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Corruption and the Regulation of Innovation

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Abstract: We study the optimal design of regulation for innovative activities which can have negative social repercussions. We compare two alternative regimes which may provide firms with different incentives to innovate and produce: lenient authorization and strict authorization. We find that corruption plays a critical role in the choice of the authorization regime. Corruption exacerbates the costs of using lenient authorization, under which production of socially harmful goods is always authorized. In contrast, corruption can be socially beneficial under strict authorization, since it can mitigate an over-investment problem. In the second part of the paper, we explore the design of bonuses, taxes, and ex-post liability to improve the regulatory outcome.

JEL Codes: D73, K42, L51.

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1 Introduction

There is often uncertainty surrounding the social effects of new products or production techniques that firms have developed and would like to market or use. For instance, a pharmaceutical company may be willing to sell a drug, which may or may not entail serious side effects. Or an energy firm may adopt a new drilling technique which allows extracting oil where it was not possible before, but this extraction technique may cause some substantial damages to the environment. The possible presence of negative externalities creates a need for regulation: ideally, only the production or the adoption of those activities for which private benefits outweigh expected social costs ought to be authorized. Unfortunately, there might not be conclusive evidence about the expected externalities associated with such activities. When this is the case, a benevolent regulator faces the choice between two suboptimal regimes. A regime of *lenient authorization* whereby an activity is authorized unless conclusive evidence that it is socially harmful is collected, and a regime of *strict authorization* whereby an activity is authorized only if conclusive evidence that it is socially beneficial is collected.

In the real world, new products or technologies which may cause harm to the public are regulated differently according to their potential negative repercussions. In the case of drugs or vaccines, the risk for public safety can be extremely high.[1] Accordingly, in most countries there is an intense scrutiny before drugs can be marketed to ensure that they do not present serious risks for patients (for an international comparison of drug approval procedures, see Mulaje, 2013). Even if they often claim to treat illnesses or promise to enhance mental or sexual performance, dietary supplements are not as tightly regulated as medicines. In the U.S., following the Dietary Supplement Health and Education Act in 1994, dietary supplements are regarded as a special category of food and, consequently, are not reviewed by the Food and Drug Administration (FDA) before they are marketed to prove that they are safe and effective.[2] For innovation in other fields, the approach followed by countries or states differ. For instance, consider hydraulic fracturing for which wide scientific consensus on environmental hazard is currently lacking. In France and Vermont the regulator has adopted a strict authorization regime invoking the precautionary principle, which states that an activity should be prohibited in the absence of

[1]In 1937, a preparation called Elixir Sulfanilamide, which had not undergone safety studies caused the deaths of more than 100 people in the U.S. and is believed to have hastened the enactment of the 1938 Federal Food, Drug, and Cosmetic Act (see Ballentine, 1981).

[2]Unlike prescription drugs and over-the counter medicines, dietary supplements do not go through clinical trials before being sold. The FDA can only take the supplements off the market if they are found to be dangerous or if the manufacturers make claims that turn out to be false and misleading (see FDA own website). Recently, the FDA announced its intention to strengthen its oversight of this booming industry and warned several supplement makers that had improperly marketed their products as treatments for diseases such as the Alzheimer's. (see "FDA challenges supplement makers' marketing claims", on the Wall Street Journal, February 12, 2019).

conclusive scientific evidence proving that it is not socially harmful.[3,4] Other countries and states, especially those which are oil rich like Texas, generally allow using hydraulic fracturing, despite the absence of conclusive evidence on its environmental impact.

In this paper, we develop a simple model to study the optimal design of regulation of innovative activities which can have negative social repercussions. In doing so, we take into account that not only do these regulatory regimes impact on production choices, but they may also affect those investment decisions that ultimately lead to the development of innovative activities. Moreover, we also consider how the possibility of corruption of public officials impacts on the optimal regulatory design. While there is a large literature in economics studying the optimal regulatory design when activities generate negative externalities, few papers have considered how regulation impacts on investment decisions. Moreover, to the best of our knowledge, none has investigated the role played by the possibility of corruption in shaping the choice of the optimal regulatory regime for innovative activities.

Corruption plays a prominent role in determining the socially desirable regulatory regime because of the large private benefits that the actors involved could split. The phenomenon of regulatory capture is rife and its consequences can be devastating. For instance, the FDA's slow response to the opioid epidemic in the U.S. has been linked to the excessive proximity of the agency to pharmaceutical companies that stood to gain billions of dollars.[5] More in general, the pharmaceutical industry's interest in capturing regulators cannot be downplayed. The FDA advisory committees and panels that wield an enormous influence over the agency's approval decisions consist of renowned scientists and researchers who should be independent. While the expert members usually do not have potential conflicts of interests at the time the decisions are made, later they often receive payments or financial support from the regulated firms, as it has been recently highlighted by Piller (2018).[6] This widespread practice questions the impartiality of the advice provided by the panelists. Importantly, regulatory capture is not a phenomenon confined to developed countries. Developing countries may find it difficult to prevent capture due to their limited budgets, lower-skilled human resources, and lower accountability (for a discussion, see Estache and Wren-Lewis, 2009, and references therein). Indeed, for these countries, there is ample anecdotal evidence documenting how public officials engaged in the regulation

[3]There are several definitions of the precautionary principle, which is often invoked in international treatises. A notable definition is provided in the 1992's Rio Declaration on environment and development, whose Principle 15 reads: *"... Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."* For an economic interpretation of the precautionary principle, see Immordino (2003).

[4]For the France's and Vermont's bans on hydraulic fracturing see "France cements fracking ban" on The Guardian, October 11, 2013, and Vermont H.464 (Act 152) "An act relating to hydraulic fracturing wells for natural gas and oil production" signed by the State Governor on May 16, 2012, respectively.

[5]It is believed that the crisis is related to the frequent prescription of opioids to treat illnesses other than those for which they have been approved by the FDA. E.g., see "F.D.A. did not intervene to curb risky fentanyl prescriptions" on The New York Times, August 2, 2018, for details on the story and FDA's inactivity.

[6]Of 107 physician advisors who voted on FDA advisory committees during the period 2013-2016, 26 later received more than $\$100,000$ from drugmakers or competing firms (in payments or research funding).

or authorization of new products and techniques receive bribes to expedite and smooth the approval process.[7]

Interestingly, corruption opportunities differ between the two regulatory regimes: under lenient authorization, the public official in charge of approving production may conceal evidence unfavorable to the firm in exchange for a bribe. This collusive agreement would lead to excessive production and spur excessive investment. In contrast, under strict authorization, the public official may be willing to blackmail the firm, demanding some money under the threat that evidence favorable to the firm will be concealed if the firm refuses to give in. This does not affect allocative efficiency but discourages investment.

In the model, we consider a firm which must decide whether or not to invest resources to develop an innovative product. If the firm manages to innovate, the good may be socially beneficial or harmful, in the sense that social costs more than offset private benefits. We assume that a benevolent regulator can send a public official to collect evidence on the social harm that the innovative activity may cause. The evidence may or may not be conclusive, though, and, to make matters worse, the public official may be able to conceal the information he has found, which gives rise to corruption opportunities. The regulator chooses between the two alternative authorization regimes to maximize social welfare, taking into account the different types of corruption they engender.

Compared to lenient authorization, strict authorization is a more prudent approach because it never approves production of socially harmful goods. This upside comes at the cost of a loss of opportunity: production of goods which are socially beneficial will not be authorized when conclusive evidence is not available. When the potential negative repercussions on society outweigh such loss of opportunity, the regime of strict authorization is preferred. Notably, strict authorization is more likely to be preferred when corruption is more commonplace. Corruption dramatically exacerbates the costs of using lenient authorization, under which production of socially harmful goods would always be authorized. In turn, this spurs the firm to invest more, thereby magnifying the over-investment problem which owes to the firm's disregard for the activity's negative externalities. In contrast, corruption under strict authorization does not affect allocative efficiency but solely the distribution of the gains stemming from authorizing production of safe goods between the public official and the firm. Furthermore, corruption discourages investment as the firm anticipates that it will have to share the proceeds of the activity with the public official and this may attenuate an over-investment problem.[8]

In the second part of the paper, we explore several measures that could be adopted to improve the regulatory outcome. Firstly, we study report-based payments to the public officials to induce truthful reporting. We find that such incentive payments are more useful under lenient

[7] For instance, see "China jails former drug regulatory official for taking bribes: state media" on Reuters, January 3, 2017 where it is reported that a former official of the China Food and Drug Administration was jailed for accepting bribes to smooth drug approval processes.

[8] Over-investment may occur in a regime of strict authorization although production will not be allowed when there is no conclusive evidence that the good is safe, since the firm does not take into account the negative externalities at the investment stage.

authorization where corruption is a more vexing issue. However, preventing corruption may require giving up large rents to the public officials, making such schemes politically infeasible. Conversely, deterring corruption is less costly under strict authorization, since the extortion threat can be made empty by paying a small bonus for an informative report. Yet, the regulator may prefer not to prevent extortion as corruption may turn out to be welfare-enhancing in this regime. Secondly, we show how the ability to impose a tax on innovative activities and coordinate taxes with regulatory evidence strengthens the case for lenient authorization. If the tax can be made contingent solely on production, then the firm will have a lower tax burden the higher the likelihood of facing a corrupt public official. By properly tailoring the tax to such probability, the firm can be made to internalize the negative externalities the activity may generate and welfare will be unaffected by the likelihood of corruption. If the tax can be made contingent on the evidence collected by the public official, a regime of lenient authorization is always optimal. Intuitively, under such regime it is always possible to replicate the outcome achievable under strict authorization by adequately setting the tax. Lastly, we study ex-post liability, showing that unbounded fines make regulation redundant. If fines are bounded, regulation is still needed and we find that courts are valuable only if ex-post there are additional informative signals about product safety that can mitigate investment inefficiency.

Related Literature. Our paper relates to different strands of the economics literature on regulation. At least since the seminal paper by Becker and Stigler (1974), economists have taken into account how the possibility that enforcers can engage in corruption affects the design of regulatory institutions. Besley and McLaren (1993) and Mookherjee and Png (1995) study the optimal compensation policy for tax collectors and inspectors, respectively. The former find that paying the tax collectors efficiency wages, which deter collusion with certainty, may not be optimal. The latter study linear incentive pay and highlight that small increases in such rewards may backfire, because they may lead to higher bribes. Acemoglu and Verdier (2000) develop a more general framework to study the resources that should be devoted to correct externalities when bureaucrats can be corrupt. They provide some relevant insights on government intervention and income levels. Immordino and Pagano (2010) compare the regulatory standard chosen by benevolent and self-interested regulators when public officials can be corrupt and find evidence consistent with the benevolent regulator's model. Hiriart et al. (2010) show that ex-ante and ex-post monitors, i.e. regulators and courts, should be two separate entities and determine the set of transfers and fines which deter collusion. In our model, we study the design of regulation in a world of incomplete contracts where corruption is an equilibrium phenomenon. In Section 4, we explore alternative instruments that the regulator could adopt to improve the regulatory outcome, including transfers paid to the public officials in order to motivate information disclosure.

In the paper, we compare alternative regulatory regimes, taking into account their effects on both production and investment incentives. How regulation affects allocative efficiency and investment decision has recently attracted scholarly attention. In particular, Anderlini et al.

(2013) compare flexible and rigid legal regimes. In the former the regulatory standard is decided after the R&D investment has been made, whereas in the latter it is decided ex-ante. Calzolari and Immordino (2005) explore the role of lobbies in providing valuable information about the safety of innovative products. They find that lobbies tied to innovative producers have an advantage in providing truthful information as compared to lobbies linked with producers of traditional goods. In their analysis, there are neither corruption opportunities nor an independent agency collecting evidence on product safety. Schwartzstein and Shleifer (2013) assume that both regulators and courts can collect information about product safety and investigate whether authorization from the regulatory body should provide firms with safe harbor from future negligence penalties. They find that this is indeed the case if social returns to activities are sufficiently large. Our paper is more closely related to Immordino et al. (2011) who assume that there might not be conclusive evidence about product safety and compare lenient and strict authorization regimes which provide firms with different incentives to innovate and produce.[9] Our contribution to this ongoing debate on the optimal regulatory regime is to explicitly allow for corruption and to highlight how different instruments should be profitably tailored in this context to align private and social interests. Lastly, akin to us, Harstad and Svensson (2011) allow for corruption in a model where regulation affects investment incentives. In addition to bending the rules to avoid compliance costs (bribery), they also allow for lobbying, that is, spending resources to relax existing rules. In their model, there is no uncertainty about the magnitude of the externality and there is no comparison of alternative authorization regimes.

Outline. The remainder of the paper proceeds as follows. Section 2 describes the set-up and presents two benchmarks. Section 3 carries out the positive analysis of the set-up. Section 4 explores several instruments that can be available to the regulator to improve the regulatory outcome. Section 5 provides some concluding remarks. All proofs are relegated in the Appendix.

2 Setup

A profit-maximizing firm (it) must decide the level of R&D expenditures to develop a new production technology or a marketable product. The problem of the benevolent regulator (he) is to decide whether or not to authorize the use of the innovation which may exhibit negative externalities. At the beginning of the game, the regulator commits to a policy, being aware of its incentive effects on the firm's investment decision.

