Corruption, Regulation, and Investment Incentives*

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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. Hence, more pervasive corruption favors the adoption of a strict authorization regime and may increase welfare.

Keywords: Authorization, Collusion, Corruption, Extortion, Innovation, Investment incentives, Regulatory capture.

JEL classifications: 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 typically 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

[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).

in the absence of 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 new products or 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 investment decisions. 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.

Interestingly, corruption opportunities differ between the two regulatory regimes: under lenient authorization, the public official in charge of approving production may *collude* with the firm and conceal unfavorable evidence. By contrast, under strict authorization, the public official may *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.

The ubiquitousness of corruption in regulatory decisions justifies the focus of our paper. International organizations recognize that regulation may be vulnerable to both collusion and blackmail (or extortion). For instance, in a report for Transparency International, Kohler et al. (2016) stress that government officials may enjoy a high level of discretion when licensing and accrediting medicines. They warn that "Without the proper accountability mechanisms suppliers have an opportunity to bribe government officials to register their medicines without meeting the necessary requirements or to speed up the registration process; or government officials may deliberately delay the registration process in order to solicit an illegal payment from suppliers or to favour competitors" (see Kohler et al., 2016, page 15). Indeed, there is ample anecdotal evidence documenting how public officials engaged in the regulation or authorization of new products and techniques receive bribes to expedite and smooth the approval process.[5] Furthermore, a growing body of empirical work highlights the pervasiveness of regulatory capture and its consequences. Recently, Tabakovic and Wollmann (2018) provide evidence indicating that patent examiners in

[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]For drug regulation, the highest-profile case arguably involved Zheng Xiaoyu who helped create and lead the Chinese counterpart of the U.S. FDA. He was sentenced to death in 2007 for approving untested medicines in exchange for bribes (see "A Chinese Reformer Betrays His Cause, and Pays" on The New York Times, July 13, 2007).

the U.S. are captured: they grant significantly more patents to the firms that subsequently hire them and the quality of such patents, as measured by the number of citations they later receive, is lower. Piller (2018) questions the impartiality of the advice provided by the expert members of the FDA advisory committees and panels that wield an enormous influence over the agency's approval decisions.[6] The World Bank's Enterprise Surveys provide a glimpse into how rife the phenomenon of extortion is, especially in developing countries, where a substantial fraction of firms typically need to pay bribes to public officials to "get things done", e.g., to get an operating license or a construction permit: for instance, over the period 2009-2018, the aforementioned fraction was 52.1% in the East Asia and Pacific region and 25.5% in South Asia. Using the same firm-level dataset for 48 developing and emerging countries, Paunov (2016) finds that extortion has a statistically negative impact on firms' ownership of quality certificates and investment in machinery. In general, corruption is particularly worrisome in developing countries, since limited budgets, lower-skilled human resources, and lower accountability make it difficult to prevent corruption (for a discussion, see Estache and Wren-Lewis, 2009, and references therein).

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 may more than offset private benefits. We assume that a benevolent regulator can charge a public official with the task of collecting 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 she 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. 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. By 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.[7] As a

[6] 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. Piller (2018) finds that 26 out of 107 physician advisors who voted on FDA advisory committees during the period 2013-2016 later received more than $100,000 from drugmakers or competing firms (in payments or research funding).

[7] Over-investment may occur in a regime of strict authorization although production will not be allowed when

result, when corruption is more pervasive, strict authorization is more likely to be preferred and, more surprisingly, welfare may actually increase.

The regulator's ability to provide the public official with report-contingent monetary incentives does not affect the above conclusions. The wage policy turns out to be more helpful in a regime of lenient authorization, where limiting collusion is always beneficial. Conversely, the regulator may decide not to use this instrument to curb extortion, even when it is socially costless. This is because tolerating some extortion may actually be desirable to discourage the firm's excessive investment. Arguably, raising funds to pay the public officials may lead to larger inefficiencies in developing countries, where tax collection is notoriously distortive. There, the cost of implementing an effective wage policy may be prohibitive. A different kind of problem emerges in developed countries, where giving up large rents to public officials may render such instrument politically unappealing. Both the inability to use the wage policy and a higher implementation cost strengthen the case for the adoption of a regime of strict authorization.

In an extension of the baseline model, we find that the regulator may optimally commit to ban some activities that are socially beneficial. By doing so, the regulator can better discipline the firm's investment incentives, although allocative efficiency is not achieved. While this is always the case in the absence of corruption, we identify conditions under which the presence of corruptible public officials enables the regulator to achieve second-best in a regime of strict authorization. In a nutshell, we show that the regulator may tolerate some extortion to govern investment decisions without having to distort allocative efficiency. By contrast, the presence of corruptible public officials always worsens social welfare under lenient authorization.

Related Literature. Our paper relates to different strands of the economics literature on regulation. First of all, in building our model we follow the archetype of the principal-monitor-agent hierarchy with a potentially corruptible monitor that was pioneered by Tirole (1986, 1992), and has long been adopted to analyze regulatory capture (e.g., see Laffont and Martimort, 1999, and Hiriart et al., 2010). Unlike the aforementioned papers, we study the design of regulation in a setting where a benevolent regulator can only use the authorization regime and the wage policy to maximize social welfare. In our framework, the principal (i.e., the regulator) and the monitor (i.e., the public official) belong to the same public institution, whereas the monitored agent (i.e., the firm) does not, and consequently it does not exchange transfers with the principal. Moreover, our model allows for both collusion and extortion, whereas the early literature mostly focused on the former.[8] In contrast to most of the previous literature, we find that extortion may turn out to be welfare improving by acting as an indirect tax that mitigates an over-investment problem.

In comparing alternative regulatory regimes, we take into account their effects on both

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there is no conclusive evidence that the good is safe. The reason is that the firm does not take into account the negative externalities at the investment stage.

[8] Notable exceptions that have developed models of extortion include Hindriks et al. (1999), Acemoglu and Verdier (2000), Auriol (2006), Khalil et al. (2010) and, more recently, De Chiara and Livio (2017) and Angelucci and Russo (2017).

production and investment incentives. How regulation affects allocative efficiency and investment decisions has recently attracted scholarly attention (e.g., see Calzolari and Immordino, 2005, Drugov, 2010, Anderlini et al., 2013, Schwartzstein and Shleifer, 2013, and Immordino and Polo, 2014). Within this literature, our paper is closely related to that by Immordino et al. (2011), from whom we borrow the distinction between lenient and strict authorization regimes. Unlike us, Immordino et al. (2011) compare authorization regimes with court-imposed penalties and they let the firm decide the activity level, which affects profits and the size of the externality - which is positive if the good is safe. Conversely, we restrict attention to the choice between lenient and strict authorization but we allow for corruption, which drastically impacts on the regulator's regime choice, as we highlight at the end of Section 3.2. Moreover, in our model there is uncertainty about the magnitude (and not about the sign) of the externality that the activity may generate and we explore the use of monetary incentives to induce truthful reporting. In studying corruption in a model where regulation affects investment incentives, we are close to Harstad and Svensson (2011). 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.

Lastly, our paper is also related to the literature on third-party certification, wherein private certifiers disclose information about sellers' product quality to buyers (an excellent survey is provided by Dranove and Jin, 2010, whereas recent contributions include Stahl and Strausz, 2017, Harbaugh and Rasmusen, 2018, and Bizzotto and Harstad, 2020). Among other things, this literature has highlighted the certifier's incentives to manipulate information to favor their client sellers, and that competition (because of rating shopping) and reputation may not help resolve this conflict of interest (e.g., see Skreta and Veldkamp, 2009, and Hubbard, 1998, 2002, respectively). In this literature, it is the certifier itself that may untruthfully disclose information, whereas in our model we distinguish between a benevolent regulator, who chooses the authorization regime, and a possibly corruptible public official, who is entrusted with the collection of information and may misreport evidence. Moreover, certification typically affects product demand, whereas authorization determines whether production will or will not be allowed.

