underscores a key difference between penalties and authorizations: a penalty regime is more flexible, since fines can be adapted to the likelihood of social harm, whereas authorizations are more rigid, being "yes-or-no" decisions. As a result, penalties can be smoothly adapted to situations of moderate social harm, where they are preferable to the harsher authorization regime. By the same token, the imperative nature of the authorization regime is more suited to situations where innovation is very likely to be socially harmful.[16]

It is interesting to consider how firms will choose the level of innovative activity when for each value of $\beta$ the policy maker adopts the corresponding optimal regime described in Proposition 1:

---

[15]Keep in mind that if $\pi \geqslant \overline{w} - \underline{w}$, then $\beta_0 = \beta_1 = 0$ and the first two cases disappear.

[16]It is worth recalling that the intervals where the preferred policy is *laissez-faire* or a fine below the maximum level (that is, where $\beta < \beta_1$) vanish when $\pi \geqslant \overline{w} - \underline{w}$: intuitively, when the profits from innovation are very large, deterring social harm requires either the maximum fine or an authorization regime.

**Proposition 2 (Optimal innovative activity)** *If the policy regime is optimally chosen, the level of innovative activity $\widehat{I}(\beta)$ is constant for $\beta \leqslant \beta_0$ and decreasing for $\beta > \beta_0$. Moreover, compared to the first best $I_{FB}$, there is underinvestment for small $\beta$ and overinvestment for large $\beta$.*

The finding that investment is decreasing in $\beta$ as soon as policy departs from *laissez faire* results from the increasing strictness of policy intervention in response to the increasing potential harm from innovation. Yet, the level of innovative activity is sub-optimally low when social harm is unlikely and sub-optimally large when social harm is likely. The reason for this apparent paradox is that in the first case firms do not internalize the entire expected social gain from innovative activity, so that even *laissez faire* does not provide sufficiently large incentives to innovate: a subsidy to innovative activity would actually be called for. Similarly, when innovation is likely to be harmful, firms do not fully internalize the expected social loss they cause, in spite of the fact that the strictness of regulation is increasing in the magnitude of the social harm. This is because regulation is assumed to be imperfectly enforced, since social harm is not identified with certainty and fines have limited deterrence.

# 7   The model without innovative activity

It is worth comparing the results obtained so far with those that would arise in a setting where firms can implement the actions in $A$ without exerting any investment in innovation, as it is the case within the standard model of law enforcement. As we will see, this change in assumptions drastically alters the conclusions about the optimal policies required to deal with social harm arising from the firms' actions. We consider the same regimes as in previous sections, and for each of them compute the associated expected welfare, so as to rank them.

In the *laissez-faire* regime , the expected welfare is simply that associated with action $\overline{a}$ by firms, that is, $\mathrm{E}(W_{LF}) = (1-\beta)\overline{wa} - \beta\overline{a}$.

In the authorization and liability regimes, the time lines are the same as in Section 4 and in Section 5 respectively, simply removing stage 1, in which the firm chooses the level of innovative activity. In the authorization regime, the expected welfare turns out to be

$$\mathrm{E}(W_{LA}) = (1-\beta)\overline{wa} - \beta(1-p)\underline{w}\overline{a} \tag{23}$$

if the agency is lenient in granting authorizations, and

$$\mathrm{E}(W_{SA}) = (1-\beta)p\overline{wa} \tag{24}$$

if the agency is strict.

In the penalty regime, the firm chooses the same actions identified in Lemma 2 if successful in innovating. If the innovation is socially harmful, it will choose $\widehat{a}$, as given by (12), and $\overline{a}$ otherwise. In this setting, public policy affects private incentives only through marginal deterrence, and the fine is always maximal if the probability $\beta$ of social harm is positive, as in Becker (1968). To see this, note that social welfare is

$$\mathrm{E}(W_P) = (1-\beta)\overline{wa} - \beta\underline{w}\widehat{a}(\overline{f},\underline{f}),$$

so that

$$\frac{\partial \mathrm{E}(W_P)}{\partial \overline{f}} = \beta\underline{w}\frac{p}{\pi} > 0 \ \text{ and } \ \frac{\partial \mathrm{E}(W_P)}{\partial \underline{f}} = -\beta\underline{w}\frac{p}{\pi} < 0.$$