In stage 1, the firm decides on the innovation intensity $I \in [0, 1]$, which coincides with the probability of a breakthrough, at cost $\frac{cI^2}{2}$ with $c > 0$. If no innovation is discovered, the firm produces a standard good which gives profits normalized to 0. If innovation is successful, the firm can produce the new product which would yield gross profits Π. In stage 2, neither the firm

[9] See also Immordino and Polo (2014) who compare different legal standards, which determine the conditions under which a practice is unlawful, and the enforcement policy, namely the sanctioning rule if the firm is found guilty.

nor the regulator know whether the good is socially beneficial or not. However, it is common knowledge that the activity will generate an expected harm (or negative externality) h, which is distributed on the interval $[0, H]$ according to the distribution $G(\cdot)$, with continuous density $g(\cdot)$ on $(0, H)$. It holds that $H > \Pi > 0$. Therefore, the innovation is socially harmful, and the good should not be produced, if $h > \Pi$. In this case, we say that the state is unsafe. Conversely, if $h \leq \Pi$, that is, the state is safe, the innovation would be socially beneficial, even though it may generate some negative externalities. Throughout, we assume that $c \geq \Pi$, which guarantees that $I \leq 1$ in equilibrium. This requires the marginal cost of the investment in R&D to be sufficiently large so that the firm would never make sure that a breakthrough is achieved with probability 1.[10] In what follows, it will often be useful to compare activities which involve different harm distributions on $[0, H]$. Specifically, consider two distribution $F(\cdot)$ and $G(\cdot)$ on $[0, H]$. We will say that the activity identified by distribution $F(\cdot)$ is *more harmful* than the activity identified by distribution $G(\cdot)$ if distribution $F(\cdot)$ conditionally stochastically dominates distribution $G_B(\cdot)$, that is:

$$\frac{f(h)}{F(h)} \geq \frac{g(h)}{G(h)} \quad \text{for all } h \in (0, H). \tag{1}$$

This means that the first-order stochastic dominance relation holds for every left-tail distribution.

2.1 Benchmarks

We consider two benchmarks against which alternative regulatory regimes must be compared.

First, we illustrate the *first-best outcome* that would be achieved if a benevolent regulator could control investment and production choices directly. Such regulator would produce only if the innovation were socially beneficial, namely in the safe state. Therefore, first-best investment is determined from:

$$I^* = \arg\max_{I \in [0,1]} \quad I \int_0^{\Pi} (\Pi - h) g(h) dh - \frac{cI^2}{2},$$

so that the optimal investment is:

$$I^* = \frac{\int_0^{\Pi} (\Pi - h) g(h) dh}{c}. \tag{2}$$

The optimal investment is increasing in the probability that the good is safe and the net social benefit of the safe product. A higher marginal cost of innovation reduces the optimal investment. Expected social welfare in this first-best world is:

$$W^* = \frac{\left(\int_0^{\Pi} (\Pi - h) g(h) dh\right)^2}{2c}. \tag{3}$$

The second benchmark we contemplate is a regime of *laissez-faire*, namely one where the regulator never intervenes. Being unfettered, the innovative firm would always produce an innovative

[10] With the sole exception of the case in which $\Pi = c$ and the firm is always allowed to produce and reaps all the profits.

product, irrespective of its social repercussions. Under laissez-faire, the investment in innovation is determined from the following expression:

$$I^{LF} = \arg\max_{I\in[0,1]} I\Pi - \frac{cI^2}{2},$$

which yields

$$I^{LF} = \frac{\Pi}{c} \leq 1. \tag{4}$$

Comparing (4) to (2) it is immediate to see that whenever the activity generates some negative externality there would be too much investment from a social viewpoint. Social welfare in a regime of laissez-faire is:

$$W^{LF} = \frac{\Pi\left[\Pi - 2\Big(\int_0^H hg(h)dh\Big)\right]}{2c}. \tag{5}$$

The rationale for regulation of innovative activities is provided by the positive wedge existing between (5) and (3). A regime of laissez-faire would give rise to excessive innovation and lead to production even when the newly-developed product is socially harmful.

Note that if a benevolent regulator could outright prohibit or authorize innovative activities but could not obtain evidence of the product safety, its guidelines should be the following: innovation activities should be allowed only if $\Pi \geq 2E_g(h)$, where $E_g(h) := \int_0^H hg(h)dh$. As a result, innovative activities would be more likely to be *per-se* legal when the externality that they are expected to bring about is lower.

3 Regulation of Innovative Activities

In this section, we assume that the regulator can send a public official (she) to collect evidence about the social benefits of the innovative good, i.e. whether it is socially harmful or not, after a breakthrough occurs. Conclusive evidence about the social repercussions of producing the good is found with probability $p < 1$. Specifically, the public official observes the true level of harm with probability p and does not collect any conclusive evidence with complementary probability $1-p$.[11] The regulator can condition the authorization of production on the evidence reported by the public official. As mentioned in the introduction, we distinguish between two authorization regimes. In a lenient authorization regime, the firm is allowed to produce unless there is conclusive evidence that the good is unsafe. In a strict authorization regime, the firm is allowed to produce only if there is conclusive evidence that the good is safe. The difference between the two approaches emerges when there is no conclusive evidence about the social harm which can be caused by the production of the good. Our aim is to determine the optimal authorization regime and relate it to the severity of the corruption concerns.[12]

[11] We can relax this assumption. For instance, all results go through if we assume that with probability p the public official observes a signal $\tilde{h} = h + \epsilon$, where ϵ is a normally distributed random variable with mean 0 and variance $\sigma_\epsilon^2 > 0$.

[12] We do not allow for *mixed authorization regimes*, whereby the firm is allowed to produce only if the reported social harm is below some threshold different from Π. This restriction can be justified by noticing that such mixed

3.1 Honest public officials

Suppose first that there are no corruption opportunities. For instance, the benevolent regulator himself collects evidence about the social effects of producing the good.

Lenient authorization. In a regime of lenient authorization, production of beneficial goods will always be allowed, whereas production of socially harmful goods will be prohibited with probability p. Therefore, lenient authorization may lead to type-II errors, namely approval of production of unsafe goods. In this authorization regime, the firm's investment decision in stage 1 solves:

$$I^{LA} = \arg\max_{I\in[0,1]} \quad I\left[p\int_0^{\Pi} \Pi g(h)dh + (1-p)\Pi\right] - \frac{cI^2}{2}.$$

Therefore, the optimal investment satisfies the following:

$$I^{LA} = \frac{\Big[1-p(1-G(\Pi))\Big]\Pi}{c}. \tag{6}$$

Investment is always above the first-best level, although it is lower than the one that would be chosen in a regime of laissez-faire if $I^{LA} < 1$. The level of welfare attained in a regime of lenient authorization is given by:

$$W^{LA} = I^{LA} \underbrace{\left[p\int_0^{\Pi} (\Pi-h)g(h)dh + (1-p)\int_0^{H} (\Pi-h)g(h)dh\right]}_{w^{LA}} - \frac{c(I^{LA})^2}{2}, \tag{7}$$

where w^{LA} represents the *surplus* due to activity authorization. Note that (7) can also be written as:

$$W^{LA} = \frac{\Big[(1-p)+pG(\Pi)\Big]^2\Pi^2}{2c} - \frac{\Big[1-p+pG(\Pi)\Big]\Pi}{c}\left[(1-p)E_g(h) + p\int_0^{\Pi} hg(h)dh\right].$$

The following lemma carries out some comparative statics on I^{LA} and W^{LA}.

Lemma 1. *An increase in p reduces investment and increases welfare. More harmful activities always lead to lower investment and unambiguously decrease welfare if $\int_0^{\Pi} hf(h)dh \geq \int_0^{\Pi} hg(h)dh$, where $F(\cdot)$ conditionally stochastically dominates $G(\cdot)$ for all $h \in (0,H)$.*

A higher precision of the signal collected by the public official unambiguously increases welfare because it reduces the likelihood that unsafe products will be authorized. This attenuates the over-investment problem and improves the set of activities that are produced. More harmful activities reduce the probability of producing the good and, as a result, lead the firm to invest less. Furthermore, they always adversely affect welfare unless they also reduce the surplus associated with the authorization of safe activities.

regimes are not "renegotiation-proof", that is, the regulator cannot commit to ban (authorize) activities that are socially beneficial (harmful). Put differently, if there is conclusive evidence that $\Pi > (<)h$, the regulator must authorize (prohibit) production.

Strict authorization. If authorization is strict, socially harmful goods are never produced but some socially beneficial goods may be prohibited too. In other words, strict authorization may lead to type-I errors, namely prohibition of production of safe goods. The firm's investment decision at stage 1 solves:

$$I^{SA} = \arg\max_{I\in[0,1]} \quad I\left[p\int_0^{\Pi}\Pi g(h)dh\right] - \frac{cI^2}{2}.$$

Therefore:

$$I^{SA} = \frac{p\Pi G(\Pi)}{c}. \tag{8}$$

A higher p increases the probability that evidence that the good is safe is uncovered allowing production. Therefore, a higher p is associated with a higher investment. Accordingly, the equilibrium investment is greater than the first-best level when p is sufficiently high:

$$p > \frac{\int_0^{\Pi} G(h)dh}{G(\Pi)\Pi}.$$

Welfare that would arise in a regime of strict authorization is:

$$W^{SA} = I^{SA}\left[p\int_0^{\Pi}(\Pi - h)g(h)dh\right] - \frac{c(I^{SA})^2}{2}. \tag{9}$$

Note that the above expression can also be rewritten as:

$$W^{SA} = \frac{[pG(\Pi)\Pi]^2}{2c} - \frac{p^2G(\Pi)\Pi}{c}\int_0^{\Pi} hg(h)dh.$$

Comparative statics on I^{SA} and W^{SA} is illustrated below.

Lemma 2. *A higher p always increases investment, whereas it positively affects welfare only if:*

$$\Pi \geq 2E_g(h|h \leq \Pi).$$

More harmful activities depress investment and reduce welfare.

When then signal is more precise, there is a higher chance that a safe product is authorized, which boosts the firm's investment incentives. A more accurate signal is also beneficial for welfare when the gross profits Π are substantially larger than the expected negative externality caused by the authorized activity. More harmful activities are detrimental to investment and welfare: for a given Π, production will be authorized less often and its associated surplus will be lower.

The optimal second-best regime in the absence of corruption is determined by comparing W^{SA} and W^{LA}. In Proposition 1, we show under what condition the regime of lenient authorization is preferred to one of strict authorization.

Proposition 1. *When all public officials are honest, the benevolent regulator prefers a regime of lenient authorization to one of strict authorization if and only if:*

$$\Pi \geq 2\left(\frac{(1-p+pG(\Pi))E_g(h)+p\int_0^{\Pi} hg(h)dh}{1-p+2pG(\Pi)}\right).$$

A marginal increase in p makes it more likely that lenient authorization is preferred to strict authorization if $E_g(h|h \geq \Pi) \geq E_g(h|h \leq \Pi)$. More harmful activities make strict authorization more desirable if

$$\int_0^{\Pi} hf(h)dh \geq \int_0^{\Pi} hg(h)dh,$$

where $F(\cdot)$ conditionally stochastically dominates $G(\cdot)$ for all $h \in (0, H)$.

Proposition 1 shows that lenient authorization is preferred when the net social benefit of the safe product is above a threshold value. Consider that strict authorization is a more prudent approach because an unsafe product is never produced. However, it entails some costs due to the lost opportunity of producing a safe product when there is no conclusive evidence of its effects on society and $\int_0^{\Pi}(\Pi - h)g(h)dh$ measures the value of such lost opportunity. In contrast, lenient authorization is a more daring approach because the good may be produced despite being unsafe. Accordingly, this regime fosters R&D investment, but it entails a high cost for the society when the unsafe product is authorized in the absence of conclusive evidence of its negative social repercussions. For activities which are relatively less harmful, the benevolent regulator should be more inclined to use a lenient authorization regime not to lose out on the opportunities they entail.[13] A more accurate signal reduces the probability that unsafe goods are authorized under lenient authorization, whereas it raises that chances that safe goods are approved under strict authorization. As a result, an increase in p makes lenient authorization relatively more desirable than strict authorization if the expected benefits of avoiding production of unsafe goods outweigh the expected benefits of producing safe goods.

3.2 Corrupt public officials

Is the optimal design of regulation affected by the presence of corruptible public officials? The assumption that all public officials are incorruptible and pursue the public good may be far-fetched. As argued in the introduction, capture of public officials who can grant approval of new products or processes is rife, especially in countries with weak institutions. In this subsection, we deal with the other polar, and admittedly unrealistic, case in which public officials are all corruptible.

In the analysis that follows we assume that a corruptible public official may be willing to conceal conclusive evidence about the social effects of the innovation in exchange for an amount

[13] Drugs which show promise in treating serious conditions and fill unmet medical needs can be granted earlier approval through the FDA's Accelerated Approval Program (see https://www.fda.gov/drugs/resourcesforyou/healthprofessionals/ucm313768.htm). This is consistent with the result that activities which may exhibit greater social benefits should not be subject to a strict authorization regime.

of money b paid by the firm. Clearly, this is a short-cut to model the phenomena of corruption and regulatory capture. Bribes may take various forms which include, but are not limited to, direct monetary transfers. Other forms can be non-monetary gifts, the promise of a future full-time job or side-hustle for the public official or for a relative, and other exchanges of favors.

Following Tirole (1986) and Laffont and Tirole (1991), we say that the information collected by the public official is hard. This implies that conclusive evidence cannot be forged. That is, a public official who has not obtained conclusive evidence cannot report that she has observed the level of expected harm the activity would bring about. However, evidence can be concealed, i.e., if the public official has observed h, she can report either h or nothing.