Outline. The remainder of the paper proceeds as follows. Section 2 describes the set-up and presents two benchmarks. Section 3 carries out the analysis of the baseline model. Section 4 examines the use of report-contingent transfers to the public official. Section 5 discusses some key assumptions of the model, whereas Section 6 explores several extensions and robustness checks. Section 7 provides some concluding remarks. All proofs are relegated to the appendices.

2 Setup

A profit-maximizing firm (it) must decide the level of investment 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, in stage 0, the regulator chooses a policy, being aware of its incentive effects on the firm's investment decision. Both the firm and the regulator are risk-neutral.[9] 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, generates no externalities, and the game ends. If the innovative effort is successful, the firm would be able to produce a new product which would yield gross profits Π. In stage 2, neither the firm nor the regulator knows 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 $h \geq \Pi$. In this case, we say that the state is unsafe. Conversely, if $h < \Pi$, 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 to be sufficiently large so that the firm would never make sure that a breakthrough is achieved with probability 1.

In what follows, it will often be useful to compare activities which involve different harm distributions on $[0, H]$. Specifically, consider two distributions $F(\cdot)$ 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 $G(\cdot)$, that is:

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

This means that the first-order stochastic dominance relation holds for every left-tail distribution. Furthermore, we will often make use of the following definitions: $E_g(h) := \int_0^H hg(h)dh$, $E_g(h|h < \Pi) := \frac{\int_0^\Pi hg(h)dh}{G(\Pi)}$, and $E_g(h|h \geq \Pi) := \frac{\int_\Pi^H hg(h)dh}{1-G(\Pi)}$.

2.1 Benchmarks

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

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

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

[9] In reality, legislators typically design the regulatory policies, whereas enforcement authority is delegated to regulatory agencies. As long as the legislator is benevolent, our simplification is inconsequential as the legislator's and the regulator's objective functions will be aligned.

so that the optimal investment is $I^* = \frac{\int_0^\Pi (\Pi - h) g(h) dh}{c}$. 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:

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

The second benchmark we contemplate is a regime of *laissez-faire*, namely one where the regulator never intervenes. Being unfettered, the firm would always produce an innovative product, irrespective of its social repercussions. Under laissez-faire, the investment in innovation is determined from the following expression:

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

which yields $I^{LF} = \frac{\Pi}{c} \leq 1$. Comparing I^{LF} to I^*, it is immediate to see that, whenever the activity generates some negative externalities, there would be too much investment from a social viewpoint. Social welfare in a regime of laissez-faire is:

$$W^{LF} = \frac{\Pi\left(\Pi - 2E_g(h)\right)}{2c}.$$

The rationale for regulation of innovative activities is provided by the positive wedge existing between W^* and W^{LF}. A regime of laissez-faire would give rise to excessive investment 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 $\Pi \geq 2E_g(h)$. 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 risk-neutral, wealth-constrained 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 $p \in (0, 1)$. Specifically, the public official observes the true level of harm with probability p and does not collect any conclusive evidence with complementary probability $1 - p$. 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.[10] For simplicity, we assume that the precision of the signal collected by the public official is the same under both regimes. As a result, the regulator's optimal regime choice will not be biased by the superior accuracy of the signal that may characterize either authorization regime. Moreover, we normalize to zero the salary received by the public official and we defer the investigation of the optimal wage policy to Section 4.

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 the 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:

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

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. The level of welfare attained in a regime of lenient authorization is given by:

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

where w^{LA} represents the *surplus* due to activity authorization. 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

[10] In the baseline model we assume that the regulator cannot commit to ban (authorize) activities that are socially beneficial (harmful). Put differently, if there is conclusive evidence that $\Pi > (\leq) h$, the regulator must authorize (prohibit) production. In Section 6.1, we remove this restriction.

the over-investment problem and improves the set of activities that are produced. As the lenient authorization regime coincides with laissez-faire for $p = 0$, this implies that lenient authorization dominates a setting without regulatory intervention for any $p > 0$. 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 increase the surplus associated with the authorization of safe activities.

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 the 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:

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

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:[11]

$$p > \frac{\int_0^{\Pi} G(h)dh}{G(\Pi)\Pi} \in (0,1).$$

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

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

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

Lemma 2. *A higher p always increases investment, whereas its effect on welfare is ambiguous. More harmful activities depress investment and reduce welfare.*

The effect of p on welfare is ambiguous. On the one hand, as the firm does not take into account the negative externalities its production would cause, the higher investment hurts welfare. On the other hand, a safe activity is authorized more often. The overall impact of a more accurate signal on welfare tends to be positive 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 how the benevolent regulator's preference for either authorization regime is affected by changes in the primitives of the model.

[11] To see that the term on the right-hand side of the inequality is lower than 1, consider that $G(\Pi)\Pi - \int_0^{\Pi} G(h)dh = \int_0^{\Pi} hg(h)dh$.

Proposition 1. *When all public officials are honest, either authorization regime can dominate and*

(a) there exists a threshold value of the expected externality $E_g(h)$ below which an increase in the firm's gross profits Π makes lenient authorization more desirable;

(b) an increase in p makes lenient authorization more likely to be preferred;

(c) 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 highlights the trade-off between the two authorization regimes. Consider that strict authorization is a more prudent approach because an unsafe product is never allowed. However, it entails some costs due to the foregone opportunity of producing a safe product when there is no conclusive evidence of its effects on society. By contrast, lenient authorization is a bolder approach because the good may be produced despite the absence of conclusive evidence on its safety. Accordingly, this regime fosters investment, but it entails a high cost for the society when an unsafe product turns out to be authorized. An increase in gross profits magnifies the lost opportunity of strict authorization and, therefore, favors a regime of lenient authorization (unless the expected negative externality of the activity, $E_g(h)$, is overly high). This may provide an explanation for the differing regulatory restrictions imposed on hydraulic fracturing by states that are oil-rich, like Texas, and others, like Vermont, that have more limited oil reserves. A more accurate signal p improves allocative efficiency in both regimes: it lowers the probability that unsafe goods are authorized under lenient authorization, whereas it increases the chances that safe goods are approved under strict authorization. Moreover, a higher signal accuracy alleviates the over-investment problem under lenient authorization, whereas it may magnify the investment distortion under strict authorization. As a result, an increase in p makes lenient authorization relatively more desirable than strict authorization. For activities that are relatively less harmful, the benevolent regulator will be more inclined to use a lenient authorization regime not to lose out on the opportunities they entail.[12]

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

[12] 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. Similarly, the EMA can recommend marketing authorization on the basis of less complete or limited evidence on the effectiveness and safety of a drug, when this is intended to treat a life-threatening disease for which there is no satisfactory treatment available or if the targeted disease is very rare. This approach is consistent with the result that activities which may exhibit greater social benefits should not be subject to a strict authorization regime.

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 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 corruption 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 corruption. We further assume that the side-contract between the parties is perfectly enforceable. 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, including reputation, emotions, and reciprocity.[13] We also assume that the public official reports truthfully when indifferent.

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 the firm will not be allowed to produce the good if the unfavorable information is revealed. 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:

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

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

[13] A large body of experimental evidence has documented the self-enforceability of corruption due to these channels. Among other things, it has shown that long-term relationships and reciprocity can give rise to mutually beneficial bribery, even when this imposes a negative externality on other subjects (see Abbink et al., 2002), or make extortion credible by harshly punishing subordinates who resist extortion demands (see Bolle et al., 2011).

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 $p[1 - G(\Pi)]$ 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:

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

If $\alpha = 1$, namely if the firm holds all the bargaining power, the investment decision is the same as under laissez-faire.[14] 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:

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

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*. We assume that the public official bears a monetary or psychological cost $R > 0$ if she does not follow through on her threat to conceal evidence in the case in which the parties do not reach an agreement. One plausible justification for this cost arises if the public official is concerned about building her reputation for being vengeful so as to increase her future payoffs. For instance, this would be the case if the public official were tasked with collecting and reporting evidence on the social repercussions of other activities. Even in the absence of reputation, some agents are willing to incur some monetary costs to punish other people's uncooperative actions, as shown by abundant experimental evidence (e.g., see Fehr and Gachter, 2000).[15] Irrespective of its source, the cost R acts as a commitment device for the public official whose threat will be credible. 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. We take the parameter γ to represent the strength of the country's institutions and higher values imply that

[14] In fact, when $\alpha = 1$, the firm will have to give up a rent to the public official to conceal evidence. In the analysis, we disregard this rent as it can be arbitrarily small.