Therefore the optimal fine schedule is $\underline{f} = 0$ and $\overline{f} = F$ for any positive $\beta$, and the expected welfare associated with the optimal policy is

$$\mathrm{E}(W_P) = (1-\beta)\overline{wa} - \beta\underline{w}(\overline{a} - \frac{pF}{\pi}). \tag{25}$$

Comparing expected welfare across the various regimes, one finds that:

**Proposition 3 (Optimal policy without innovative activity)** *When new actions do not require innovative activity, authorizations always dominate penalties, with lenient authorization for $\beta \leqslant \overline{w}/(\overline{w} + \underline{w})$ and strict authorization otherwise.*

Proposition 3 indicates that, absent innovative activity, public policies should rely exclusively on authorizations (more lenient or stricter depending on the likelihood of social harm), and *laissez faire* is never optimal. The reason for this result is that in this setting penalties have the drawback of limited deterrence, even when set at the maximum level. The authorization regime overcomes this limitations by simply barring firms from carrying out undesirable actions, a more drastic form of marginal deterrence.

This stark choice of regulatory tools is in sharp contrast with the richer array of regulatory regimes prescribed by Proposition 1 in the presence of innovative activity. In that case, authorization is optimal only when social harm is very likely, while penalties are used when it is moderately likely, and *laissez faire* is preferable when it is unlikely. In the standard model, authorization always dominates other regimes because regulation should not be concerned with hampering innovative activity: the only policy objective is to guide firms towards an optimal choice of actions, and to this purpose authorization is a more powerful tool. In contrast, if new actions require costly private investment, the regulator must also be concerned with the need to avoid discouraging innovation when it is unlikely to have harmful effects. To this purpose, authorization is too blunt a tool, hence the need to have recourse to more nuanced policies. In other words, in the standard model only marginal deterrence matters. In contrast, in the presence of innovative activity policies must be judged also on the basis of their average deterrence, that is, of their disincentive effects on innovation.

# 8 Conclusion

The literature on law enforcement has disregarded that norms may affect the decision to invest in innovative activity. We fill this gap by presenting a model where firms can invest in such an activity (e.g., R&D) and then, contingent upon successful innovation, undertake new types of production that, although privately profitable, may prove harmful to society.

In such cases, public policy should design the intervention so as to balance the prevention of social harm with the benefits from innovative activity, and therefore try to preserve firms' incentives to innovate as far as possible. We consider three different regulatory regimes: (i) *laissez faire*, (ii) a regime where innovations can be exploited commercially only if authorized, and (ii) a regime where firms are penalized *ex post* according to a legal rule if their innovations are found to be socially harmful, the severity of the penalty depending on the magnitude of social harm. We also distinguish two variants of authorization regimes: a more lenient one where firms are authorized to exploit all innovations that are not proven to be harmful, and a stricter one where only innovations that are proven to be safe are authorized.

Our key result is that the regulatory regime should become increasingly stringent as the danger of social harm increases: when such danger is very low, *laissez faire* is optimal; as the danger of social harm rises, regulation should switch to a regime of penalties, then to a lenient authorization regime, and finally to a strict one. This is because *ex-post* penalties can be calibrated to different situations of moderate social harm, whereas the more drastic nature of *ex-ante* authorization is more suited to control the commercial use of innovations that are very likely to cause social harm.

We also show that this principle is tightly connected to the assumption that the regulated firms invest in (potentially beneficial) innovative activity. If the firm can take the new actions without engaging in any preliminary research activity, the optimal form of regulation becomes the authorization regime (more or less lenient depending on the likelihood of social harm), and *laissez-faire* is never optimal, as in this case the regulator simply wishes to deter potentially harmful actions. Due to its limited deterrence, a regime based on penalties would be less effective in this case. In conclusion, we show that the regulation of innovative industries should be designed quite differently from that of traditional ones: as a general principle, it should play on a wider range of regulatory regimes, and in many circumstances it should be "softer" so as to preserve private incentives to innovate.