We make the following assumptions concerning how the collusion sub-game plays out. The parties are assumed to have symmetric information about the evidence collected by the public official and bargain cooperatively according to the generalized Nash bargaining solution in which the firm receives a share $\alpha \in [0, 1]$ of the gains from collusion. We further assume that the side-contract between the parties is perfectly enforceable.[14]

The two authorization regimes have remarkable implications for the types of corruption opportunities. We denote the solutions when public officials are corrupt by the subscript C.

Lenient authorization. In a lenient-authorization regime, the parties could negotiate a bribe in exchange of which the public official conceals evidence that the good is socially harmful, since the lack of decisive information about the good does not prevent production. In other words, this authorization regime is exposed to the issue of *collusion*. The firm's threat point is nil because, if the information is revealed, the firm will not be allowed to produce the good. Similarly, the public official's threat point is zero because she does receive the same salary - which we have normalized to zero - irrespective of the content of the report. Therefore, the bribe solves the following:

$$b = \arg\max_{b \in \mathbb{R}} \quad b^{1-\alpha}(\Pi - b)^{\alpha},$$

whose solution gives $b_C^{LA} = (1 - \alpha)\Pi$ and the public official only enjoys $(1 - \alpha)\Pi$. Since there are obvious gains from colluding, production will always be allowed, even when there is evidence revealing that the good is socially harmful. However, in deciding the investment level, the firm will take into account that, in the case of a breakthrough, with probability βp the public official will authorize production but will reap a fraction $(1 - \alpha)$ of the net private gains. Therefore, the investment decision will be made to maximize the following:

$$I_C^{LA} = \arg\max_{I \in [0,1]} I \left[p \int_0^{\Pi} \Pi g(h) dh + (1 - p)\Pi + p\alpha \int_{\Pi}^{H} \Pi g(h) dh \right] - \frac{cI^2}{2}.$$

As a result, the investment in innovation satisfies:

$$I_C^{LA} = \frac{[1 - p(1 - G(\Pi))(1 - \alpha)]\Pi}{c}. \tag{10}$$

[14]There are several complementary mechanisms which can ensure that the parties will adhere to the side-contract, that we leave exogenous and we do not explicitly model. These include reputation, emotions, and reciprocity, and are discussed in the literature on corruption in hierarchies. For instance, see Tirole (1992), Vafaï (2002), and Vafaï (2010).

If $\alpha = 1$, namely if the firm holds all the bargaining power, the investment decision is the same as under laissez-faire. A lower α has a negative impact on the firm's investment choice because it means that the profit share accruing to the public official is larger. Irrespective of the value taken by α, there is always over-investment in this regime. Welfare in a regime of lenient authorization is:

$$W_C^{LA} = I_C^{LA}\Big[\int_0^H (\Pi - h)g(h)dh\Big] - \frac{cI_C^{LA}}{2}. \tag{11}$$

Replacing the value of I_C^{LA} found in (10), we get:

$$W_C^{LA} = \frac{[1 - p(1 - G(\Pi))(1-\alpha)]\Pi}{c}\left(\frac{[1 + p(1 - G(\Pi))(1-\alpha)]\Pi}{2} - E_g(h)\right).$$

For activities which are more harmful, the consequences of granting authorization are more socially detrimental but the over-investment problem is less prominent. As expected, the presence of corrupt public officials causes a reduction in social welfare when authorization is lenient, because it magnifies the over-investment problem and leads to excessive production.

Strict authorization. With strict authorization, bribery may occur if the public official has collected conclusive evidence that is favorable to the firm: By concealing such information, the firm would not be allowed to produce. Hence, in this regime, corruption takes the form of *extortion* or *blackmail*. The public official would be willing to follow through on her threat to conceal evidence if the parties do not find an agreement because she is indifferent between reporting truthfully and concealing the collected evidence. However, since there is evidence available showing that the good would be socially beneficial, we also assume that the firm can appeal the public official's decision and with probability $\gamma \in [0, 1]$ it wins and is allowed to produce. The public official does not suffer any loss if the firm wins the appeal. The parameter γ represents the strength of the country's institutions and higher values imply that the public official is able to extract less surplus in the bargaining with the firm. In particular, the firm knows that if bargaining with the public official breaks down, it can appeal the decision, getting $\gamma\Pi$. Therefore, better institutions improve the firm's threat point in the bargaining with the public official. The bribe will be determined from the following:

$$b = \arg\max_{b\in\mathbb{R}} \quad b^{1-\alpha}[(1-\gamma)\Pi - b]^{\alpha},$$

which leads to $b_C^{SA} = (1-\alpha)(1-\gamma)\Pi$. The investment decision is determined by the following expression:

$$I_C^{SA} = \arg\max_{I\in[0,1]} I\left(p\int_0^{\Pi}(\Pi - b_C^{SA})g(h)dh\right) - \frac{cI^2}{2},$$

that is, replacing the value of b_C^{SA}:

$$I_C^{SA} = \arg\max_{I\in[0,1]} I\left(p\int_0^{\Pi}[\gamma + \alpha(1-\gamma)]\Pi g(h)dh\right) - \frac{cI^2}{2}.$$

The firm anticipates that if the investment is successful, it will be allowed to produce the good only if conclusive evidence is found. However, the firm will reap only a fraction $\gamma + \alpha(1-\gamma)$ of the benefits. Therefore, if $\alpha = 1$, the firm is in the same situation as when the public official is always honest, whereas it only obtains a fraction γ of the profits if $\alpha = 0$. The equilibrium investment level satisfies:

$$I_C^{SA} = \frac{p[\gamma + \alpha(1-\gamma)]G(\Pi)\Pi}{c}. \tag{12}$$

Welfare gives:

$$W_C^{SA} = I_C^{SA}\left(p\int_0^\Pi (\Pi - h)g(h)dh\right) - \frac{c(I_C^{SA})^2}{2}. \tag{13}$$

Replacing the value of I_C^{SA}, welfare can be rewritten as:

$$W_C^{SA} = \frac{p[\gamma + \alpha(1-\gamma)]G(\Pi)\Pi}{c}\left[\frac{pG(\Pi)\Big[1 + (1-\gamma)(1-\alpha)\Big]\Pi}{2} - p\int_0^\Pi hg(h)dh\right].$$

Social welfare attainable in a regime of strict authorization is affected by the possibility of corruption. As a result, both the bargaining power distribution and the strength of the institutions matter for welfare purposes. A more accurate signal p has a dampened effect on investment incentives because a share of the gross profits is reaped by the corrupt public official. Conversely, a higher p continues to increase the likelihood that a safe product is authorized. Accordingly, when there is corruption, the threshold value above which p has a positive impact on welfare is lower.[15]

As stated in the following proposition, strict authorization dominates lenient authorization when Π is sufficiently small.

Proposition 2. *When public officials are corrupt, the regulator prefers a regime of lenient authorization to one of strict authorization if and only if the following inequality holds:*

$$\Pi \geq 2\frac{[1 - p(1 - G(\Pi))(1-\alpha)]E_g(h) + p^2[\gamma + \alpha(1-\gamma)]G(\Pi)\int_0^\Pi G(h)dh}{1 - p^2\Big[(G(\Pi))^2 + (1-\alpha)^2[1 - (2-\gamma)G(\Pi)][1 - \gamma G(\Pi)]\Big]}.$$

In a regime of strict authorization, corruption may turn out to be good for welfare. To understand why, consider that even in a regime of strict authorization there might be over-investment as the firm does not internalize the external effects caused by production. When public officials are corrupt, the firm is less willing to invest because it anticipates that it will enjoy only a fraction of the gains from production. Therefore, corruption acts in the same fashion as an indirect tax, mitigating the over-investment problem and leading to higher welfare.

In Figures 1 and 2, we graphically compare social welfare in the two regimes as a function of p.[16] The solid (dashed) lines represent welfare when public officials are all honest (corrupt). Given the parametric assumptions, welfare rises in both regimes with the probability of finding conclusive evidence, p. In the absence of corruption, a meaningful difference between lenient

[15] We formally prove this claim in the proof of Proposition 2.

[16] In drawing the figures, we have assumed that the distribution of h has a point mass at 0 to lessen the expected negative externality caused by the activity. This stands in contrast to what is assumed in the model and is done for illustrative purposes only. Relaxing this distributional assumption in the analysis would make the computations more cumbersome without qualitatively affecting the results.

and strict authorization arises when the signal is not very precise. Indeed, when p tends to 1, welfare in the two regimes coincide. Corruption unequivocally reduces the benefits of lenient authorization, whereas it might be beneficial under strict authorization, as in the cases illustrated in the figures.

When the expected harm is relatively low as compared to the gains stemming from production, it is socially desirable to adopt lenient authorization. Being a more daring approach, lenient authorization allows enjoying the benefits of production more frequently. This is so unless there is corruption, in which case the shortcomings of lenient authorization (excessive production and overinvestment) are exacerbated, which make strict authorization more attractive. This scenario is illustrated in Figure 1: Lenient authorization always outperforms strict authorization in the absence of corruption. Instead, if public officials are corrupt, strict authorization becomes socially desirable when the signal is accurate enough (i.e., for $p \geq 0.664$).

In contrast, when the expected negative externality is relatively high as compared to the benefits of production, it is better to ban production of innovative activities when the signal is not very accurate. As a matter of fact, welfare under lenient authorization may even be negative. This scenario is illustrated in Figure 2, wherein lenient authorization outperforms strict authorization only if there is no corruption and p is sufficiently high (i.e., higher than 0.444).

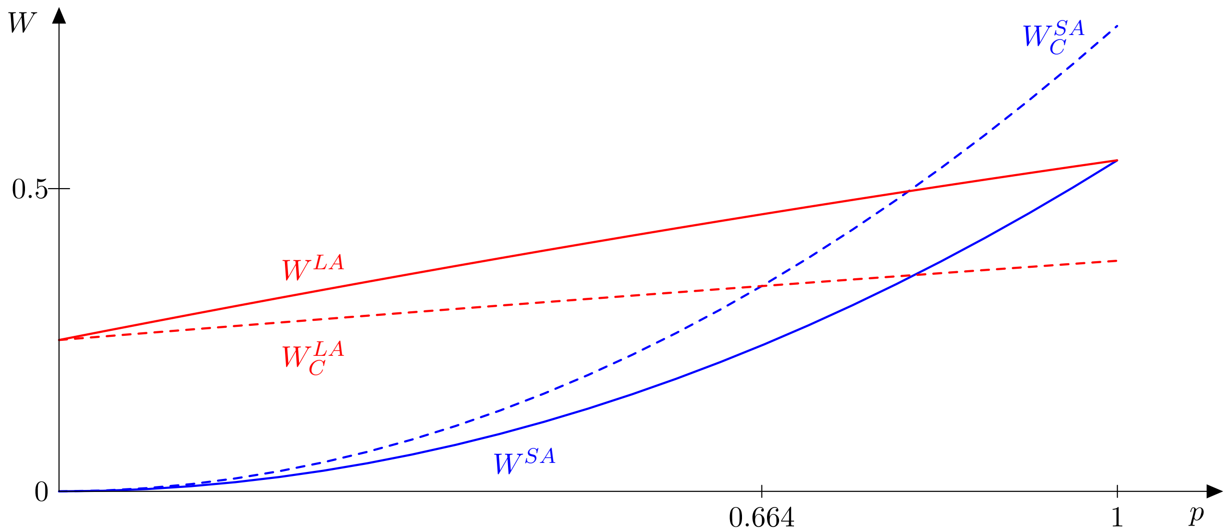

Figure 1: Welfare in the different authorization regimes. The figure is drawn assuming the following values for the parameters: $\Pi = 5$, $c = 5$, $\alpha = 0.5$, $\gamma = 0.5$ and h has a point mass of 0.25 at 0 and is distributed according to the Uniform Distribution on $(0, H]$, where $H = 6$.