[15] This can be explained by reciprocity or emotions (like irritation and contempt as in the experiment by Bosman and Van Winden, 2002, or like anger as in that by Ben-Shakhar et al., 2007).

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, expecting to get $\gamma\Pi$. We also assume that the public official does not suffer any loss if the firm wins the appeal.[16] The bribe will be determined from the following:[17]

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

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:

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

Welfare gives:

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

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. As before, a higher p increases the likelihood that a safe product is authorized. Accordingly, it is more likely that an increase in p has a positive impact on welfare when there is corruption as compared to the case in which public officials are honest.[18] The ensuing implication is that an increase in the precision of the signal may induce the regulator to tighten the regulatory regime.

Proposition 2. *When all public officials are corrupt, either authorization regime can dominate and an increase in p does not always make lenient authorization more likely to be preferred by the benevolent regulator. It also holds that $W^{LA} \geq W_C^{LA}$, whereas $W_C^{SA} \geq W^{SA}$ if and only if $\frac{E_g(h|h<\Pi)}{\Pi} \geq \frac{(1-\gamma)(1-\alpha)}{2}$.*

[16] We more extensively comment on the parameter γ and other related assumptions in Section 5.

[17] Note that R does not appear in the maximization problem because the public official will avoid it by concealing evidence if the side-agreement is not reached. In other words, the public official's threat point is 0 because R is only borne off-the-equilibrium path.

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

In a regime of strict authorization, corruption may turn out to be good for welfare. To understand why, consider that even a regime of strict authorization may entail 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 and investment, respectively, in the two regimes as a function of p.[19] The solid (dashed) lines represent welfare and investment when public officials are all honest (corrupt). Given the parametric assumptions, welfare rises in both regimes with the probability of finding conclusive evidence, p. Corruption unequivocally reduces the benefits of lenient authorization, whereas it might be beneficial under strict authorization, as in the cases illustrated in Figure 1.

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 bolder 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 over-investment) are exacerbated, which make strict authorization more attractive. This scenario is illustrated in Panel (a): 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 $p \geq 0.664$).

By 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 Panel (b), wherein lenient authorization outperforms strict authorization only if there is no corruption and p is sufficiently high (i.e., higher than 0.444).

To help visualize the role played by corruption, in Table 1 we report how the regulator's choice of the authorization regime depends on the precision of the signal and the expected harm, with and without corruption. In the absence of corruption, strict authorization is chosen only if the expected negative externality is high and the signal is not very precise: intuitively, the regulator will prefer to ban activities when it is highly likely that there will be no conclusive evidence of their safety, if their expected side effects are very noxious. Essentially, without corruption, we retrieve the finding of Immordino et al. (2011) concerning the optimal authorization regime (see their Lemma 1).[20] The presence of corruption dramatically alters the regulator's choice:

[19] 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.

[20] Notably, authorization regimes tend to engender over-investment in our model, whereas they result in under-investment in that of Immordino et al. (2011). This owes to the assumption that, in the good state, products entail positive externalities in their set-up, whereas they involve negative externalities in ours.

strict authorization tends to dominate also for high values of p, even when the expected harm is relatively low. Due to corruption, allocative efficiency is unaffected by the precision of the signal under lenient authorization, whereas it positively depends on p under strict authorization. The effect of the signal precision on investment incentives is instead dampened in both regimes, as can also be seen in Figure 2.

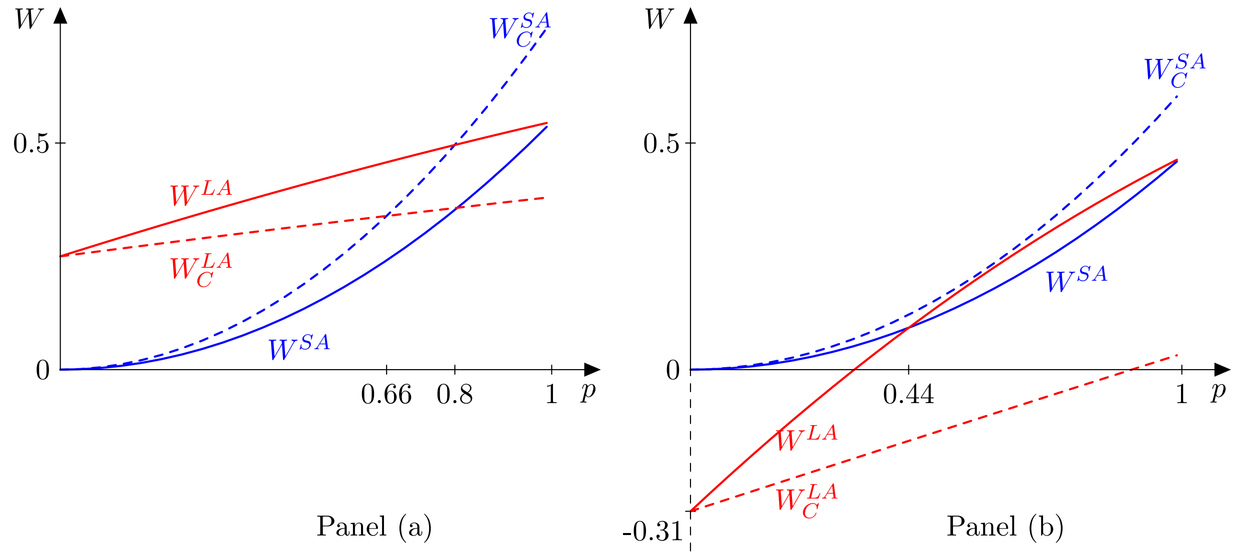

Figure 1: Welfare in the different authorization regimes. Both figures are drawn assuming the following values for the parameters: $\Pi = 5$, $c = 5$, $\alpha = 0.5$, $\gamma = 0.5$ and h has a point mass of 0.25 at 0 and is distributed according to the Uniform Distribution on $(0, H]$, where $H = 6$ in *Panel (a)* and $H = 7.5$ in *Panel (b)*.

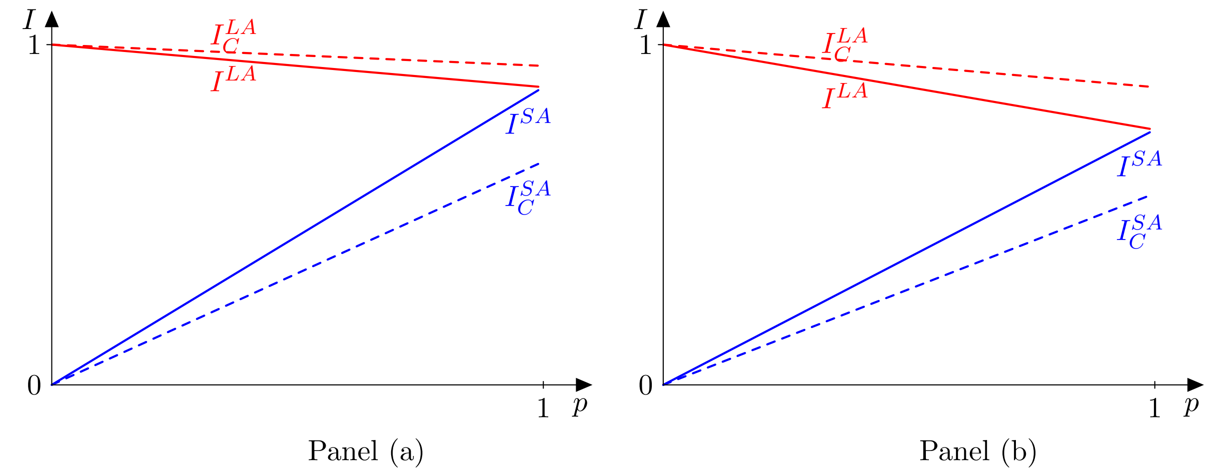

Figure 2: Investment in the different authorization regimes. Both figures are drawn assuming the following values for the parameters: $\Pi = 5$, $c = 5$, $\alpha = 0.5$, $\gamma = 0.5$ and h has a point mass of 0.25 at 0 and is distributed according to the Uniform Distribution on $(0, H]$, where $H = 6$ in *Panel (a)* and $H = 7.5$ in *Panel (b)*.