# Appendix

**Proof of Lemma 1.** Since in all regimes social welfare is a function of $\beta$, we shall refer to it as $W(\beta)$. The Lemma is proved in three steps. First, we show that $\mathrm{E}(W_{LA}(0)) > \mathrm{E}(W_{SA}(0))$ and $\mathrm{E}(W_{LA}(1)) < \mathrm{E}(W_{SA}(1))$. Indeed

$$\mathrm{E}(W_{LA}(0)) = \frac{\pi\overline{a}^2}{c}\left(\overline{w} - \frac{\pi}{2}\right) > \mathrm{E}(W_{SA}(0)) = \frac{\pi\overline{a}^2}{c}p^2\left(\overline{w} - \frac{\pi}{2}\right)$$

and

$$\mathrm{E}(W_{LA}(1)) = -\frac{\pi\overline{a}^2}{c}(1-p)^2\left(\underline{w} + \frac{\pi}{2}\right) < \mathrm{E}(W_{SA}(1)) = 0.$$

Second, the two expressions are decreasing in $\beta$:

$$\frac{\partial \mathrm{E}(W_{LA}(\beta))}{\partial \beta} = \frac{\pi\overline{a}^2}{c}(1 - 2p\beta)\left[-\underline{w} - \overline{w} + p\left(\underline{w} + \frac{\pi}{2}\right)\right] - \frac{\pi\overline{a}^2}{c}p\left(\overline{w} - \frac{\pi}{2}\right) < 0$$

and

$$\frac{\partial \mathrm{E}(W_{SA}(\beta))}{\partial \beta} = -2\frac{\pi\overline{a}^2}{c}(1-\beta)p^2\left(\overline{w} - \frac{\pi}{2}\right) < 0.$$

Third, both functions are convex in $\beta$:

$$\frac{\partial^2 \mathrm{E}(W_{LA}(\beta))}{\partial \beta^2} = -2p\frac{\pi\overline{a}^2}{c}\left[-\underline{w} - \overline{w} + p\left(\underline{w} + \frac{\pi}{2}\right)\right] > 0$$

and

$$\frac{\partial^2 \mathrm{E}(W_{SA}(\beta))}{\partial \beta^2} = 2p^2\frac{\pi\overline{a}^2}{c}\left(\overline{w} - \frac{\pi}{2}\right) > 0.$$

Hence, the two functions cross only once, for some $\widetilde{\beta} \in (0,1)$. ∎

**Proof of Lemma 4.** The fine (18) gives the optimal unconstrained policy. It must be compared with the admitted range of fines defined in the legal rule, $[0, F]$. First of all, notice that

$$\frac{\partial \overline{f}(\beta)}{\partial \beta} = \frac{\pi\overline{a}\left[\overline{w} - \underline{w} - \pi\right]p(2\underline{w} + \pi)}{\left[\beta p(2\underline{w} + \pi)\right]^2} > 0.$$

Setting $\overline{f}(\beta) = 0$ and solving for $\beta$ we obtain $\beta = \beta_0 > 0$ if $\overline{w} - \underline{w} - \pi > 0$. Then, for any $\beta < \beta_0$ the constraint $f \geqslant 0$ binds and we have the corner solution $\overline{f} = 0$. Analogously, setting $\overline{f}(\beta) = F = \pi\overline{a}$ and solving for $\beta$ we obtain:

$$\beta_1 = \frac{\overline{w} - \underline{w} - \pi}{\overline{w} + \underline{w} - p(\pi + 2\underline{w})} < 1. \tag{26}$$

Notice that $0 < \beta_0 < \beta_1$ if $\overline{w} - \underline{w} - \pi > 0$. Finally, for $\beta > \beta_1$ the constraint $f \leqslant F$ binds and we have the corner solution $\overline{f} = F$. ∎

**Proof of equation (22).** From Lemma 1 we know that if $\mathrm{E}(W_{LA}(\beta')) \gtreqqless \mathrm{E}(W_{SA}(\beta'))$ for any given $\beta'$, then $\beta' \lesseqqgtr \widetilde{\beta}$. Substituting $\beta' = \beta_1$ in these two expressions for expected welfare and rearranging, we obtain:

$$\mathrm{E}(W_{LA}(\beta_1)) = \frac{\pi\overline{a}^2}{c}\frac{(\overline{w} + \underline{w})^2(1-p)^2(\pi + 2\underline{w})}{2\left[\overline{w} + \underline{w} - p(\pi + 2\underline{w})\right]^2}$$

and

$$E(W_{SA}(\beta_1)) = \frac{\pi \overline{a}^2}{c} \frac{(2\overline{w} - \pi)(1-p)^2 p^2 (\pi + 2\underline{w})^2}{2 \left[ \overline{w} + \underline{w} - p(\pi + 2\underline{w}) \right]^2}.$$