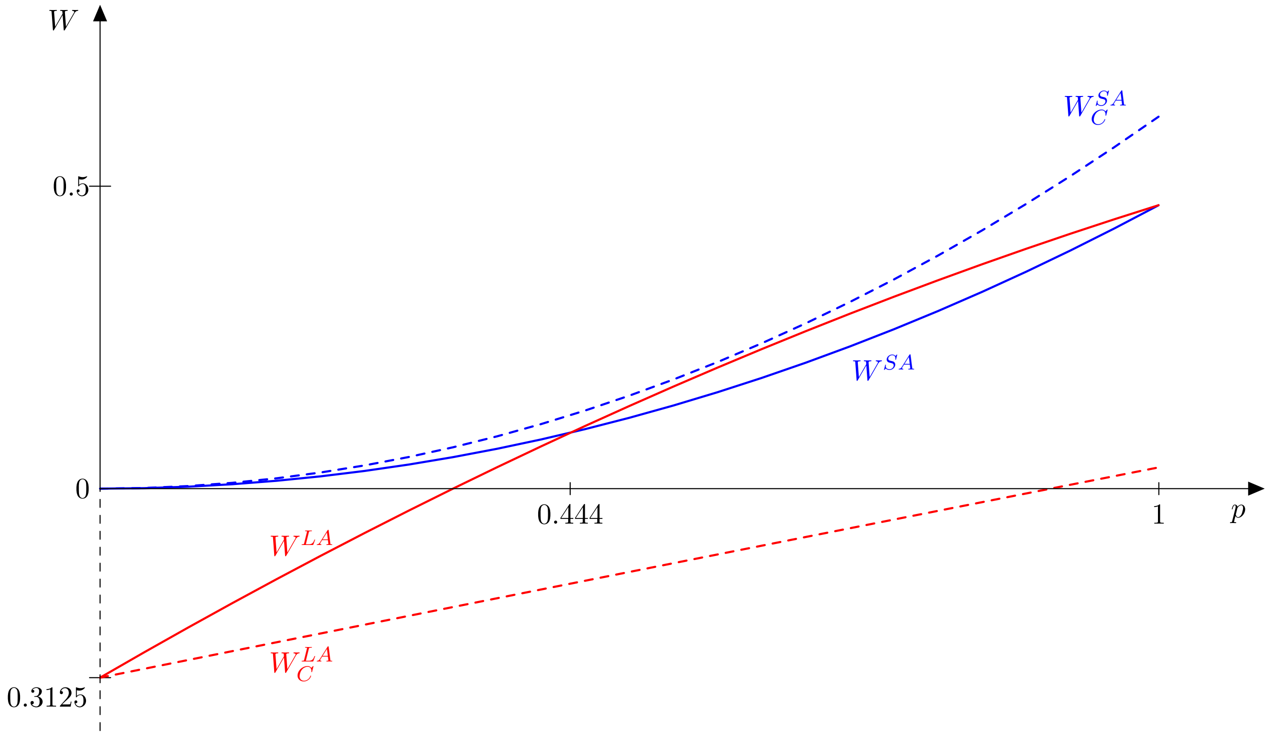

Figure 2: Welfare in the different authorization regimes. The figure is drawn assuming the following values for the parameters: $\Pi = 5$, $c = 5$, $\alpha = 0.5$, $\gamma = 0.5$ and h has a point mass of 0.25 at 0 and is distributed according to the Uniform Distribution on $(0, H]$, where $H = 7.5$.

3.3 Heterogeneous public officials

Now we carry out the analysis for the more general and realistic setting in which only a fraction of the public officials are corruptible. In particular, we assume that a public official is honest with probability $\upsilon \in [0, 1]$ so as to encompass the cases described in the previous subsections. The public official's type is her private information and the firm learns her type at the bargaining stage. Akin to Besley and McLaren (1993), we make the assumption that preference for an honest behavior is immutable. This implies that an honest public official values her integrity more than any bribe she could extract from the firm. In contrast, a dishonest public official is merely interested in maximizing her income.

In both regimes, the pervasiveness of corruption in the population has an indirect effect on welfare through its impact on the firm's investment incentives. In a regime of lenient authorization, corruption also worsens the pool of products which are authorized. Before studying the overall impact of corruption on welfare, it is useful to define the following function:

$$\Gamma \equiv \upsilon + (1 - \upsilon)[\gamma(1 - \alpha) + \alpha].$$

The above function Γ represents the fraction of the gross benefits Π that accrues to the firm if there is evidence that the good is safe in a regime of strict authorization. It is immediate to see that Γ is increasing in all its arguments: that is, the higher the fraction of honest public officials, the stronger the institutions, the larger the share of the corruption gains which are seized by the firm, the higher Γ. Proposition 3 shows the impact of a change in the likelihood of facing an honest public official, υ, on welfare in the two regimes and represents one of the chief results of the paper.

Proposition 3. *The impact of an increase in υ on welfare*

(a) is always positive in a regime of lenient authorization;

(b) is negative in a regime of strict authorization if

$$\Gamma > \frac{\int_0^{\Pi} (\Pi - h) g(h) dh}{\int_0^{\Pi} \Pi g(h) dh}, \tag{14}$$

where this inequality is more likely to hold when the activity is more harmful.

This section has shown that corruption plays a very critical role in determining which regulatory regime to adopt. While corruption is always detrimental to welfare under lenient authorization, it may actually be beneficial under strict authorization.

In a regime of lenient authorization, a higher fraction of honest public officials in the population increases the chances that an unsafe product will be prohibited. In addition to improving ex-post efficiency, an increase in υ also mitigates the over-investment problem that affects the lenient authorization regime. This is because the firm anticipates that production will be authorized less often. Therefore, there is an unambiguously positive relationship between υ and welfare in a regime of lenient authorization.

More surprisingly, in a regime of strict authorization, welfare may be adversely affected by an increase in the fraction of honest public officials. Note first that υ does not affect the authorization outcome but only the distribution of the gains between the firm and the public official. In this regime, a higher level of υ encourages R&D investment as the firm anticipates that it will be more likely that it will reap all the gains stemming from the innovation when there is evidence that the product is safe. For this reason, an increase in υ may exacerbate an over-investment problem. This negative effect on welfare is more likely to occur when Γ is high. Intuitively, the higher the fraction of the gross benefits that the firm obtains, the more likely it is that there is an overinvestment from a social standpoint. Therefore, an increase in υ (or in γ or α) magnifies the over-investment problem when Γ is already large enough. Therefore, one should be wary of institutional improvements that increase the value of these parameters (e.g., γ) as they may backfire. An increase in υ is more likely to have a detrimental effect on welfare for more harmful activities. Intuitively, stimulating investment is less desirable when its social return is lower. Referring to Figures 1 and 2, for those values of the parameters, the level of welfare in the regime of lenient (respectively, strict) authorization as a function of β is a curve which lies between W_C^{LA} and W^{LA} (resp., W_C^{SA} and W^{SA}).

4 Additional Policy Instruments

In this section, we examine separately how bonuses, taxation, and liability could be used to improve the regulatory outcome.

4.1 Wage policy

In the previous section, we did not solve for the optimal corruption-proof mechanism, that is, we did not work out a system of report-contingent transfers paid to the public official to preempt corruption. Despite the well-established argument made in their favor in the economics literature, such schemes are little used in practice. According to some scholars, such schemes might be infeasible because of the very high payments to public servants they might entail (see Dal Bó, 2006, and Estache and Wren-Lewis, 2009). We abstract from this implementation issue below and we study the features of the optimal salary schemes.

We assume that the regulator announces non-negative salaries to the public official which are contingent on the report, $s_r \geq 0$, where $r \in \{h, \emptyset\}$. In line with the existing literature in regulation (e.g., see Laffont and Tirole, 1993), we assume that paying 1\$ salary to the public official costs $(1 + \lambda)$\$ to the regulator, where the parameter $\lambda \geq 0$ represents the inefficiency associated with raising public funds. We discuss in turn how the wage policy should be designed in the two authorization regimes. We focus on the more general scenario developed in Section 3.3 and we denote the solutions by the subscript G.

Lenient authorization. In this regime, the regulator may want to induce corruptible public officials to report evidence that the activity is unsafe. As a result, without loss of generality, we can impose $s_\emptyset = 0$ and $s_h = 0$ for all $h < \Pi$. The stake of corruption in this regime is equal to Π, the gross profit the firm obtains if production is allowed when there is evidence of its unsafety. Therefore, to induce a corruptible public official who has observed $h \geq \Pi$ to truthfully report this information, it must be that the salary she receives is at least Π. In order to completely weed out corruption, the regulator should pay $s_h = \Pi$ whenever $h \in [\Pi, H]$. However, this policy may be unappealing if $\lambda > 0$ and all the more so if the fraction υ of the public officials in the population is larger. This is because honest public officials need not receive a reward to truthfully report evidence. In what follows, we maintain two assumptions. First, the regulator would ban production if the surplus the activity generates, w_G, were negative. Second, we make the following parametric assumption.

Assumption 1. *For all $h \in [0, H]$, it holds that $g(h) + hg'(h) > 0$.*

This assumption is always satisfied if $G(\cdot)$ is (weakly) convex or if it is not overly concave. Its implication is that the regulator prioritizes deterring corruption for larger than smaller states of the world as shown in the following lemma.

Lemma 3. *The regulator prefers to prevent corruption for larger than smaller states.*

When the difference between the expected externality and the firm's gross profit is not very large, the regulator may prefer to tolerate collusion. That is, if the regulator ever tolerates collusion, he prefers that the welfare loss is minimized. In the maximization problem, we determine the threshold level $h_L \in [\Pi, H]$ above which collusion is prevented.

Proposition 4. *In a regime of lenient authorization, the regulator sets a salary* $s_h = \Pi$ *for all* $h \in [h_L, H]$ *and* $s_h = s_\emptyset = 0$ *otherwise, where*

$$h_L = \max\left\{\Pi, \min\left\{\Pi\left[1 + \frac{\lambda}{1-\upsilon} + \frac{\alpha}{c}\frac{\left(w_G^{LA} - cI_G^{LA}\right)}{I_G^{LA}}\right], H\right\}\right\}. \tag{15}$$

The regulator prevents corruption when $h \in [h_L, H]$ by paying the corruptible public official the minimum salary that induces her to report truthfully that the activity is unsafe. When the fraction of honest public officials grows large or it is more costly to pay the salary to the public official (i.e., when υ or λ are higher), the threshold h_L (weakly) increases and corruption is tolerated more often. The last term of the interior solution roughly refers to the marginal welfare return of investment, which is always negative because there is over-investment in a regime of lenient authorization. Note that, if $\alpha = 0$, the possibility of engaging in corruption with the public official does not affect the firm's investment decision. This is because all the gains from collusion will be reaped by the public official. Therefore, the threshold h_L is optimally set to take into account only the ex-post welfare benefits of preventing corruption, namely, the disallowance of unsafe goods, and its welfare costs, associated with the parameter λ.[17] When $\alpha > 0$, the anticipation of corruption stimulates investment. In that case, the regulator finds it optimal to prevent corruption more often by lowering the threshold h_L so as to mitigate the over-investment problem.

Strict authorization. In this regime, room for corruption (extortion) arises when there is conclusive evidence that the good is safe, that is, $\Pi > h$. Deterring extortion is not very costly, though, as the regulator could promise a small reward when the public official reveals that $h \in [0, \Pi]$. This is enough to make the extortion threat not credible. To see this, suppose that the public official obtains conclusive evidence that the activity does not generate substantial negative externality and she approaches the firm to extract a payment under the threat of concealing such information. If the firm decides not to give in to the public official's demand, the public official will be unwilling to follow through on her threat. Intuitively, she will prefer to collect the reward the regulator has set for an informative report. Anticipating this, the firm will never make a side agreement with the public official. Yet, even though preventing extortion does not entail a noticeable monetary cost, the regulator may in fact prefer to tolerate some degree of corruption. As shown in Proposition 3, allowing corruption in a regime of strict authorization might be beneficial in order to mitigate the over-investment problem.

Under strict authorization, the regulator will never pay a positive salary for an uninformative report, i.e., $s_\emptyset^{SA} = 0$, or for evidence that the good is safe, i.e., $s_h^{SA} = 0$ for all $h \in (\Pi, H]$. Conversely, the regulator could pay a positive salary when $h \in [0, \Pi]$. However, we can normalize

[17] When $\alpha = 0$, collusion does not affect the firm's investment decision and the optimal h_L is given by:

$$h_L = \max\left\{\Pi, \min\left\{\Pi\left[1 + \frac{\lambda}{1-\upsilon}\right], H\right\}\right\}. \tag{16}$$

to zero the wage bill as this salary will be very small. In the following proposition, we determine the threshold value $h_S \in [0, \Pi]$ above which corruption is deterred.[18]

Proposition 5. *In a regime of strict authorization, the regulator sets a positive but small salary* s_h^{SA} *for all* $h \in [h_S, \Pi]$ *and* $s_h^{SA} = s_\emptyset^{SA} = 0$ *otherwise, where*

$$h_S^{SA} = \min\left\{ G^{-1}\left(\frac{\int_0^\Pi hg(h)dh}{(1-\upsilon)(1-\gamma)(1-\alpha)} \right), \Pi \right\}. \tag{17}$$

The regulator is more willing to tolerate corruption when the firm expects to receive a higher fraction of the return on its investment, that is, the higher the fraction of honest public officials, the larger the firm's bargaining power, and the stronger the institutional framework. This is because all these factors lead to higher investment, thereby making extortion a more appealing, albeit unorthodox, tool for the benevolent regulator to avoid that the firm devotes excessive resources to the development of the innovative activity. In contrast, the threshold is independent of λ, given the small cost that must be borne to thwart extortion.

This subsection has highlighted that the wage policy appears to be more effective under lenient authorization, where curbing corruption is needed to both reduce excessive investment and over-production. Conversely, under strict authorization, the regulator may prefer not to use this instrument even though it may be very cheap.[19] This finding may provide an additional rationale for the lack of monetary incentives to public officials that is observed in the real world.

We caution that preventing corruption through salaries may be very costly in a regime of lenient authorization. All the more so when raising the funds to pay the public officials leads to larger inefficiencies (i.e., when λ is higher). Arguably, this is more likely to be the case in developing countries. There, the cost of implementing an effective wage policy may be prohibitive. More in general, deterring corruption in this regime requires giving up large rents to the public officials which may render such instrument politically unappealing.

4.2 Taxes and Regulation

We now assume that the benevolent regulator can commit to a tax $t \in \mathbb{R}_+$ that a firm must pay in order to undertake production. The aim of this subsection is to provide some insights on the relation between the optimal authorization regime and the ability to tailor the tax to the outcome of the regulatory process.

Lenient authorization. The firm's investment decision now also depends on the tax:

$$I_G^{LA}(t) = \arg\max_{I\in[0,1]} \quad I\left[p\int_0^\Pi (\Pi - t)g(h)dh + (1-p)(\Pi - t) + p(1-\upsilon)\alpha\int_\Pi^H (\Pi - t)g(h)dh \right] - \frac{cI^2}{2},$$

[18] As deterring corruption does not entail monetary costs, this assumption that corruption is deterred for h sufficiently high is without loss of generality.