	Honest public officials		Corrupt public officials	
	Low harm	High harm	Low harm	High harm
Low p	LA	SA	LA	SA
High p	LA	LA	SA	SA

Table 1: Regulator's choice of the authorization regime with low and high signal precision, low and high expected harm, with and without corruption. LA (respectively, SA) stands for lenient authorization (strict authorization).

3.3 Heterogeneous public officials

We now 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 the 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. By contrast, a dishonest public official is merely interested in maximizing her income. Henceforth, we say that corruption is more pervasive when υ takes a lower value.

Before studying the overall impact of the pervasiveness of corruption on welfare, it is useful to draw attention to two expressions. The former is $\frac{E_g(h|h<\Pi)}{\Pi}$, which is the *expected externality-to-profit ratio* for a safe activity. This ratio is always lower than 1 and higher values imply that the net social benefits of authorizing a safe activity are smaller and, as a result, that investment is less desirable from a social standpoint. The latter is $(1-\upsilon)(1-\gamma)(1-\alpha)$, which is the fraction of the gross profits that the firm does *not* expect to enjoy when there is evidence that the activity is safe in a regime of strict authorization. It is immediate to see that this fraction is decreasing in the share of honest public officials in the population, in the strength of the institutions, and in the firm's bargaining power. Under strict authorization, the firm will be more reluctant to invest when this fraction is higher. 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

$$\frac{E_g(h|h < \Pi)}{\Pi} > (1-\upsilon)(1-\gamma)(1-\alpha), \tag{1}$$

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

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 expected distribution of the gains between the firm and the public official. A higher level of υ encourages investment as the firm anticipates that there is a lower chance that it will have to share the gains stemming from the authorization of production with a corrupt public official. Whether this investment-boosting effect of an increase in υ is beneficial or detrimental to welfare depends on (i) the expected externality-to-profit ratio and (ii) the fraction of the gross profits that the firm does not expect to enjoy as Condition (1) shows. If the expected externality-to profit ratio is sufficiently high and the firm already expects to reap a significant fraction of the gross profits, there would be an over-investment problem. Then, an increase in υ would exacerbate this issue, thereby reducing welfare. Notably, from inspecting Condition (1), we can see that there always exists a threshold value of $\upsilon \in [0, 1)$ above which an increase in the fraction of honest public officials would be welfare-decreasing in a regime of strict authorization. Moreover, 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.

This section has shown that corruption plays a very critical role in determining which authorization regime the regulator will adopt.[21] While corruption is always detrimental to welfare under lenient authorization, it may actually be beneficial under strict authorization. Not only does more pervasive corruption induce the regulator to opt for a tighter regulatory regime, but it may also have a positive impact on social welfare. This key take-away of the baseline model is summarized in the following corollary.

Corollary 1. *An increase in the pervasiveness of corruption may benefit welfare.*

4 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

[21] Referring to Figure 1, for those values of the parameters, the level of welfare in the regime of lenient (respectively, strict) authorization as a function of p is a curve which lies between W_C^{LA} and W^{LA} (resp., W_C^{SA} and W^{SA}).

Dal Bó, 2006, and Estache and Wren-Lewis, 2009). The baseline model allowed us to highlight the key result that corruption may improve welfare by reducing an over-investment problem in a regime of strict authorization, thereby leading to its adoption by a benevolent regulator. Abstracting from the implementation issue, we now study the features of the optimal salary schemes and we investigate whether our main conclusion is affected by their availability.

We assume that the regulator announces non-negative salaries to the public official which are contingent on the report, $s_r \geq 0$, where $r \in [0, H] \bigcup \{\emptyset\}$. 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. Focusing on the more general scenario developed in Section 3.3, we now discuss how the wage policy should be designed in the two authorization regimes. Welfare is given by the sum of the firm's expected profits and the public official's expected utility, minus the externalities the activity generates and the inefficiency cost associated with the public official's salary, λs.

4.1 Wage policy under 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 $s_{\emptyset}^{LA} = 0$ and $s_h^{LA} = 0$ 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 honest public officials in the population is large. This is because honest public officials need not receive a reward to truthfully report evidence. We now make the following parametric assumption.

Assumption 1. *For all $h \in (0, H)$, it holds that* $\frac{\partial hg(h)}{\partial h} > 0$.

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 when the externalities that the authorized activity would bring about are larger. As a result, if the regulator ever tolerates collusion, he prefers to do so for levels of h closer to Π.[22] In the welfare maximization problem, we determine the threshold level $h_L^{LA} \in [\Pi, H]$ above which collusion is prevented, and the following lemma illustrates the results.

Lemma 3. *In a regime of lenient authorization, there exists a threshold $\hat{h}_L^{LA}$, that is weakly increasing in υ, such that the regulator sets $s_{\emptyset}^{LA} = 0$ and*

$$s_h^{LA} = \begin{cases} \Pi, & \textit{for all } h \in [h_L^{LA}, H]; \\ 0, & \textit{otherwise,} \end{cases}$$

[22] This result is formally shown in the proof of Lemma 3.

where $h_L^{LA} = \max\{\Pi, \min\{\hat{h}_L^{LA}, H\}\}$.

The regulator prevents corruption for $h \in [h_L^{LA}, H]$ by paying the minimum salary that induces the corruptible public official to report truthfully that the activity is unsafe. When the fraction of honest public officials grows larger, i.e., when υ takes a higher value, the threshold h_L^{LA} (weakly) increases. Intuitively, when corruption is less likely to be an issue, the regulator finds it socially beneficial to spend less resources on collusion prevention. An increase in the cost of raising public funds, λ, makes it more socially costly to prevent collusion and it has two counteracting effects on the optimal threshold h_L^{LA}. On the one hand, a higher λ motivates the regulator to tolerate more collusion by increasing the threshold: conditional on having a breakthrough, the public official will be rewarded less often for her report. On the other hand, an increase in λ prompts the regulator to lower the threshold in order to discourage the firm's investment: as the likelihood of a breakthrough will diminish, the regulator will be able to save on the cost of rewarding the public official. The latter tends to be a second-order effect, though, and can offset the former only when the marginal impact of increasing h_L on investment incentives is particularly strong. Therefore, an increase in λ normally induces the regulator to raise h_L^{LA}. Lastly, note that the possibility of engaging in corruption with the public official does not affect the firm's investment decision if $\alpha = 0$. This is because all the gains from collusion will be reaped by the public official. In that case, the threshold $\hat{h}_L^{LA}$ is optimally set to take into account only the ex-post welfare benefits of preventing corruption and takes a simple form:

$$\hat{h}_L^{LA} = \Pi + \frac{\lambda}{1-\upsilon}\Pi.$$

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 $\hat{h}_L^{LA}$ so as to mitigate the over-investment problem, unless λ is too high.

4.2 Wage policy under strict authorization

In this regime, the public official who has collected conclusive evidence that the activity is safe must decide whether or not to engage in extortion. If she does not engage in extortion, she can either report truthfully (obtaining s_h from the regulator) or conceal the collected evidence (obtaining $s_\emptyset$). Alternatively, she can engage in extortion, threatening the firm to conceal this favorable information. If the public official and the firm do not reach an agreement in the extortion subgame, the public official will either follow through on her threat, getting $s_\emptyset$, or report truthfully, in which case her payoff is $s_h - R$, as she would bear the cost of failing to carry out the threat. In Figure 3, we illustrate the game tree describing the public official's possible actions, as well as the resulting payoffs, following the collection of conclusive evidence that the activity is safe. Ultimately, her choice will be made to maximize her own payoff.