From this, we have:

$$\text{sign}[E(W_{LA}(\beta_1)) - E(W_{SA}(\beta_1))] = \text{sign}[(\overline{w} + \underline{w})^2 (\pi + 2\underline{w}) - p^2 (\pi + 2\underline{w})^2 (2\overline{w} - \pi)] > 0$$

since this latter expression corresponds to $(\pi + 2\underline{w})(\overline{w} - \underline{w} - \pi)^2 > 0$ when $p = 1$, and it is therefore *a fortiori* positive when $p < 1$. Hence, we have $\beta_1 < \widetilde{\beta}$. Since $\beta_0 < \beta_1$, it follows that $\beta_0 < \beta_1 < \widetilde{\beta}$. ∎

**Proof of Proposition 1.** Let us start by considering the case in which $\pi < \overline{w} - \underline{w}$, so that $0 < \beta_0 < \beta_1$.

First, for $\beta \in [0, \beta_0]$, the penalty regime is equivalent to *laissez faire*, and the lenient authorization regime dominates the strict one since $\beta_0 < \widetilde{\beta}$. Hence, the relevant comparison is between *laissez faire* and a lenient authorization regime. Expected welfare is larger under the former, since

$$E(W_{LF}(\beta)) - E(W_{LA}(\beta)) = \frac{\pi \overline{a}^2}{c} p\beta \left[ p\beta(\frac{\pi}{2} + \underline{w}) + (1 - \beta)\overline{w} - (1 + \beta)\underline{w} - \pi \right] > 0$$

when $\beta < \beta_0$. To see this, consider that the term in the square brackets is decreasing in $\beta$, and is positive when evaluated for $\beta = \beta_0$. Hence it is positive for any $\beta < \beta_0$.

Second, let us consider the interval $\beta \in (\beta_0, \beta_1]$. Since $\beta_1 < \widetilde{\beta}$, in this interval the expected welfare in the penalty regime, $E(W_P(\beta))$, is given by the expression in the second line of (21). As this is an unconstrained maximum, it cannot be lower than the expression in the third line of (21), where the fine is set at $F$. The latter expression in turn equals the expected welfare in the lenient authorization regime, $E(W_{LA}(\beta))$, which is the preferred regime in the authorization policy for all $\beta < \widetilde{\beta}$. Hence, the penalty regime dominates the authorization regime for $\beta \in (\beta_0, \beta_1)$.

Third, for $\beta \in \left( \beta_1, \widetilde{\beta} \right]$, $E(W_{LA}(\beta)) = E(W_P(\beta))$, being both given by the expression in the third line of (21), so that the penalty regime and the lenient authorization regime are equivalent.

Fourth, for $\beta \in \left( \widetilde{\beta}, 1 \right]$ we have $E(W_{SA}(\beta)) > E(W_{LA}(\beta)) = E(W_P(\beta))$, so that the strict authorization regime dominates.

Let us complete the proof by considering the case in which $\pi \geqslant \overline{w} - \underline{w}$, so that $\beta_0 = \beta_1 = 0$. In this case, the first and second intervals considered above are empty, and only the third and fourth are not. ∎

**Proof of Proposition 2.** The level of innovative activity chosen by the firm is given by (13) in the *laissez faire* and penalty regimes, and by (5) and (7) in the lenient and strict

authorization regimes, respectively. Therefore, recalling the optimal policies in Proposition 1, for $\beta \in [0, \beta_0]$, $\widehat{I}(\beta)$ is obtained by setting $\overline{f} = 0$ in (13), which yields a constant $\pi\overline{a}/c$. For $\beta \in (\beta_0, \beta_1]$, it is obtained by setting $f = \overline{f}(\beta)$ in (13), so that

$$\widehat{I}(\beta) = \frac{\pi\overline{a}}{c} \frac{(\overline{w} + \underline{w})}{\pi + 2\underline{w}} (1 - \beta),$$

which is decreasing in $\beta$. For $\beta \in \left(\beta_1, \widetilde{\beta}\right]$, the lenient authorization and the penalty regime with maximum fine $F = \pi\overline{a}$ are equivalent, and under both regimes