[19] Note that if the regulator has to pay a minimum bonus to induce the public official to truthfully report $h \leq \Pi$, the attractiveness of preventing extortion will be further reduced.

which yields:

$$I_G^{LA}(t) = \frac{\Big[1 - p(1 - G(\Pi))[1 - \alpha(1 - \upsilon)]\Big](\Pi - t)}{c}.$$

Welfare, also expressed as a function of t, is:

$$W_G^{LA}(t) = I_G^{LA}(t)w_G^{LA} - c\frac{(I_G^{LA})^2}{2},$$

where

$$w_G^{LA} = \int_0^H (\Pi - h)g(h)dh - p\upsilon \int_\Pi^H (\Pi - h)g(h)dh.$$

Note that t is a transfer and, as such, it only affects investment incentives but not the surplus that can be generated by producing the innovative activity. In Stage 0, the regulator announces the tax that the firm will have to pay if production takes place. The tax is chosen so as to maximize welfare and the solution is presented in the following lemma.

Lemma 4. *In a regime of lenient authorization, the tax on production is:*

$$t^{LA} = \frac{E_g(h) - p\upsilon \int_\Pi^H hg(h)dh - p(1 - G(\Pi))(1 - \upsilon)(1 - \alpha)\Pi}{1 - p(1 - G(\Pi))[1 - \alpha(1 - \upsilon)]}, \tag{18}$$

where t^{LA} increases in α and decreases in p and υ if $w_G^{LA} > 0$.

The firm will invest only if the activity generates a positive surplus and equilibrium investment and welfare are:

$$I_G^{LA}(t^{LA}) = \max\left\{\frac{w_G^{LA}}{c}, 0\right\}; \quad W_G^{LA}(t^{LA}) = \begin{cases} \frac{(w_G^{LA})^2}{2c}, & \text{if} \quad w_G^{LA} > 0; \\ 0, & \text{if} \quad w_G^{LA} \leq 0. \end{cases} \tag{19}$$

Welfare is (weakly) increasing in p and (weakly) decreasing in the harmfulness of the activity.

The tax that the regulator may set can be such that the firm is not willing to invest, in which case overall welfare is 0. This occurs whenever the surplus that the activity is expected to generate is negative. When the tax is positive in equilibrium, its size is increasing in the firm's bargaining power and decreasing in both the fraction of honest public officials and the accuracy of the signal. A higher α is associated with more investment because the firm will reap a larger fraction of the gross profits. Then, to curb investment, the regulator increases the tax in such a way that the equilibrium levels of investment and welfare turn out to be independent of the distribution of the bargaining power. Like an increase in α, a reduction in υ stimulates investment and, for this reason, prompts the regulator to increase the tax. On top of that, a lower υ also reduces the surplus that the activity can bring about, w_G^{LA}, as it increases the probability that an unsafe good is authorized. Welfare in this regime continues to be increasing in the fraction of honest public officials υ. Lastly, an increase in the precision of the signal makes it more likely that evidence that the good is unsafe is uncovered and production prohibited, thereby reducing investment. Accordingly, there is a negative relationship between signal precision and the equilibrium tax. As the tax allows the regulator to govern the investment decision, a change in the harmfulness of the activity now only affects surplus. As a result, more harmful activities unambiguously decrease welfare.

Strict authorization. The firm's investment decision as function of the tax is:

$$I_G^{SA}(t) = \frac{p\Gamma G(\Pi)(\Pi - t)}{c}.$$

Welfare, also expressed as a function of t, is:

$$W_G^{SA}(t) = I_G^{SA}(t) w_G^{SA} - c\frac{(I_G^{SA})^2}{2},$$

where

$$w_G^{SA} = p\int_0^{\Pi} (\Pi - h) g(h) dh,$$

which is independent of t. The tax is chosen in Stage 0 to maximize $W_G^{SA}(t)$. The solution is characterized in the following lemma.

Lemma 5. *In a regime of strict authorization, the tax on production is:*

$$t^{SA} = \Pi - \frac{1}{\Gamma G(\Pi)} \int_0^{\Pi} (\Pi - h) g(h) dh, \tag{20}$$

where t^{SA} increases in Γ. The firm will invest $I_G^{SA}(t^{SA}) = \frac{w_G^{SA}}{c}$ and welfare is:

$$W_G^{SA}(t^{SA}) = \frac{(w_G^{SA})^2}{2c}. \tag{21}$$

Welfare is increasing in p and decreasing in the harmfulness of the activity.

The tax never deters the firm from producing as the surplus that the activity generates is never negative in a regime of strict authorization. Once again, the regulator uses the tax on production to govern the firm's investment incentives. The tax is inversely related to the gross profits of production that the firm expects to gain, i.e., the parameter Γ, to ensure that the firm will not devote excessive resources to investment. Whenever $\gamma < 1$ and $\alpha < 1$, the firm must pay an indirect tax to the public official to have production authorized. Anticipating this, the regulator will impose a lower tax burden on the firm. Put differently, there is a substitution between the indirect tax paid to the public officials and the direct tax paid to the regulator. As a result, when a tax on production can be imposed, welfare in a regime of strict authorization is unaffected by the likelihood that corruption takes place. Since the firm is made to pay for the externality generated by the activity, an increase in the precision of the signal does not give rise to over-investment but only to a higher surplus. Therefore, an increase in p is welfare enhancing.

In the next proposition, we compare welfare under both lenient and strict authorization when the regulator can levy a tax on production.

Proposition 6. *When the regulator can set a tax on production, a regime of lenient authorization is (weakly) preferred to one of strict authorization if and only if:*

$$(1 - p)\int_0^{\Pi} (\Pi - h) g(h) dh \geq (1 - p\upsilon)\int_{\Pi}^{H} (h - \Pi) g(h) dh. \tag{22}$$

This condition is more difficult to satisfy when the activity is more harmful.

The left-hand side of condition (22) captures the differential advantage of lenient authorization as compared to strict authorization: Production of safe goods is allowed even when there is no conclusive evidence of their harm. The right-hand side of (22) represents the downside of adopting lenient authorization: Unsafe goods may be authorized. This always occurs in the absence of conclusive evidence (an event which has probability $1-p$) and it also happens if there is evidence that the negative externality outweighs the private benefits but the public official is corrupt (an event which has probability $p(1-\upsilon)$). Therefore, lenient authorization is more likely to be preferred when the fraction of honest public officials in the population is higher. More harmful activities accentuate the benefits of pursuing a more prudent approach and, accordingly, make it harder to satisfy inequality (22).

Tax contingent on regulatory evidence. Suppose that the regulator could impose a tax contingent on both the production decision and the signal collected by the public official. That is, the tax is conditional on $r \in \{h, \emptyset\}$. This does not affect the solution previously described for the strict authorization regime. There, production is allowed only if there is positive evidence that the good is safe. The regulator will impose a tax t_h^{SA} for all $h \in [0, \Pi]$. We find that the regulator may as well set $t_h^{SA} = t^{SA}$ characterized above. Intuitively, the regulator does not want to prohibit production when $\Pi \geq h$ and the tax only affects investment incentives. Such incentives only depend on the expected tax bill. Therefore, there is no gain from setting a different tax for a different expected level of harm.

The conclusion is sharply different for the lenient authorization regime because the regulator can gain from setting $t_\emptyset^{LA} \neq t_h^{LA}$, where $t_\emptyset^{LA}$ is the tax that the innovative firm must pay to produce the good if there is no conclusive evidence about product safety. The regulator has an additional instrument it can use to provide the firm with incentives to invest and produce. The following proposition shows that with such a tax schedule, there is no loss of generality in restricting attention to a lenient-authorization regime.

Proposition 7. *When the tax can be made contingent on both the production decision and the signal, lenient authorization weakly dominates strict authorization, i.e.* $W^{LA} \geq W^{SA}$.

The intuition for this result is the following. With a lenient authorization regime it is always possible to replicate the solution under strict authorization by appropriately setting $t_\emptyset^{LA}$. In particular, production may be discouraged if the signal is uninformative by setting a very high tax that the firm will be unwilling to pay. Moreover, if allowing production when evidence is inconclusive is socially desirable, $t_\emptyset^{LA}$ would be set in such a way that the firm is still willing to produce in those states, leading to a strict social preference for a regime of lenient authorization.

Discussion. When the regulator can use a tax, the firm can be made to bear some of the expected social cost that its activity generates. This helps reduce the disadvantages associated with a regime of lenient authorization. In particular, when the tax can be made contingent on the signal collected by the regulator, there is no benefit from using strict authorization. If the risk of producing an unsafe good is too high, the tax can be set in such a way that the firm is unwilling to produce when evidence is inconclusive. In that case, welfare is the same under the two authorization regimes. If the risk is not too high, the tax can be set in a way that the firm is still willing to undertake production if the evidence is inconclusive and welfare is strictly higher than under strict authorization.

When the tax can only depend on whether the firm undertakes production or not, the regime of strict authorization may dominate. This is exactly because the tax cannot be perfectly tailored to make the firm pay the expected social cost when regulatory evidence is inconclusive. Notably, the likelihood that the regime of strict authorization is preferred is increasing in the fraction of corrupt public officials.

In the absence of a tax, the argument for the adoption of a more prudent approach is stronger: the firm cannot be made to bear the social costs that its activity generates. Therefore, its incentive to over-invest and over-produce in a regime of lenient authorization cannot be limited.

4.3 Ex-post Liability

In this subsection, we suppose that the expected harm $h \in [0, H]$ is the product of the probability that an accident occurs, defined $\eta(h) \in [0, 1]$, and the social damage that the accident causes, D. That is, $h = \eta(h)D$. As we keep D fixed, a higher expected externality necessarily means that $\eta(h)$ is higher. Our aim is to study how the possibility of imposing fines contingent on the occurrence of an accident affects investment and welfare in the two regimes and contribute to the debate on the relationship between ex-ante regulation and ex-post liability.

We assume that courts can fine the firm if an accident occurs but cannot gather evidence on product safety. Only the regulator and its public officials have the capability of collecting this evidence.[20]

Let us begin by considering an institutional setting wherein firms are free to produce innovative goods - that is, a regulator cannot collect evidence on the safety of the innovation. However, if an accident occurs, firms face liability. The social planner can at the very beginning of the game commit to a fine that the firm will have to pay if there is an accident. Thus, the envisioned legal regime is one of strict liability.

Specifically, the timing of the game is as follows. At the onset, the social planner commits to a fine ϕ the firm will have to pay if an accident occurs. Knowing the fine, the firm makes the investment and, in the case of a breakthrough, it decides whether or not to produce. Later on, if an accident occurs, the court imposes the predetermined fine on the firm.

We solve the game backwards and we can distinguish between two main scenarios, depending on whether or not the fine that can be imposed on the firm is bounded or not. The firm may not have enough financial resources to cover the entire cost of the disaster and in most jurisdictions

[20] While other papers in the literature assume that courts can obtain evidence, it is often argued that courts may be less able to collect information about specific features of technologies or industries than regulators, who are specialists (e.g., see Schwartzstein and Shleifer, 2013).

the firm's resources set a ceiling to the maximum fine which can be imposed on firms.[21] The firm is assumed not to own assets and a natural ceiling to the fine that can be imposed by the court is represented by the profit that would otherwise accrue to the firm.

When the fine is unbounded, i.e., $\phi \in \mathbb{R}_+$, the benevolent social planner will optimally set a fine which induces the firm to make the first-best investment and production decisions. This optimal fine is $\phi = D$. Confronted with such a fine, a firm will find it profitable to produce only if the activity is expected to be socially beneficial, that is, only if $\Pi > E_g(h)$. Moreover, at the investment stage the firm will choose I so as to maximize social welfare. Namely, with the optimal unbounded fine, the firm is made to internalize the social cost caused by the innovative good and first-best is achieved.

Unsurprisingly, an environment wherein fines are bounded dramatically limits the effectiveness of this tool to induce the optimal investment and production decisions. In what follows, we assume that the firm can pay up to the profit that it has earned if an accident occurs. The Maximal Punishment Principle (Becker, 1968) applies and the firm will pay Π in the event of an accident. Such a fine is not enough to always deter the firm from carrying out production when this is socially undesirable, i.e. when $\Pi \leq E_g(h)$. The firm will only partially take into account the negative social repercussions of production. In other words, investment will be below, and social welfare will be above, that observed in a regime of laissez-faire. The following proposition summarizes the optimal fines, investments, and welfare in a regime of ex-post liability.

Proposition 8. *When fines are unbounded, $\phi = D$, investment and production decisions are first-best and, as a result, first-best welfare is achieved. If fines are bounded, $\phi = \Pi$, there is over-production and over-investment, and welfare is below first-best.*

In a regime of unbounded fines, there is no need for regulation, whereas there might be scope for regulation when fines are bounded and below we explore the interplay between ex-ante regulation and ex-post liability.

4.3.1 Ex-ante Regulation and Ex-post Liability.

A regime in which ex-ante regulation and ex-post liability are jointly used to induce the firm to make more socially desirable investment and production decisions may lead to a higher level of welfare than a regime where only liability or regulation is employed. This result was shown by Shavell (1984) in a setting in which a firm must be induced to expend resources to reduce the probability of an accident.