In the following lemma, we show that the public official would engage in extortion only if the threat of framing the firm when an agreement is not reached is credible.

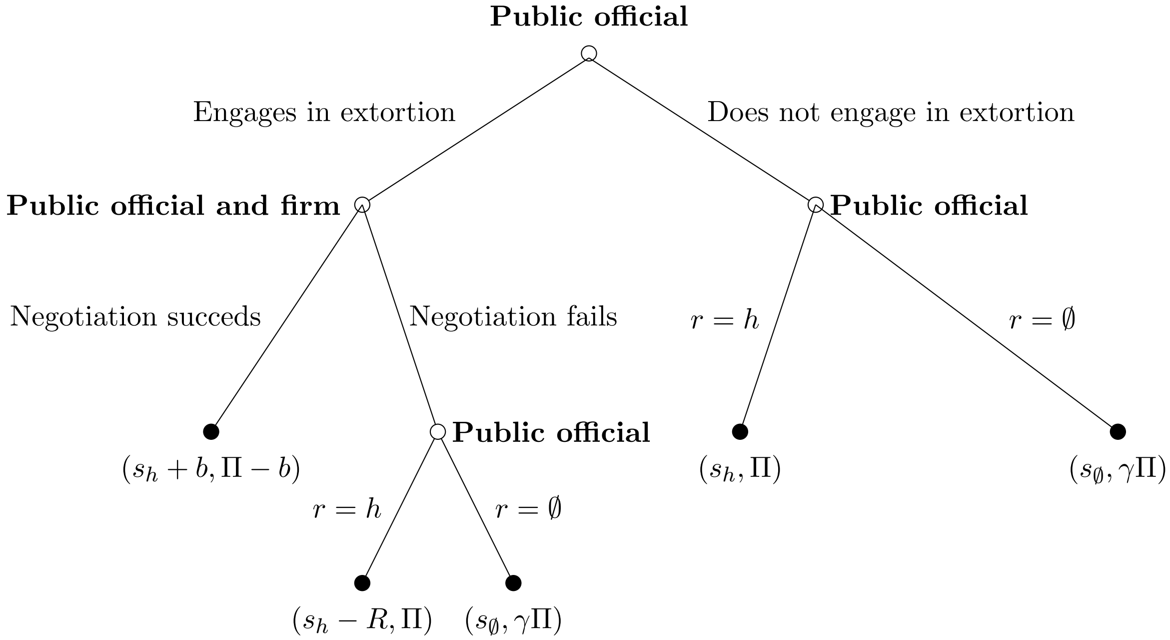

Figure 3: Public official's possible actions and payoffs after observing $h \in [0, \Pi)$. The first (respectively, the second) payoff in the round brackets is the public official's (the firm's).

Lemma 4. *At $h \in [0, \Pi)$, extortion occurs in equilibrium only if $s_h - R < s_\emptyset$.*

For extortion to occur in equilibrium, it must be that the public official would be willing to hurt the uncooperative firm, and this requires that $s_\emptyset > s_h - R$. Henceforth, we say that blackmail is credible when this inequality holds. When this is the case, the public official's and the firm's threat points in the side-bargaining are $s_\emptyset$ and $\gamma\Pi$, respectively. The parties can split the surplus $(1-\gamma)\Pi + (s_h - s_\emptyset)$ and the bribe will be determined from the following:

$$b_G^{SA} := \arg\max_{b \in \mathbb{R}} \quad [b + s_h - s_\emptyset]^{1-\alpha}[(1-\gamma)\Pi - b]^{\alpha}.$$

This leads to $b_G^{SA} = (1-\alpha)(1-\gamma)\Pi - \alpha(s_h - s_\emptyset)$ and the public official's utility if the negotiation succeeds is $(1-\alpha)[(1-\gamma)\Pi + s_h - s_\emptyset] + s_\emptyset$. Note that the public official can always refrain from engaging in extortion getting the maximum between s_h and $s_\emptyset$. It follows that, when $s_h > s_\emptyset$, the public official will engage in extortion only if her bargaining power vis-à-vis the firm, $1-\alpha$, is sufficiently high so as to ensure that $b_G^{SA} \geq 0$.

The benevolent regulator has a tool to prevent extortion from occurring: the salary scheme that he offers to the public official. Yet, he may be willing to tolerate some extortion and the reason is twofold: firstly, as highlighted in Section 3, corruption may not be detrimental to welfare as it mitigates the over-investment problem; secondly, extortion is socially costly to prevent because of the inefficiency of raising public funds, λ. In what follows, we assume that, if the regulator prevents extortion for some h, he does so for levels of h closer to Π.[23] In the

[23]This assumption is only made for ease of exposition and is inconsequential for our results. As extortion does not affect allocative efficiency but only investment decisions, it does not matter for which specific levels of

welfare maximization problem, we determine the threshold value h_S^{SA} above which extortion is deterred and the equilibrium salaries, and Lemma 5 illustrates the results.

Lemma 5. *In a regime of strict authorization, there exists a threshold* $\hat{h}_S^{SA} > 0$*, that is weakly increasing in* R*,* λ*, and* υ*, such that the regulator sets* $s_\emptyset^{SA} = 0$ *and*

$$s_h^{SA} = \begin{cases} \min\left\{R, \frac{1-\alpha}{\alpha}(1-\gamma)\Pi\right\}, & \text{for all } h \in (h_S^{SA}, \Pi); \\ 0, & \text{otherwise,} \end{cases}$$

where $h_S^{SA} = \min\left\{\hat{h}_S^{SA}, \Pi\right\}$.

The regulator thwarts extortion when $h \in (h_S^{SA}, \Pi)$ by paying the minimum salary that ensures that the corruptible public official reports truthfully. To this end, the regulator can follow two approaches. He can either make blackmail non-credible by setting $s_h = s_\emptyset + R$, or render extortion unprofitable for the public official by setting $s_h = s_\emptyset + (1-\alpha)[(1-\gamma)\Pi + s_h - s_\emptyset]$. As paying higher salaries entails a welfare loss, the regulator who wants to prevent extortion for some $h \in [0, \Pi)$ would choose the cheaper alternative. As a result,

$$s_h = \min\left\{R, \frac{1-\alpha}{\alpha}(1-\gamma)\Pi\right\} + s_\emptyset.$$

As the above expression illustrates, when the public official's gains from extortion are smaller (i.e., when α or γ are higher), it is more desirable to render extortion non-profitable than blackmail non-credible. Either way, it is immediate to see that $s_\emptyset^{SA} = 0$ so as to minimize the wage bill.

Preventing extortion enables the firm to fully appropriate the gains from production, thereby stimulating investment. This comes at the direct social cost of paying a high salary to the public official for an informative report. When λ takes larger values, this direct social cost of extortion prevention is magnified. Accordingly, the regulator is more inclined to tolerate this type of corruption for higher values of λ. A similar effect arises when R takes a higher value, as this (weakly) increases the salary that must be paid to make blackmail non-credible. By contrast, an increase in υ makes fighting corruption, by means of a costly salary, less valuable: as it is less likely that the public official is corruptible, the firm's payoff is less sensitive to whether or not extortion is prevented, diminishing the regulator's incentive to spend resources on corruption deterrence.[24] Increases in α or γ have two counteracting effects which make their impact on the regulator's willingness to deter extortion ambiguous. On the one hand, they both translate into higher gains from the side-contract that the firm appropriates. This shrinks the potential benefits of preventing extortion. On the other hand, increases in α or γ (weakly) reduce the direct welfare cost of deterring extortion, as the salary s_h is weakly decreasing in both these parameters.[25]

h extortion is prevented. What ultimately matters is the mass of probability for which extortion does not take place.

[24] Note that s_h does not depend on υ. Therefore, υ does not affect the marginal cost of preventing extortion.

[25] In the proof of Lemma 5, we show that the way this trade-off is resolved may depend on the value of λ, that measures the direct welfare cost of preventing corruption.