$$\widehat{I}(\beta) = \frac{(1 - p\beta)\pi\overline{a}}{c} = I_{LA}(\beta),$$

which is again decreasing in $\beta$. Finally, for $\beta \in \left(\widetilde{\beta}, 1\right]$ the strict authorization regime dominates, so that innovative activity equals the expression for $I_{SA}(\beta)$ in (7), which is clearly decreasing and strictly lower than $I_{LA}(\beta)$ in (5). Hence, the optimal investment jumps down at $\beta = \widetilde{\beta}$ and decreases for higher values of $\beta$. To show the second part of the proposition, recall that the first-best level of innovative activity is $I_{FB} = (1 - \beta)\overline{w}\overline{a}/c$. This exceeds the equilibrium investment $\pi\overline{a}/c$ if $\beta$ is close to 0, since $\overline{w} > \pi$ by assumption. By the same token, if $\beta$ is close to 1 there is overinvestment: $I_{FB} < \widehat{I}(\beta) = I_{SA}(\beta) = (1 - \beta)p\pi\overline{a}/c$. ∎

**Proof of Proposition 3.** Comparing the lenient authorization and the penalty regimes yields

$$\mathrm{E}(W_{LA}) - \mathrm{E}(W_P) = \beta\underline{w}p(\overline{a} - \frac{F}{\pi}) \geqslant 0,$$

while comparing the strict authorization and the penalty regimes yields

$$\mathrm{E}(W_{SA}) - \mathrm{E}(W_P) = (1 - \beta)\overline{w}(p - 1) + \beta\underline{w}p\left(\overline{a} - \frac{pF}{\pi}\right),$$

which is positive for $\beta > \overline{w}/(\overline{w} + \underline{w})$. But using (23) and (24), one sees that $\mathrm{E}(W_{LA}) > \mathrm{E}(W_{SA})$ for $\beta \leqslant \overline{w}/(\overline{w} + \underline{w})$ and $\mathrm{E}(W_{LA}) > \mathrm{E}(W_{SA})$ otherwise. Hence, the lenient authorization regime is optimal for $\beta \leqslant \overline{w}/(\overline{w} + \underline{w})$, while strict authorization is optimal for $\beta > \overline{w}/(\overline{w} + \underline{w})$. ∎

# References

[1] Acemoglu, Daron, and Thierry Verdier (2000), "The Choice Between Market Failures and Corruption," *American Economic Review* **90**(1), 194–211.

[2] Banerjee, Abhijit V. (1997), "A Theory of Misgovernance," *Quarterly Journal of Economics* **112**(4), 1289–1332.

[3] Becker, Gary S. (1968), "Crime and Punishment: An Economic Approach," *Journal of Political Economy,* **76**, 169-217.

[4] Becker, Gary S., and George J. Stigler (1974), "Law Enforcement, Malfeasance and Compensation of Enforcers," *Journal of Legal Studies* **17**(1), 65-81.

[5] Blankfein, Lloyd (2009), "Do Not Destroy the Essential Catalyst of Risk," *Financial Times*, 8 February, 7.

[6] Glaeser, Edward L., and Andrei Shleifer (2003), "The Rise of the Regulatory State," *Journal of Economic Literature* **41**(2), 401-25.

[7] Gual, Jordi, Martin Hellwig, Anne Perrot, Michele Polo, Patrick Rey, Klaus Schmidt, and Rune Stenbacka, *An Economic Approach to Article 82*, Report for the DG Competition, European Commission. 2005.

[8] Hayek, Friedrich (1935), *Collectivist Economic Planning: Critical Studies on the Possibilities of Socialism*, London, Routledge.

[9] Hayek, Friedrich (1940), "Socialist Calculation: the Competitive 'Solution'," *Economica* **7**, 125-49.

[10] Kaplow, Louis (1995), "A Model of the Optimal Complexity of Legal Rules," *The Journal of Law, Economics and Organization,* **11**, 150-163.

[11] Krueger, Anne (1974), "The Political Economy of the Rent-Seeking Society," *American Economic Review* **64**(3), 291-303.

[12] Immordino, Giovanni, and Marco Pagano (2008), "Legal Standards, Enforcement and Corruption," *Journal of the European Economic Association*, forthcoming.

[13] Immordino, Giovanni, Marco Pagano and Michele Polo (2006), "Norms' Flexibility and Firms' Initiative," CSEF Working Paper No. 163.

[14] Immordino, Giovanni, and Michele Polo (2008), "Judicial Errors and Innovative Activity," CSEF Working Paper No. 196 and IGIER Working Paper No. 337.