If regulation and liability coexist, the game unfolds as follows. At the onset, the social planner announces the fine the firm will pay if an accident occurs. Knowing the fine, the firm decides how much to invest in R&D. If a breakthrough occurs, the regulator collects a signal about the good safety. If production is authorized, the firm decides whether to produce the good or not and, if an accident occurs, the firm will have to pay the announced fine.

[21] This problem known as judgement proof has been extensively studied in the law and economics literature (e.g., see Shavell, 1986).

We focus on fines which are the same within an authorization regime, irrespective of the evidence and we study how such penalties affect investment incentives and, thereby, welfare. Given that the fines do not affect production decision, there is no loss of generality in restricting attention to just one fine per regime - what matters for investment decisions is the expected fine facing the firm. In fact, the fine might as well be contingent on regulatory evidence or the lack thereof (i.e., $r = \emptyset$). However, different results with respect to the case studied here would arise only if the contingent fine were so high that either the firm would not go ahead with production when it is ex-post efficient or the two regimes would turn out to be identical.[22]

The following lemma illustrates the optimal bounded fines in the two regimes.

Lemma 6. *In a lenient authorization regime, the optimal fine is:*

$$\phi^{LA} = \min\left\{D\left(1 - \frac{p(1-\alpha)(1-\upsilon)[1-G(\Pi)]\Pi}{E_g(h) - p\upsilon\int_{\Pi}^{H} hg(h)dh}\right), \Pi\right\},$$

and ϕ^{LA} *is weakly decreasing in* p.

In a regime of strict authorization, the optimal fine is:

$$\phi^{SA} = \min\left\{D\left(1 - \frac{(1-\Gamma)G(\Pi)\Pi}{\int_0^{\Pi} hg(h)dh}\right), \Pi\right\},$$

and ϕ^{SA} *is independent of* p *and weakly increasing in* Γ.

In a regime of strict authorization, the social planner may prefer not to fully confiscate the firm's gross profits after a disaster if Γ is very low as this would excessively discourage investment. Put differently, if the corrupt public officials already extract a large fraction of the profits, the firm is reluctant to invest and, as a result, there is no need to impose a very large fine following an accident. In a regime of lenient authorization, the fine is equal to Π unless p is very high, in which case the social planner may not want to discourage the investment by setting a fine that is overly high.

The fine improves welfare because the regulator can make the firm (partially) bear the negative externalities caused by production. However, fines are not as effective as taxes in aligning private and social interests. The reason is that fines are paid only when an accident occurs and are limited above by the firm's assets. In contrast, taxes are paid with certainty when the firm decides whether or not to undertake production of the innovative good. The following remark formally proves this claim.

Remark 1. *The following inequalities hold:*

$$W_G^{LA}(t^{LA}) \geq W_G^{LA}(\phi^{LA}) \geq W_G^{LA}; \quad W_G^{SA}(t^{SA}) \geq W_G^{SA}(\phi^{SA}) \geq W_G^{SA}.$$

[22]The former case would arise if $\phi(h)$ were very high for some $r = h$ and such that the firm decides against producing even though $\Pi > h$. As argued in a previous footnote, this is a circumstance that we do not deal with in this paper. The latter case would occur if $\phi(\emptyset)$ were so high that the firm would not produce if the report is uninformative. But then lenient and strict authorization regimes would coincide.

It is easy to show that when the regulator can impose a tax, there is no additional benefit from using (bounded) fines. Intuitively, ex-post liability does not give rise to additional signals about product safety and cannot improve the firm's incentives to invest. For instance, consider a regime of strict authorization, wherein the optimal tax in the absence of fines induces the firm to take into account social benefits at the investment stage. If the social planner can set a fine contingent on the occurrence of the accident, any positive fine would force the firm to bear an excessive burden. As a result, the problem is over-determined. The same argument applies in a regime of lenient authorization where the attainable social welfare is unchanged if the social planner can set a fine. Note also that there is a negative relationship between taxes and fines: higher fines reduce taxes.

To conclude, when a tax can be imposed, regulation makes liability superfluous. However, if fines are used, taxes should be commensurately lower and the presence of courts would not affect the choice of the authorization regime. If the regulator cannot set a tax, fines improve welfare.

5 Conclusions

In this paper, we have studied the optimal choice of the authorization regime for goods which may exhibit negative externalities. We have focused on how regulation can impact on firm's investment incentives. We have found that the pros and cons of alternative regulatory regimes may be critically affected by corruption opportunities. A strict authorization regime always avoids that socially harmful goods are produced. This comes at the expense of losing the opportunity to approve production of socially beneficial goods when evidence of their safety is lacking. This more prudent approach is more likely to be favored over a lenient authorization regime when activities are more harmful and the likelihood of collecting conclusive evidence is lower.

Corruption is shown to have a stronger negative impact on a regime of lenient authorization because the parties may find it profitable to strike an agreement to allow production of socially harmful goods. This also prompts the firm to devote even more resources to investment. As a results, corruption exacerbates the two drawbacks of this regime: excessive investment and production. On the contrary, corruption may even be socially beneficial in a regime of strict authorization. This occurs because extortion is inconsequential for allocative efficiency but its anticipation mitigates the firm's tendency to devote excessive resources to investment in R&D. In distinguishing between bribery and extortion, Auriol (2006) reaches a conclusion with a similar flavor for public procurement: bribery undermines allocative efficiency whereas extortion does not. We extend this result by showing that private investments are furthered by the anticipation of collusion and discouraged by the expectation of blackmail.

We have mentioned several real-world applications for our analysis: from the approval process of drugs, vaccines, and dietary supplements to the authorization of new production technologies which are suspected of adversely affecting the environment. Another topical application concerns financial regulation. Most customers may have difficulty understanding features of more sophisticated financial products, which should then be subject to a more stringent authorization regime: for instance, by authorizing trade opportunities to accredited investors only.[23] The design of consumer financial protection is an active field of research in economics and finance and centers on financial consumers' behavioral biases and cognitive limitations and is especially concerned about its distributional implications (e.g. see Campbell et al., 2011).

Empirically determining how corruption affects regulation is a fascinating research question that warrants in-depth analyses which goes beyond the scope of the present paper. However, to provide some suggestive evidence, we correlate two indexes of pharmaceutical regulation developed by Pezzola and Sweet (2016) (called *Monitoring the Private Market* and *Public Quality Control*), who draw from data originated by the World Health Organization Pharmaceutical Sector Country Profile 2011 survey,[24] with the popular *Corruption Perception Index* (CPI) provided by Transparency International for the same year for 73 developed and small countries. Specifically, Monitoring the Private Market gauges the degree to which each country regulates the private market for medicines (e.g., whether manufacturers, wholesalers, and pharmacists must be licensed and are inspected), whereas Public Quality Control assesses the standard of quality controls (e.g., whether medicines are tested prior to acceptance). Higher values of these indexes are associated with higher standards in generic markets. We find that the CPI and the two indexes of regulation are inversely correlated, with values -0.068 and -0.15 (recall that a lower score in the CPI means that the public sector is perceived as more corrupt).[25] These results are in line with our model which shows that a benevolent regulator should adopt more stringent regulatory standards when corruption is a more pervasive phenomenon.

[23] Requirements to be classified as an accredited investors change from one legislation to another. Individual investors are typically eligible if they have a substantial net worth. In the United States, requirements have been tightened following the 2007-2009 financial crisis.

[24] This is a standardized questionnaire in which country representatives report on the status of the national pharmaceutical situation.

[25] We also regress the regulatory indexes on corruption. However, the OLS regressions yield coefficients for the CPI variable which are of the predicted sign but are statistically insignificant, even when adding GDP per capita as a control. The results can be provided on request.

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Appendix

Proof of Lemma 1

Consider the effect of a marginal increase in p on investment:

$$\frac{\partial I^{LA}}{\partial p} = -\frac{1-G(\Pi)}{c}\Pi < 0;$$

an increase in p on welfare has a positive impact. To see this consider that

$$\frac{\partial W^{LA}}{\partial p} = \frac{\partial I^{LA}}{\partial p}[w^{LA} - cI^{LA}] + I^{LA}\frac{\partial w^{LA}}{\partial p}.$$

Note that

$$\frac{\partial w^{LA}}{\partial p} = -\int_{\Pi}^{H}(\Pi - h)g(h)dh > 0,$$

whereas $\frac{\partial I^{LA}}{\partial p} < 0$ and so is $w^{LA} - cI^{LA}$ as this equals:

$$-p\int_0^{\Pi} hg(h)dh - (1-p)\int_0^{H} hg(h)dh.$$

Therefore, $\frac{\partial W^{LA}}{\partial p} > 0$.

Consider two distribution of harm on $[0, H]$: $F(\cdot)$ and $G(\cdot)$ where $F(h)$ conditionally stochastically dominates (csd) $G(h)$ for all h. Then,

$$I_g^{LA} = \frac{[1-p+pG(\Pi)]\Pi}{c} \geq \frac{[1-p+pF(\Pi)]\Pi}{c} = I_f^{LA}$$

because csd implies first-order stochastic dominance and, as a result, $G(\Pi) \geq F(\Pi)$.

As for welfare,

$$\begin{aligned} W_g^{LA} =& \frac{\Big[(1-p)+pG(\Pi)\Big]^2\Pi}{c}\left[\frac{\Pi}{2} - \frac{1}{\Big[1-p+pG(\Pi)\Big]}\left((1-p)E_g(h) + p\int_0^{\Pi} hg(h)dh\right)\right] \\ \geq& \frac{\Big[(1-p)+pF(\Pi)\Big]^2\Pi}{c}\left[\frac{\Pi}{2} - \frac{1}{\Big[1-p+pF(\Pi)\Big]}\left((1-p)E_f(h) + p\int_0^{\Pi} hf(h)dh\right)\right] = W_f^{LA} \end{aligned}$$

always holds if

$$\frac{\left((1-p)E_f(h) + p\int_0^{\Pi} hf(h)dh\right)}{\Big[1-p+pF(\Pi)\Big]} \geq \frac{\left((1-p)E_g(h) + p\int_0^{\Pi} hg(h)dh\right)}{\Big[1-p+pG(\Pi)\Big]} \quad \text{(A1)}$$

because

$$\frac{\Big[(1-p)+pG(\Pi)\Big]^2\Pi}{c} \geq \frac{\Big[(1-p)+pF(\Pi)\Big]^2\Pi}{c}$$

as $G(\Pi) \geq F(\Pi)$. In (A1), note that $E_f(h) \geq E_g(h)$ and therefore a sufficient condition for welfare to be decreasing is that:

$$\int_0^{\Pi} hf(h)dh \geq \int_0^{\Pi} hg(h)dh.$$

□

Proof of Lemma 2

Consider the effect of a marginal increase in p on investment:

$$\frac{\partial I^{SA}}{\partial p} = \frac{G(\Pi)}{c}\Pi > 0;$$

an increase in p on welfare has a positive impact only if Π is sufficiently large as compared to the expected externality generated by the safe activity.

$$\frac{\partial W^{SA}}{\partial p} = \frac{2p[G(\Pi)]^2\Pi}{c}\left[\frac{\Pi}{2} - \frac{1}{G(\Pi)}\int_0^{\Pi} hg(h)dh\right].$$

This is non-negative if:

$$\Pi \geq \frac{2}{G(\Pi)}\int_0^{\Pi} hg(h)dh = 2E_g(h|h \leq \Pi).$$

Consider two distributions of harm on $[0, H]$: $F(\cdot)$ and $G(\cdot)$ where $F(h)$ conditionally stochastically dominates (csd) $G(h)$ for all h. Then,

$$I_g^{SA} = \frac{pG(\Pi)\Pi}{c} \geq \frac{pF(\Pi)\Pi}{c} = I_f^{SA}$$

because $G(\cdot) > F(\cdot)$. Considering welfare:

$$W_g^{SA} = \frac{p^2[G(\Pi)]^2\Pi}{c}\left[\frac{\Pi}{2} - E_g(h|h \leq \Pi)\right] \geq \frac{p^2[F(\Pi)]^2\Pi}{c}\left[\frac{\Pi}{2} - E_f(h|h \leq \Pi)\right] = W_f^{SA},$$

because $\frac{p^2[G(\Pi)]^2\Pi}{c} \geq \frac{p^2[F(\Pi)]^2\Pi}{c}$ and

$$\begin{aligned} E_f(h|h \leq \Pi) &\geq E_g(h|h \leq \Pi) \\ \Leftrightarrow \Pi - \frac{\int_0^{\Pi} F(h)dh}{F(\Pi)} &\geq \Pi - \frac{\int_0^{\Pi} G(h)dh}{G(\Pi)} \\ \Leftrightarrow \frac{\int_0^{\Pi} f(h)dh}{\int_0^{\Pi} F(h)dh} &\geq \frac{\int_0^{\Pi} g(h)dh}{\int_0^{\Pi} G(h)dh} \end{aligned}$$

The first step derives from integration by parts, whereas the second step is due to conditional stochastic dominance. □

Proof of Proposition 1

The threshold value of Π above which lenient authorization is preferred to strict authorization can be retrieved from $W^{LA} - W^{SA} \geq 0$. As for the effect of p on this inequality note that the derivative of the rhs with respect to p yields:

$$\frac{-2\left(G(\Pi)E_g(h) - \int_0^{\Pi} hg(h)dh\right)}{\left[1 - p + 2pG(\Pi)\right]^2},$$

which is negative if and only if $G(\Pi)\int_{\Pi}^{H} hg(h)dh \geq [1 - G(\Pi)]\int_0^{\Pi} hg(h)dh$.