4.3 Comparison of lenient and strict authorization

In this subsection, we examine how the wage policy affects the comparison between lenient and strict authorization. We begin our analysis by studying how the optimal regime choice is influenced by λ, as this parameter captures the cost of using the salary as a tool to curb corruption. We denote welfare under lenient and strict authorization by $W_G^{LA}(h_L^{LA})$ and $W_G^{SA}(h_S^{SA})$, respectively, to indicate that these are the levels of welfare achieved when the optimal thresholds that we have characterized in the first part of this section, h_L^{LA} and h_S^{SA}, are chosen.

To carry out the comparison, it is useful to first consider the scenario in which paying a positive salary to the public official does not entail any welfare loss, i.e., $\lambda = 0$. Under lenient authorization, the regulator would fully weed out collusion, that is, $h_L^{LA} = \Pi$. Intuitively, collusion has been shown to be always detrimental to welfare. If the salary scheme does not engender any other welfare distortion, the regulator would never allow this form of corruption. As a result, social welfare under lenient authorization would coincide with that which emerges when all public officials are honest, namely, $W_G^{LA}(h_L^{LA}) = W^{LA}$. Conversely, under strict authorization, the regulator might prefer to fully tolerate extortion, obtaining $W_G^{SA}(h_S) = W_G^{SA}$. This occurs if Condition (1) holds.[26] To understand why, consider that the regulator optimally chooses the extent to which extortion is allowed so as to influence the firm's investment decision. Anticipating that it will reap only a fraction of the benefits from production, the firm has a dampened incentive to invest when extortion is allowed. Therefore, tolerating extortion may be an appealing, albeit unorthodox, tool for the benevolent regulator to avoid that the firm devotes excessive resources to the development of the innovative activity. Indeed, recall that Condition (1) is more likely to hold when the activity is more harmful. At the same time, the regulator must also avoid that the firm has too little incentive to invest, which is the case when the firm expects to reap a too meagre fraction of the gains from investment, i.e., when α, γ, and v are smaller. If so, it is more difficult for Condition (1) to hold, in which case the regulator deters some extortion. Even in that case, it is worth noticing that extortion is not entirely weeded out: the regulator would tolerate some extortion to induce $w_G^{SA}(h_S^{SA}) = cI_G^{SA}(h_S^{SA})$, thereby achieving second-best welfare.

We now consider the scenario in which $\lambda > 0$. Welfare in a regime of lenient authorization is always lower with respect to W^{LA} as deterring a side-agreement between the public official and the firm is socially costly and, as a result, some collusion will optimally be tolerated. In a regime of strict authorization, welfare will not depend on the value of λ if Condition (1) holds. Stated differently, the possibility of paying wages may be immaterial in a regime of strict authorization as the regulator may prefer to fully tolerate extortion.[27] In the following proposition, we illustrate how changes in λ affect welfare under the two authorization regimes and its ensuing implications for the regulator's choice.

Proposition 4. *The impact of an increase in λ on welfare*

[26] This claim is formally shown in the proof of Proposition 4.

[27] This finding may provide a rationale for the lack of monetary incentives to public officials that is often observed in the real world.

(a) is always negative in a regime of lenient authorization, whenever $h_L^{LA} < H$;

(b) is negative in a regime of strict authorization only if Condition (1) is not satisfied.

An increase in λ makes corruption more likely to arise in equilibrium and makes the benevolent regulator more inclined to adopt a regime of strict authorization when Condition (1) is satisfied.

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 the wage policy even when it is very inexpensive.

Proposition 4 illustrates that, when Condition (1) holds, strict authorization becomes relatively more desirable as λ takes higher values. If Condition (1) is not satisfied, welfare decreases under both regimes when λ rises. In that case, the impact of changes in λ on the likelihood of adopting either regime is ambiguous. The parameter values used in the graphical analysis of both panels of Figures 1 and 2 are such that Condition (1) is satisfied. Suppose that all public officials are corrupt, i.e., $\upsilon = 0$. If $\lambda = 0$, $W_G^{LA}(h_L^{LA}) = W^{LA}$ and $W_G^{SA}(h_S^{SA}) = W_C^{SA}$. Therefore, the wage policy is valuable only if lenient authorization is used. In the scenario illustrated in Panel (a) of Figure 1, a stricter authorization regime would dominate for high values of p (e.g., for $p > 0.803$). As λ takes higher values, welfare under strict authorization does not change, whereas that under lenient authorization decreases. As a result, the threshold value of p above which strict authorization is preferred diminishes with λ.[28]

We now turn to determining the effect of changes in υ on welfare in the two regimes.

Proposition 5. *The impact of an increase in υ on welfare*

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

(b) is always (weakly) negative in a regime of strict authorization.

Proposition 5 shows that an increase in the pervasiveness of corruption makes the regulator more inclined to adopt a regime of strict authorization. This occurs because an increase in the fraction of honest public officials has an opposing effect on welfare in the two regimes: it is always beneficial under lenient authorization and detrimental under strict authorization. Akin to the baseline model, an increase in υ reduces investment and improves allocative efficiency under lenient authorization. Under strict authorization, an increase in υ makes it more difficult to obtain second-best as it facilitates the satisfaction of Condition (1). When Condition (1) holds, or it does not but $\lambda > 0$, welfare falls short of second-best in this regime as there is some over-investment. An increase in υ would exacerbate this issue, thereby reducing welfare. In the following corollary, we confirm the key take-away of the baseline model concerning the surprising effect of an increase in the pervasiveness of corruption on welfare in the scenario where the regulator can reward the public official with report-contingent monetary transfers.

[28] In the scenario presented in Panel (b) of Figure 1, the wage policy would be immaterial as the regime of strict authorization would continue to be preferred for any value of p.

Corollary 2. *When the regulator can use the wage policy, an increase in the pervasiveness of corruption may benefit welfare.*

5 Discussion

In this section we discuss the role played by some of the most notable assumptions of our model and we elaborate on the implications of some of our chief results. Technicalities are relegated to Appendix B.

Ex-post efficiency only. In our model, the benevolent regulator values both investment incentives and allocative efficiency in deciding the authorization regime. If the regulator only cares about ex-post efficiency in his welfare function, the thresholds characterized in Section 4 will differ. In particular, in a regime of lenient authorization collusion will be prevented for $h \in [h_L^{LAexpost}, H]$ where

$$h_L^{LAexpost} = \min\left\{\Pi + \frac{\lambda}{1-\upsilon}\Pi, H\right\}.$$

The regulator will optimally weed out collusion when it is costless to prevent, i.e., $\lambda = 0$, as this form of corruption distorts allocative efficiency. When λ rises, the regulator tolerates some collusion. There is also a positive relationship between the pervasiveness of corruption and the use of monetary incentives to deter collusion, namely the threshold will optimally decrease as $(1-\upsilon)$ takes higher values. On the contrary, in a regime of strict authorization, the regulator will be unwilling to spend resources to deter extortion as this side of corruption does not affect allocative efficiency. Stated differently, the set of projects which are authorized and, consequently, ex-post welfare are independent of whether extortion is allowed or not.[29] In the following remark, we illustrate the regulator's choice of the authorization regime when only ex-post efficiency matters for welfare.

Remark 1. *Suppose that the regulator is only concerned about ex-post welfare. When $\upsilon = 1$ or $\lambda = 0$, the regulator chooses a regime of strict authorization if and only if $E_g(h) \geq \Pi$. As υ decreases and/or λ increases, strict authorization becomes relatively more socially desirable.*

When all public officials are honest or it is costless to deter collusion, the regulator will choose a regime of lenient authorization if and only if it is socially desirable to allow production when there is no evidence about product safety. When public officials are corrupt, the regulator is concerned about the threat of corruption only in a regime of lenient authorization. Accordingly, as υ decreases and λ increases, the regulator is more inclined to choose a regime of strict authorization. Taking also into account investment incentives allows highlighting the potentially beneficial effect that corruption may have on welfare thanks to the alleviation of the over-investment problem in a regime of strict authorization.

[29] 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. However, in her model, she does not explore the impact of corruption on private investments.