[15] Mookherjee, Dilip, and Ivan P. L. Png (1994), "Marginal Deterrence in the Enforcement of Law," *Journal of Political Economy* **102**, 1039-66.

[16] Polinsky, A. Mitchell, and Steven M. Shavell (2000), "The Economic Theory of Public Enforcement of Law," *Journal of Economic Literature* **38**(1), 45-76.

[17] Posner, Richard A. (1992), *The Economic Analysis of Law*, 4th Edition. Boston: Little Brown.

[18] Rose-Ackermann, Susan (1978), *Corruption: A Study in Political Economy*, New York, NY: Academic Press.

[19] Schwartzstein, Joshua, and Andrei Shleifer (2009), "Litigation and Regulation," NBER Working Paper No. 14752.

[20] Shavell, Steven (1980), "Strict Liability versus Negligence," *The Journal of Legal Studies*, **9**, 1-25.

[21] Shavell, Steven (1984), "Liability for Harm versus Regulation of Safety," *Journal of Legal Studies,* **13**, 357-374.

[22] Shavell, Steven (1992), "A Note on Marginal Deterrence," *International Review of Law and Economics* **12**(3), 345-355.

[23] Shavell, Steven (2007), "Do Excessive Legal Standards Discourage Desirable Activity?," *Economics Letters*, **95**, 394-397.

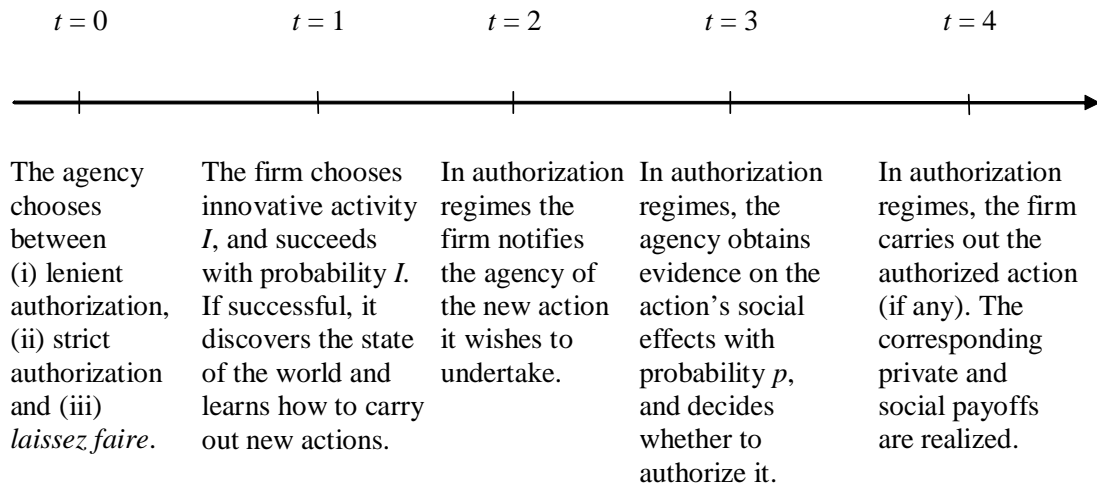[24] Stigler, George J. (1970), "The Optimum Enforcement of Laws," *Journal of Political Economy,* **78**(3), 526-536.

| $t = 0$ | $t = 1$ | $t = 2$ | $t = 3$ | $t = 4$ |



| The agency chooses between (i) lenient authorization, (ii) strict authorization and (iii) *laissez faire*. | The firm chooses innovative activity *I*, and succeeds with probability *I*. If successful, it discovers the state of the world and learns how to carry out new actions. | In authorization regimes the firm notifies the agency of the new action it wishes to undertake. | In authorization regimes, the agency obtains evidence on the action's social effects with probability $p$, and decides whether to authorize it. | In authorization regimes, the firm carries out the authorized action (if any). The corresponding private and social payoffs are realized. |