Consider two distribution of harm on $[0, H]$: $F(\cdot)$ and $G(\cdot)$ where $F(h) \leq G(h)$ for all h. The threshold value of Π above which lenient authorization is preferred to strict authorization is higher under distribution $F(\cdot)$ than $G(\cdot)$. This is the case only if:

$$\frac{(1-p+pG(\Pi))E_g(h)+p\int_0^{\Pi} hg(h)dh}{1-p+2pG(\Pi)} \leq \frac{(1-p+pF(\Pi))E_f(h)+p\int_0^{\Pi} hf(h)dh}{1-p+2pF(\Pi)}.$$

After some computations, it is possible to see that the above inequality is satisfied when:

$$\begin{aligned}
&[E_f(h)-E_g(h)][(1-p)^2+2p^2G(\Pi)F(\Pi)]+p(1-p)\left(\int_0^{\Pi} hf(h)dh-\int_0^{\Pi} hg(h)dh\right)\\
&+2p^2\left(G(\Pi)\int_0^{\Pi} hf(h)dh-F(\Pi)\int_0^{\Pi} hg(h)dh\right)+p(1-p)\Big[G(\Pi)E_f(h)-F(\Pi)E_g(h)\Big]\\
&+p(1-p)[G(\Pi)-F(\Pi)][E_f(h)-E_g(h)] \geq 0.
\end{aligned}$$

Since $E_f(h) \geq E_g(h)$ and $G(\Pi) \geq F(\Pi)$ all terms in the above expression are unambiguously non-negative with the exception of the second. Therefore, a sufficient condition for the threshold value to increase when activities are more harmful is $\int_0^{\Pi} hf(h)dh \geq \int_0^{\Pi} hg(h)dh$. □

Proof of Proposition 2

The inequality can be recovered by setting $W_C^{LA} - W_C^{SA} \geq 0$.

A marginal increase in p positively affects welfare in a regime of strict authorization if the following inequality holds:

$$\frac{\partial W_C^{SA}}{\partial p} = \frac{p\Big[\gamma+\alpha(1-\gamma)\Big]G(\Pi)\Pi}{c}\left[G(\Pi)\Pi[2-(\gamma+\alpha(1-\gamma))]-2\int_0^{\Pi} hg(h)dh\right] \geq 0$$

The first term is always positive, whereas the term in the square brackets is non-negative only if:

$$\Pi \geq \frac{2}{2-[\gamma+\alpha(1-\gamma)]}E_g(h|h \leq \Pi).$$

Note that $\frac{2}{2-[\gamma+\alpha(1-\gamma)]} < 2$ and, as a result, the threshold value above which p positively affects welfare in a regime of strict authorization is lower when public officials are corrupt. □

Proof of Proposition 3

Denote by the subscript G investment and welfare in this general scenario. Start by considering a regime of lenient authorization (point a). Investment is chosen so as to maximize the following

$$I_G^{LA} = \arg\max_{I\in[0,1]} \quad I\left[p\int_0^{\Pi} \Pi g(h)dh+(1-p)\Pi+p(1-\upsilon)\alpha\int_{\Pi}^{H} \Pi g(h)dh\right]-\frac{cI^2}{2},$$

which yields:

$$I_G^{LA} = \frac{\Big[1-p(1-G(\Pi))[1-\alpha(1-\upsilon)]\Big]\Pi}{c}.$$

Welfare is:

$$W_G^{LA} = I_G^{LA} \underbrace{\left[\int_0^H (\Pi - h) g(h) dh - p\upsilon \int_\Pi^H (\Pi - h) g(h) dh \right]}_{w_G^{LA}} - c\frac{(I_G^{LA})^2}{2}.$$

Replacing the investment into the above equation, we easily obtain the welfare attainable with lenient authorization.

Let us consider the effect of a marginal increase in the fraction of honest public officials on welfare:

$$\frac{\partial W_G^{LA}}{\partial \upsilon} = \frac{\partial I_G^{LA}}{\partial \upsilon} w_G^{LA} + I_G^{LA} \frac{\partial w_G^{LA}}{\partial \upsilon} - c I_G^{LA} \frac{\partial I_G^{LA}}{\partial \upsilon},$$

which is positive when:

$$I_G^{LA} \frac{\partial w_G^{LA}}{\partial \upsilon} > -\frac{\partial I_G^{LA}}{\partial \upsilon} \left[w_G^{LA} - c I_G^{LA} \right]. \tag{A2}$$

Notice that the left-hand side is always positive because

$$\frac{\partial w_G^{LA}}{\partial \upsilon} = -p \int_\Pi^H (\Pi - h) g(h) dh > 0,$$

since $h \geq \Pi$ for any $h \in [\Pi, H]$. Moreover, the right-hand side is negative because

$$\frac{\partial I_G^{LA}}{\partial \upsilon} = -\frac{\alpha p (1 - G(\Pi))\Pi}{c} < 0,$$

and

$$\begin{aligned} w_G^{LA} - c I_G^{LA} &= -\int_0^H h g(h) dh + p\upsilon \int_\Pi^H h g(h) dh + p(1-\alpha)(1-\upsilon) \int_\Pi^H \Pi g(h) dh \\ &< -\int_0^H h g(h) dh + p \int_\Pi^H h g(h) dh < 0. \end{aligned}$$

Hence, the inequality in (A2) is always satisfied.

Now consider a regime of strict authorization (part b). Investment is chosen so as to maximize the following

$$I_G^{SA} = \arg \max_{I \in [0,1]} I [p \underbrace{[\upsilon + (1-\upsilon)(\gamma(1-\alpha) + \alpha)]}_{\Gamma} \int_0^\Pi \Pi g(h) dh] - \frac{cI^2}{2}$$

which yields:

$$I_G^{SA} = \frac{p \Gamma G(\Pi) \Pi}{c}.$$

Welfare is:

$$W_G^{SA} = I_G^{SA} \underbrace{\left[p \int_0^\Pi (\Pi - h) g(h) dh \right]}_{w_G^{SA}} - c\frac{(I_G^{SA})^2}{2}$$

Welfare is easily obtained from plugging in the investment equation. Let us consider the effect of a marginal increase in the fraction of honest public officials on welfare under strict authorization:

$$\frac{\partial W_G^{SA}}{\partial \upsilon} = \frac{\partial I_G^{SA}}{\partial \upsilon} w_G^{SA} + I_G^{SA} \frac{\partial w_G^{SA}}{\partial \upsilon} - c I_G^{SA} \frac{\partial I_G^{SA}}{\partial \upsilon}.$$

This is positive only if:

$$I_G^{SA}\frac{\partial w_G^{SA}}{\partial \upsilon} + \frac{\partial I_G^{SA}}{\partial \upsilon}[w_G^{SA} - cI_G^{SA}].$$

Now note that $\frac{\partial w_G^{SA}}{\partial \upsilon} = 0$ and

$$\frac{\partial I_G^{SA}}{\partial \upsilon} = \frac{p(1-\alpha)(1-\gamma)G(\Pi)\Pi}{c} > 0,$$

whereas

$$w_G^{SA} - cI_G^{SA} = p\int_0^{\Pi}(\Pi - h)g(h)dh - p\Gamma G(\Pi)\Pi > 0$$

when

$$\Gamma > \frac{\int_0^{\Pi}(\Pi - h)g(h)dh}{G(\Pi)\Pi}.$$

Consider two distribution of harm on $[0, H]$: $F(\cdot)$ and $G(\cdot)$ where the activity identified by distribution $F(\cdot)$ is more harmful than that identified by distribution $G(\cdot)$. It holds that

$$\frac{\int_0^{\Pi}(\Pi - h)g(h)dh}{G(\Pi)\Pi} \geq \frac{\int_0^{\Pi}(\Pi - h)f(h)dh}{F(\Pi)\Pi},$$

only if

$$G(\Pi)\int_0^{\Pi} hf(h)dh \geq F(\Pi)\int_0^{\Pi} hg(h)dh.$$

Integrating by parts and rearranging, this holds only if:

$$\frac{\int_0^{\Pi} f(h)dh}{\int_0^{\Pi} F(h)dh} \geq \frac{\int_0^{\Pi} g(h)dh}{\int_0^{\Pi} G(h)dh},$$

which is always the case because $F(\cdot)$ conditionally stochastically dominates $G(\cdot)$. $\square$

Proof of Lemma 3

Let $h_2 = h_1 + \epsilon$, with $h_1 \geq \Pi$ and $\epsilon > 0$. The marginal welfare benefit of preventing corruption when the externality is $h_i \in \{h_1, h_2\}$:

$$I_G^{LA}\Big[p(1-\upsilon)(h_i - \Pi)g(h_i) - \lambda p\Pi g(h_i)\Big] + \frac{p(1-\upsilon)\alpha\Pi g(h_i)}{c}[cI_G^{LA} - w_G^{LA}].$$

If $g(h_2) \geq g(h_1)$, preventing corruption always gives a higher welfare benefit when the externality is larger. Now focus on the case in which $g(h_1) > g(h_2)$. The welfare gain of preventing corruption is higher in state h_2 if

$$\frac{h_1 g(h_1) - h_2 g(h_2)}{g(h_1) - g(h_2)} < \Pi\left(1 + \frac{\lambda}{1-\upsilon} - \frac{cI_G^{LA} - w_G^{LA}}{cI_G^{LA}}\right).$$

The right-hand side is positive under the assumption that, if w_G^{LA} were negative, the regulator would rather ban production of innovative activities than implement a regime of lenient authorization. The left-hand side is negative if $h_2 g(h_2) > h_1 g(h_1)$. Take the limit for $\epsilon \to 0$, then the condition holds if $g(h_1) + h_1 g'(h_1) > 0$, which is always satisfied by Assumption 1. $\square$

Proof of Proposition 4

The regulator chooses the threshold h_L which maximizes welfare:

$$\max_{h_L \in [\Pi, H]} W_G^{LA}(h_L) = \max_{h_L \in [\Pi, H]} I_G^{LA}(h_L) w_G^{LA}(h_L) - \frac{c(I_G^{LA}(h_L))^2}{2},$$

where

$$I_G^{LA}(h_L) = \frac{\int_0^{\Pi} \Pi g(h)dh + (1-p)\int_{\Pi}^{H} \Pi g(h)dh + p(1-\upsilon)\alpha \int_{\Pi}^{h_L} \Pi g(h)dh}{c},$$

and

$$\begin{aligned} w_G^{LA}(h_L) = & \int_0^{\Pi} (\Pi - h)g(h)dh + (1-p)\int_{\Pi}^{H} (\Pi - h)g(h)dh \\ & + p(1-\upsilon)\int_{\Pi}^{h_L} (\Pi - h)g(h)dh - \lambda p\Pi[1 - G(h_L)]. \end{aligned}$$

Note that

$$\frac{\partial w_g^{LA}}{\partial h_L} = p(1-\upsilon)(\Pi - h_L)g(h_L) + \lambda p g(h_L)\Pi$$

and

$$\frac{\partial I_G^{LA}}{\partial h_L} = \frac{\alpha}{c} p(1-\upsilon)\Pi g(h_L).$$

Focus on the interior solution. First-order necessary condition for a maximum requires that:

$$I_G^{LA}\Big[p(1-\upsilon)(\Pi - h_L)g(h_L) + \lambda p g(h_L)\Pi\Big] = \frac{p(1-\upsilon)\alpha}{c}\Pi g(h_L)[cI_G^{LA} - w_G^{LA}].$$

This can be rearranged as:

$$\begin{aligned} h_L = & \Pi + \frac{\lambda}{1-\upsilon}\Pi + \frac{\alpha}{c}\Pi \frac{\left(w_G^{LA} - cI_G^{LA}\right)}{I_G^{LA}} \\ = & \Pi\left[1 + \frac{\lambda}{1-\upsilon} + \frac{\alpha}{c}\frac{\left(w_G^{LA} - cI_G^{LA}\right)}{I_G^{LA}}\right], \end{aligned} \tag{A3}$$

where:

$$\begin{aligned} w_G^{LA} - cI_G^{LA} = & -p(1-\upsilon)\int_{\Pi}^{h_L} [h - (1-\alpha)\Pi]g(h)dh - \int_0^{\Pi} hg(h)dh \\ & - (1-p)\int_{\Pi}^{H} hg(h)dh - \lambda p\Pi[1 - G(h_L)]. \end{aligned}$$

For the threshold h_L determined in (A3) to be a maximum, it must be that the second-order condition is also satisfied. This condition is:

$$\begin{aligned} & \frac{\partial I_G^{LA}}{\partial h_L}\frac{\partial w_G^{LA}}{\partial h_L} + \frac{\partial^2 w_G^{LA}}{\partial h_L^2} I_G^{LA} + \frac{\partial^2 I_G^{LA}}{\partial h_L^2}(w_G^{LA} - cI_G^{LA}) + \frac{\partial I_G^{LA}}{\partial h_L}\frac{\partial(w_G^{LA} - cI_G^{LA})}{\partial h_L} < 0 \\ & \Leftrightarrow I + \frac{\partial I_G^{LA}}{\partial h_L}\alpha\Pi\left(\frac{(2w_G^{LA} - cI_G^{LA})}{cI_G^{LA}}\right) > 0, \end{aligned}$$

and it is always satisfied when $\alpha = 0$ or when $2w_G^{LA} - cI_G^{LA} > 0$. □