Institutional strength. In analyzing the strict authorization regime, we have supposed that the firm can challenge the public official's report and, if the appeal has indeed some merits, production will be authorized. In the real world, instances in which firms can ask for a review of an unfavorable decision abound: in the U.S., patent applicants whose claims have been twice rejected can appeal to the Patent Trial and Appeal Board (see the U.S. Code, Title 35 Section 134), whereas in Europe Part VI of the European Patent Convention governs the appeal procedure for applicants whose applications have been refused by the European Patent Office; in Europe, drugmakers seeking marketing authorization can request the European Medicines Agency to have the evidence assessed by another group of experts. Furthermore, a firm can also turn to the judicial authority if it believes to have been treated unfairly. In the model, we have assumed that, if there is evidence that the product is safe, production will be authorized with probability γ and we have argued that this parameter may be tied to the institutional strength. Implicitly, we have supposed that the entity reviewing the application, let it be a court, another regulatory agency, or a distinct examiner within the same agency, has access to information that is correlated with that collected by the public official. Accordingly, the parameter γ may be increasing in p: a valid appeal is more likely to be upheld when conclusive evidence can be obtained more easily. This positive relationship between γ and p means that a higher precision of the signal improves the firm's threat point and reduces the equilibrium bribe. Under strict authorization, a positive correlation between p and γ implies that welfare is more likely to increase in the pervasiveness of corruption when the signal is more precise. To understand why, notice that Condition (1) is easier to hold when p takes higher values, if γ is an increasing function of p.

We can also put forward a different interpretation for the parameter γ. While the firm may be eventually granted approval to produce, the initial hindrance to production will result in a profit loss equal to $(1-\gamma)\Pi$. Stated differently, the parameter γ can be inversely proportional to the time needed to review, and possibly overturn, the public official's initial decision. This interpretation is related to the notion of facilitating payments (see Argandoña, 2005): the public official can stall the firm's application process or delay the authorization of the activity, hurting its profits, unless the firm accepts to give in to the public official's bribery request.

Lastly, it is worth highlighting that the possibility of appealing the public official's report is not essential for our results to arise.

Penalties. We have also assumed that the public official cannot be fined if the firm wins the appeal. The underlying reason is that the public official could plausibly claim that she had not found conclusive evidence. In any case, this assumption is inconsequential for our results. To understand why, consider that the firm appeals the decision only off-the-equilibrium path, following the public official's decision to conceal favorable evidence. To prevent extortion for some $h \in [0, \Pi)$, the regulator would set

$$s_h = \min\left\{R, \frac{1-\alpha}{\alpha}(1-\gamma)\Pi\right\} + s_\emptyset - \gamma F,$$

where F denotes the fine. As the public official is wealth constrained, the fine would be bounded above by $s_\emptyset$. Thus, imposing a positive fine does not help the regulator to prevent extortion and setting $s_\emptyset = 0$ continues to be optimal. In addition, consider that setting $s_\emptyset > 0$ would have unintended consequences, since it might induce a public official who has observed $h \geq \Pi$ to conceal evidence so as to collect the reward. However, if the fine also includes some non-pecuniary loss for the public official, due to peer sanctioning or social stigma associated with overturning her initial decision, extortion may be more easily deterred. As extortion may be optimally tolerated, the model would provide a rationale for safeguarding public officials from backlash against their decisions that turn out to be incorrect.

Monetary or psychological cost R. In the analysis of the strict authorization regime, we have posited that the public official incurs a loss R if she fails to carry out the threat of concealing evidence favorable to the firm when negotiation fails. By contrast, under lenient authorization, we have supposed that the public official does not incur a similar loss if she does not hurt the firm in the case in which negotiation with the firm breaks down. The reason for treating this cost asymmetrically in the two regimes lies in the sharply different nature of collusion and extortion. Under collusion, the firm and the public official work together to obtain a mutually beneficial outcome and there is no reason for the firm not to accept the deal. Instead, extortion is antagonistic in that it always hurts the firm. Therefore, a credible threat of framing is needed to persuade the firm to give in to the public official's demand for a bribe.[30] This suggests that, in order to extract bribes, the public official is more eager to build a reputation for being vengeful in a regime of strict authorization.

Furthermore, it is worth stressing that the results of the analysis would be unaffected if the public official suffered a psychological cost also in a regime of lenient authorization.[31] To understand why, recall that when blackmail is credible under strict authorization, the public official would be willing to lie and report that no conclusive evidence has been found to hurt the firm. Making blackmail non-credible for a given $h' < \Pi$ requires paying the public official $s_{h'} = R > 0 = s_\emptyset$, so that she reports truthfully. Under lenient authorization, the threat of harming the firm if negotiation breaks down means that the public official should report the true level of externality. Making this threat non-credible for a given $h'' \geq \Pi$ requires paying the public official $s_\emptyset = R > 0 = s_{h''}$ so that she conceals evidence. However, rewarding the public official for hiding evidence is clearly undesirable and, accordingly, the regulator will never weigh this option. As the threat of hurting the firm if negotiation fails is credible, R does not affect the threat point, since it is borne only off-the-equilibrium path. Hence, it will not appear in the welfare expressions.

[30] This distinction between collusion and extortion is well-established in the literature (e.g., see Khalil et al., 2010).

[31] Specifically, the public official could threaten the firm to reveal unfavorable evidence to the firm, that is, $h \geq \Pi$, unless the firm gives the public official a bribe.

Disclosing information. If the accuracy of the signal at least partially depends on the information that the firm itself provides in its application, we might expect p to be higher in a regime of strict authorization. As the firm is unaware of the actual externality that the activity generates, it will have a more muted incentive to disclose valuable information in a regime of lenient authorization, in the knowledge that approval will be granted in the absence of conclusive evidence on the safety of the activity. On the contrary, such incentive to withhold information is absent in a regime of strict authorization. This last point is relevant in that regulatory agencies often base their authorization decision on the information provided by the firms themselves. For instance, drug developers seeking marketing authorization must first conduct preclinical and clinical trials. In doing so, they must follow regulatory guidelines and may be later asked to address experts' questions and doubts (for an overview of the European procedure, see Jawahar et al., 2015, and Nieto-Gutierrez, 2017). To approve other activities, the regulator directly runs tests and checks. For instance, before carrying out hydraulic fracturing in the UK, shale operators must obtain a "hydraulic fracturing consent" from the Secretary of State as mandated by the 2015 Infrastructure Act. For the consent to be granted, an independent inspection of the integrity of the relevant well is required in addition to several environmental permits that must be secured from the relevant environmental authorities, aimed at ensuring, for instance, the monitoring of the level of methane in groundwater. Ultimately, the probability of having conclusive information, p, will be affected by regulatory procedures, protocols, the agencies' resources and policies, public officials' skills and time - all of these factors may well be country and sector dependent. However, according to our model, if the firm plays a crucial role in furnishing information about the safety of the activity, the case for the adoption of strict authorization is undoubtedly strengthened as this regime will lead to the disclosure of more critical information and, as a consequence, a higher precision of the signal.

Anti-corruption measures. The regulator can implement several additional measures to avoid or at least curb corruption opportunities that we have not contemplated in the model. For instance, setting up teams of experts who collectively evaluate whether an activity should be approved or withholding information about the experts' identity from the applicants. These measures may make corruption more complicated to organize but may not always work or be undertaken. In some contexts, the applicant may easily learn the identity of the evaluator. This is the case of patent protection, where the purview of the evaluators' expertise tends to be very narrow and they interact with the applicants (typically, law firms) during the evaluation process (for more details, see Tabakovic and Wollmann, 2018). In a group of evaluators, there could be some critical or pivotal expert the firm could target in the case of collusion or who could blackmail the firm in the case of extortion. It must also be stressed that some of these measures are costly (having many experts at payroll for any single decision) and, as highlighted in our model, tolerating some corruption in the form of extortion is not always detrimental to welfare. In light of this, one implication of our paper is that the value of these measures may be greater in a regime of lenient authorization.

6 Extensions and Robustness Checks

In this section, we examine several extensions to the baseline model and we discuss the robustness of our results.