Figure 1: Time line in the authorization regimes

| $t = 0$ | $t = 1$ | $t = 2$ | $t = 3$ | $t = 4$ |



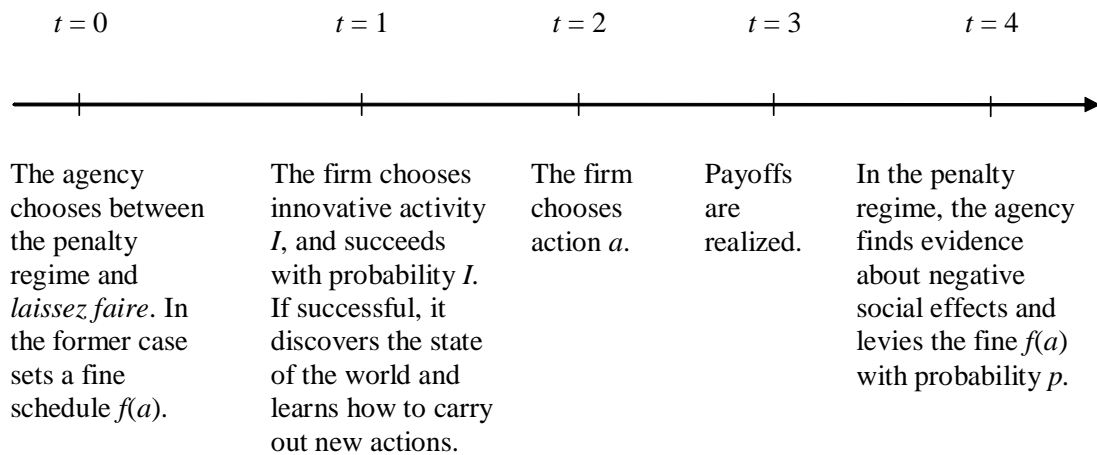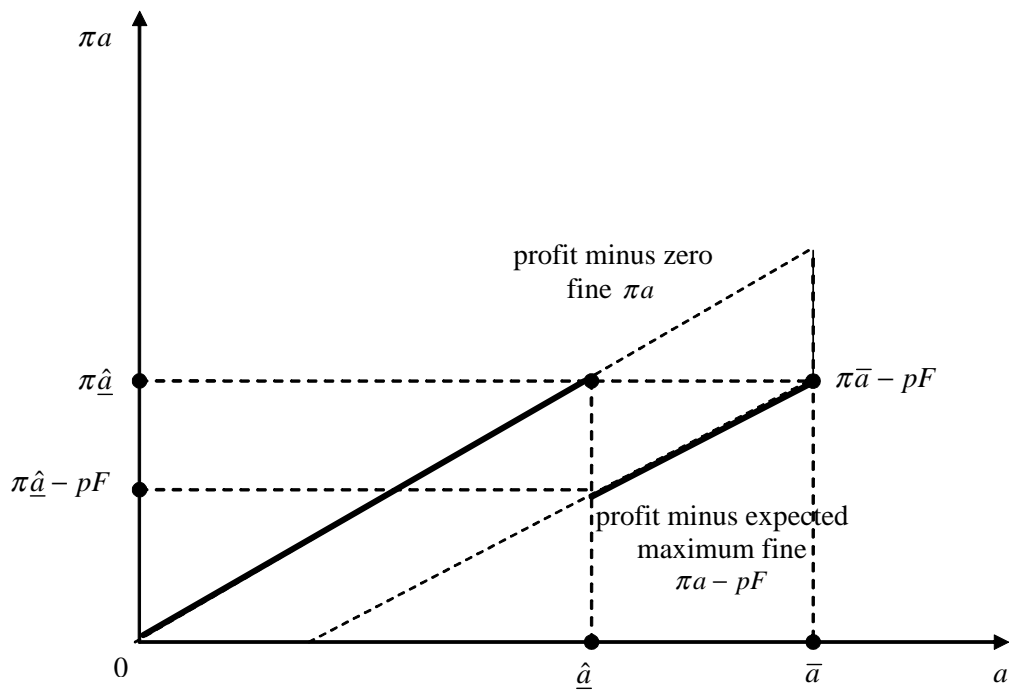| The agency chooses between the penalty regime and *laissez faire*. In the former case sets a fine schedule $f(a)$. | The firm chooses innovative activity *I*, and succeeds with probability *I*. If successful, it discovers the state of the world and learns how to carry out new actions. | The firm chooses action $a$. | Payoffs are realized. | In the penalty regime, the agency finds evidence about negative social effects and levies the fine $f(a)$ with probability $p$. |

Figure 2: Time line in the penalty regime

Figure 3: Actions, profits and fines