Proof of Proposition 5

The regulator chooses the threshold h_S which maximizes welfare:

$$\max_{h_S \in [0,\Pi]} W_G^{SA}(h_S) = \max_{h_S \in [0,\Pi]} I_G^{SA}(h_S) w_G^{SA}(h_S) - \frac{c(I_G^{SA}(h_S))^2}{2},$$

Investment in strict authorization is:

$$I_G^{SA} = \frac{p\Big[v \int_0^{\Pi} \Pi g(h)dh + (1-v)[\gamma + \alpha(1-\gamma)] \int_0^{h_S} \Pi g(h)dh + (1-v) \int_{h_S}^{\Pi} \Pi g(h)dh\Big]}{c}.$$

Welfare if a breakthrough is achieved is:

$$w_G^{SA} = p \int_0^{\Pi} (\Pi - h) g(h) dh,$$

as extortion does not affect the pool of activities which are approved. First-order condition yields

$$-p(1-v)(1-\gamma)(1-\alpha)\Pi g(h_S)[w_G^{SA} - cI_G^{SA}]. \tag{A4}$$

When $w_G^{SA} - cI_G^{SA} < 0$, the regulator wants to increase h_S, whereas when $w_G^{SA} - cI_G^{SA} > 0$ the regulator wants to decrease h_S. Note that:

$$w_G^{SA} - cI_G^{SA} = p(1-v)(1-\gamma)(1-\alpha) \int_0^{h_S} \Pi g(h)dh - p \int_0^{\Pi} hg(h)dh.$$

It is easy to see that, when h_S is small, $w_G^{SA} - cI_G^{SA} < 0$ and the regulator wants to increase h_S. The optimal threshold is then given by:

$$h_S^{SA} = \min\left\{ G^{-1}\left(\frac{\int_0^{\Pi} hg(h)dh}{(1-v)(1-\gamma)(1-\alpha)} \right), \Pi \right\}.$$

That is, the regulator will increase h_S up to the point at which $w_G^{SA} = cI_G^{SA}$, if such $h_S < \Pi$. Otherwise, the regulator will increase h_S up to Π, that is corruption will never be deterred in a regime of strict authorization. Note that, at the candidate interior optimum, the second order condition amounts to:

$$-\Big[p(1-v)(1-\gamma)(1-\alpha)\Pi g(h_S^{SA})\Big]^2 < 0.$$

□

Proof of Lemma 4

The equilibrium tax is derived directly from maximizing $W_G^{LA}(t)$ with respect to t and setting it equal to 0. Note that the second order condition holds as $\frac{\partial I_G^{LA}(t)}{\partial t} < 0$. Given t^{LA}, the firm will invest only if $\Pi > t^{LA}$. It is easy to check that this is the case whenever $w_G^{LA} > 0$. Therefore, if $w_G^{LA} \leq 0$, the firm will not invest and $W_G^{LA}(t^{LA}) = 0$. In contrast, if $w_G^{LA} > 0$, the firm will invest and $W_G^{LA}(t^{LA}) = \frac{(w_G^{LA})^2}{2c}$.

The impact of an increase in α on the equilibrium tax, t^{LA}, that is, $\frac{\partial t^{LA}}{\partial \alpha}$ is positive if:

$$\Pi\Big[1 - pv(1 - G(\Pi))\Big] - E_g(h) + pv\int_{\Pi}^{H} hg(h)dh > 0,$$

which is always satisfied if $w_G^{LA} > 0$.

The impact of an increase in v on the equilibrium tax, t^{LA}, that is, $\frac{\partial t^{LA}}{\partial v}$ is negative if:

$$\alpha(1 - G(\Pi))\int_0^H (\Pi - h)g(h)dh - \Big[1 - p(1-\alpha)(1 - G(\Pi))\Big]\int_{\Pi}^{H}(\Pi - h)g(h)dh > 0$$

which is always satisfied if $w_G^{LA} > 0$ because

$$\frac{1 - p(1-\alpha)(1 - G(\Pi))}{\alpha(1 - G(\Pi))} > pv.$$

The impact of an increase in p on the equilibrium tax, t^{LA}, that is, $\frac{\partial t^{LA}}{\partial v}$ is negative if:

$$(1 - G(\Pi))\int_0^H (\Pi - h)g(h)dh + \Big[v + \alpha(1 - v)(1 - G(\Pi))\Big]\int_{\Pi}^{H}(\Pi - h)g(h)dh < 0$$

which is always satisfied if $w_G^{LA} > 0$.

If $W_G^{LA}(t^{LA}) = 0$, a change in p does not affect welfare. Conversely, if $W_G^{LA}(t^{LA}) > 0$,

$$\frac{\partial W_G^{LA}(t^{LA})}{\partial p} = -v\int_{\Pi}^{H}(\Pi - h)g(h)dh > 0.$$

Compare now two distributions of harm, $F(\cdot)$ and $G(\cdot)$ where the former csd the latter. Notice that if $W_G^{LA}(t^{LA}) > 0$, the surplus $w_{G,g}^{LA}(t^{LA})$ can be rewritten as:

$$\int_0^{\Pi} G(h)dh + (1 - pv)\int_{\Pi}^{H} G(h)dh - (1 - pv)(H - \Pi),$$

which is always higher than $w_{G,f}^{LA}(t^{LA})$ because $G(h) \geq F(h)$ for all h. It follows that $W_{G,g}^{LA}(t^{LA}) \geq W_{G,f}^{LA}(t^{LA})$. □

Proof of Lemma 5

The equilibrium tax is derived from the first-order condition of the maximization problem. Note that the second order condition holds. Given t^{SA}, the firm will always invest a positive amount equal to $\frac{w_G^{SA}}{c}$ and the overall welfare can be easily retrieved. It is easy to see that the derivative of t^{SA} with respect to Γ is positive.

It is immediate to see that $W_G^{SA}(t^{SA})$ is increasing in p. To check that more harmful activities reduce welfare, compare $F(\cdot)$ and $G(\cdot)$ where $F(\cdot)$ csd $G(\cdot)$. It holds:

$$\begin{aligned}\Pi G(\Pi) - \int_0^{\Pi} hg(h)dh &\geq \Pi F(\Pi) - \int_0^{\Pi} hf(h)dh \\ \Leftrightarrow G(\Pi)\Big[\Pi - E_g(h|h \leq \Pi)\Big] &\geq F(\Pi)\Big[\Pi - E_f(h|h \leq \Pi)\Big],\end{aligned}$$

since $G(\Pi) \geq F(\Pi)$ and $E_f(h|h \leq \Pi) \geq E_g(h|h \leq \Pi)$. □

Proof of Proposition 6

Condition (22) is straightforwardly derived by comparing welfare under the two authorization regimes. To see that (22) is more difficult to satisfy for distribution $F(\cdot)$ which conditionally stochastically dominates distribution $G(\cdot)$, note that after some computations (22) can be rewritten as:

$$(1-pv)\Pi - (1-pv)H + (1-p)\int_0^{\Pi} G(h)dh + (1-pv)\int_{\Pi}^{H} G(h)dh \geq 0.$$

As $F(h) \leq G(h)$ for any h, then if (22) is satisfied for distribution $G(\cdot)$, it may not hold for distribution $F(\cdot)$. □

Proof of Proposition 7

Consider a regime of strict authorization. The regulator will set $t_h^{SA} \geq 0$ for all $h \in [0, \Pi]$. The regulator never sets $t_h^{SA} \geq \Pi$, for otherwise the firm would not produce in a state where $\Pi \geq h$ and this is ex-post socially inefficient. Hence, the tax only affects the firm's investment decision, which solely depends on the expected tax bill. It follows that there is no loss from restricting to $t_h^{SA} = t^{SA}$ for all $h \in [0, \Pi]$.

Consider now a regime of lenient authorization. The regulator sets $t_h^{LA} \geq 0$ for all $h \in [0, \Pi]$ and $t_{\emptyset}^{LA} \geq 0$ when $r = \emptyset$. As before, the regulator would always set $t_h^{LA} \leq \Pi$ not to discourage production when the good is safe. As this tax only affects investment decisions, there is no loss of generality to set the same tax for all $r = h \in [0, \Pi]$. The regulator may set $t_{\emptyset}^{LA} \neq t_h^{LA}$. Specifically, by setting $t_{\emptyset}^{LA} > \Pi$, the regulator can obtain the same welfare as in strict authorization because the firm will not produce whenever there is inconclusive evidence. In that case, $t_h^{LA} = t^{SA}$. If the regulator sets $t_{\emptyset}^{LA} \leq \Pi$, the firm will produce whenever the signal in uninformative. As the tax does not affect production decision, but only investment incentives, which depend on the expected tax bill, the regulator might as well set $t_h^{LA} = t_{\emptyset}^{LA} = t^{LA}$. □

Proof of Proposition 8

Suppose fines are unbounded. Then, at the investment stage, the firm will choose $I \in [0, 1]$ to max

$$I\left[\Pi - \phi\int_0^H \eta(h)g(h)dh\right] - \frac{cI^2}{2}.$$

The firm's optimal investment choice as function of the fine is then:

$$I(f) = \max\left\{\frac{\Pi - \phi\int_0^H \eta(h)g(h)dh}{c}, 0\right\}.$$

The social planner chooses the fine to maximize:

$$I(\phi)\left[\int_0^H (\Pi - h)g(h)dh\right] - \frac{c[I(\phi)]^2}{2}.$$

If $I(\phi) > 0$, the first-order condition yields:

$$-\frac{\int_0^H \eta(h)g(h)dh}{c}\left[-\int_0^H hg(h)dh + \phi\int_0^H \eta(h)g(h)dh\right] = 0.$$

Therefore, the optimal unbounded fine is:

$$\phi^U = \frac{\int_0^H hg(h)dh}{\int_0^H \eta(h)g(h)dh} = D,$$

because $h = \eta(h)D$. Faced with this fine, firm will produce only if:

$$\Pi - \phi^U \int_0^H \eta(h)g(h)dh \geq 0$$
$$\Leftrightarrow \Pi - \int_0^H hg(h)dh \geq 0.$$

It follows that investment is first best.

Suppose that the fine is bounded above at $\phi = \Pi < D$ as $\Pi < H = \eta(H)D$ and $\eta(H) \leq 1$. The social planner would set $\phi^B = \Pi$. The firm will produce whenever $\Pi \geq \Pi \int_0^H \eta(h)g(h)dh$ and it would follow that investment is above first-best. □

Proof of Lemma 6

In a regime of lenient authorization, equilibrium investment as a function of ϕ is:

$$I_G^{LA}(\phi) = \frac{\Big[1 - p(1 - G(\Pi))[1 - \alpha(1 - \upsilon)]\Big]\Pi}{c} - \phi\left(\frac{\int_0^H \eta(h)g(h)dh - p\upsilon\int_\Pi^H \eta(h)g(h)dh}{c}\right).$$

Welfare is:

$$W_G^{LA}(\phi) = I_G^{LA}(\phi)w_G^{LA} - c\frac{(I_G^{LA}(\phi))^2}{2}.$$

The social planner chooses $\phi \leq \Pi$ to maximize $W_G^{LA}(\phi)$. In an interior solution, the fine is derived from the first-order condition:

$$\frac{\partial I_G^{LA}(\phi)}{\partial \phi}[w_G^{LA} - cI_G^{LA}(\phi)] = 0.$$

Since the first term is always negative, the interior solution is derived from $w_G^{LA} = cI_G^{LA}(\phi)$. It is immediate to see that, in the interior solution, the optimal value of ϕ is decreasing in p.

In a regime of strict authorization, the firm's investment decision as a function of ϕ yields:

$$I_G^{SA}(\phi) = \frac{p\Gamma G(\Pi)\Pi}{c} - \phi\left(\frac{p\int_0^\Pi \eta(h)g(h)dh}{c}\right).$$

Welfare is:

$$W_G^{SA}(\phi) = I_G^{SA}(\phi)w_G^{SA} - c\frac{(I_G^{SA}(\phi))^2}{2}.$$

The social planner chooses $\phi \leq \Pi$ to maximize $W_G^{SA}(\phi)$. In an interior solution, the optimal fine is derived from:

$$\frac{\partial I_G^{SA}(\phi)}{\partial \phi}[w_G^{SA} - cI_G^{SA}(\phi)] = 0.$$

Since the first term is always negative, the interior solution is derived from $w_G^{SA} = cI_G^{SA}(\phi)$. It is immediate to see that, in the interior solution, the optimal value of ϕ is increasing in Γ and independent of p. $\square$

Proof of Remark 1

Consider first lenient authorization. $W_G^{LA}(\phi^{LA}) \geq W_G^{LA}$ follows from ϕ being chosen to maximize W_G^{LA}. To show that $W_G^{LA}(t^{LA}) \geq W_G^{LA}(\phi^{LA})$, suppose that $W_G^{LA}(t^{LA}) > 0$ and the unconstrained fine can be imposed. In this case, note that:

$$I_G^{LA}(t^{LA}) = \frac{w_G^{LA}}{c} = I_G^{LA}(\phi^{LA}),$$

and

$$w_G^{LA} - \frac{cI_G^{LA}(t^{LA})}{2} = \frac{w_G^{LA}}{2} = w_G^{LA} - \frac{cI_G^{LA}(\phi^{LA})}{2}.$$

Therefore, when the unconstrained solution can be implemented, welfare is the same with the two instruments. Conversely, if the unconstrained solution cannot be implemented, so that $\phi^{LA} = \Pi$, then it must be that $W_G^{LA}(t^{LA}) > W_G^{LA}(\phi^{LA})$. The second set of inequalities can be shown by following the same approach. $\square$