6.1 Regulator's commitment ability

Thus far, we have restricted the regulator to ban activities that are known to be socially harmful and authorize those that are known to be socially beneficial. In this subsection, we assume that the regulator can initially choose, and commit to, a threshold $\bar{h}$ above which an activity will be disallowed. The regulator will determine this regime-dependent threshold taking into account both the firm's incentives to invest and ex-post allocative efficiency.

We can still distinguish between lenient and strict authorization by taking as the defining characteristic of an authorization regime whether or not production is allowed in the absence of conclusive evidence on its negative social repercussions. Accordingly, we define as *modified lenient authorization* (MLA) a regime in which products are authorized if conclusive evidence is lacking, and as *modified strict authorization* (MSA) a regime in which products are banned in the absence of evidence on their safety. Corruption opportunities will continue to differ between the two regimes, as they depend on the regulator's authorization decision when evidence is absent: under modified lenient authorization, the issue of collusion emerges because the public official and the firm could conspire to conceal evidence that reveals $h > \bar{h}$; under modified strict authorization, the issue of extortion arises because the public official could threaten the firm to suppress evidence that $h \leq \bar{h}$. In Proposition 6, we illustrate how the pervasiveness of corruption impacts on the regulator's threshold choices.

Proposition 6. *When $\upsilon = 1$, $\bar{h} < \Pi$ in both regimes. When $\upsilon < 1$ and $\lambda = 0$,*

(a) collusion occurs in equilibrium in a regime of modified lenient authorization;

(b) extortion is fully tolerated in a regime of modified strict authorization if Condition (1) is satisfied; otherwise, some extortion is prevented and second-best is achieved.

Suppose first that all public officials are honest, namely, $\upsilon = 1$. Under both regimes, the regulator optimally sets $\bar{h} < \Pi$ as he uses this threshold as a tool to simultaneously pursue two distinct objectives: disciplining investment decisions and safeguarding ex-post efficiency. The regulator solves this trade-off by committing not to authorize some ex-post beneficial activities to mitigate the over-investment problem.[32]

When $\upsilon < 1$, the regulator must also cope with the issue of corruption. In a regime of modified strict authorization, the presence of corruptible public officials may turn out to be a blessing. This is because the regulator can avail himself of two tools (h_S and $\bar{h}$) to pursue his

[32] It is worth noting that when the regulator pursues the sole objective of maximizing ex-post welfare, he need not distort allocative efficiency, that is, $\bar{h} = \Pi$ in both regimes. This result also holds in the presence of corruption. The proof can be provided upon request.

two objectives. As before, when $\lambda = 0$, the regulator will fully tolerate extortion if Condition (1) is satisfied. If Condition (1) does not hold, the regulator will tolerate some extortion to overcome the over-investment problem without having to distort allocative efficiency, thereby achieving second-best. By contrast, in a regime of modified lenient authorization, the issue of collusion is always socially harmful. Although the regulator has an additional instrument at his disposal to pursue his multiple objectives, using h_L to improve investment incentives necessarily distorts allocative efficiency. Ultimately, this is due to a fundamental difference between extortion and collusion: the former only affects investment decisions, whereas the latter also impacts on allocative efficiency. By contrast to what we have found in Section 4, the regulator would allow some collusion at the equilibrium even when $\lambda = 0$. However, welfare would always fall short of second-best in a regime of modified lenient authorization. In light of this, when λ increases, welfare under modified strict authorization may not change, whereas it always decreases under a regime of modified lenient authorization. The following remark highlights the implication of a change in λ for the adoption of either regime.

Remark 2. *An increase in λ makes the benevolent regulator more inclined to adopt a regime of strict authorization when Condition (1) is satisfied.*

We conclude by highlighting that the chief finding that an increase in the pervasiveness of corruption may lead to a higher level of social welfare holds up in the different framework analyzed in this section. The intuition behind this result is essentially the same as that spelled out in Section 4.3.

Corollary 3. *When the regulator can commit to a threshold $\bar{h}$ above which an activity is banned, an increase in the pervasiveness of corruption may lead to a higher level of social welfare.*

6.2 Incorrect signal

We have assumed that the public official either receives a perfectly informative signal about the externality the activity would generate or no conclusive evidence. More generally, one could imagine that the public official obtains some imprecise information about the state of the world, which can also turn out to be incorrect. To take this possibility into account, we now amend the baseline model in two ways. First, we assume that the signal is imprecise, in that the public official does not learn the exact value of the externality. Second, we let the information be incorrect with some positive probability. Specifically, with probability p the public official gathers a signal which only reveals whether the activity is safe or unsafe, that is, if $h < \Pi$ or $h \geq \Pi$. This information is correct with probability $q > 1/2$ and incorrect with complementary probability $1-q$. With probability $1-p$ the public official observes nothing. In this scenario, we mostly confirm the results of Section 3.3 on the impact of an increase in the fraction of honest public officials on welfare, as illustrated in the following remark.

Remark 3. *When the signal can be incorrect, the impact of an increase in v on welfare is* *(a) always positive in a regime of lenient authorization if*

$$q > \frac{\int_0^{\Pi}(\Pi - h)g(h)dh}{\int_0^{\Pi}(\Pi - h)g(h)dh - \int_{\Pi}^{H}(\Pi - h)g(h)dh};$$

(b) negative in a regime of strict authorization if

$$\frac{qG(\Pi)E_g(h|h < \Pi) + (1-q)[1-G(\Pi)]E_g(h|h \geq \Pi)}{\Big[qG(\Pi) + (1-q)(1-G(\Pi)\Big]\Pi} > (1-\upsilon)(1-\gamma)(1-\alpha).$$

In a regime of strict authorization, the results are qualitatively the same; only the value of $(1-\upsilon)(1-\gamma)(1-\alpha)$ above which the effect of υ on welfare is negative changes and actually decreases, making it easier for our key result to arise. In a regime of lenient authorization, the positive effect of honest public officials on welfare always holds if the signal is sufficiently precise. Intuitively, when the signal is inaccurate, the firm is often denied authorization even when the product is safe, which lowers ex-post welfare.[33] The possibility of colluding with the public official to conceal unfavorable evidence can right this wrong. In the literature on collusion in organizations, a result with a similar flavor can be found in Che et al. (2020).

6.3 Corruption opportunities and manipulation power

In our model, we have assumed that the public official's manipulation ability is limited to concealing evidence, namely, information is hard. Plausibly, a public official can report that the information she has gathered does not conclusively lead to evaluate the damages to third parties that the activity would entail. As we have seen, this gives rise to different corruption opportunities in the two regimes: collusion in lenient authorization, that can result in the approval of unsafe products, and extortion in strict authorization, that can result in the firm being stripped of part of the profits to produce safe products.

If the information were soft, the public official could also fabricate evidence and either claim that damages are different from what they actually are or that the evidence she has collected is indeed conclusive when it is not. This opens up the possibility for having collusion in a regime of strict authorization and extortion in a regime of lenient authorization. In the latter, the public official could request a bribe from the firm not to fabricate a report that the activity is unsafe. In the former, the public official and the firm could conspire to forge evidence that the activity entails minor negative externalities.

Soft information blurs the differences between the two authorization regimes, both in terms of corruption opportunities and societal outcomes. There is an important caveat, though. Even if the public official could fabricate evidence, it stands to reason that her report cannot be overly disconnected from the signal: for instance, it might be very challenging to report that an

[33] To provide an example, the signal must be correct with probability $q > 0.8888$ for an increase of υ to have a beneficial effect on welfare under lenient authorization when $\Pi = 5$ and h has a point mass of 0.25 at 0 and is distributed according to the Uniform Distribution on $(0, H]$, where $H = 7.5$. When there is more mass of probability on $h \in (\Pi, H]$, the threshold value of q decreases.

activity brings about only negligible negative externalities when, in fact, its consequences would be devastating. Similarly, a public official would have difficulty making an activity out to be very noxious when its actual side effects would be minor. Note that this is less problematic for concealment as the public official could plausibly deny that she had enough evidence to make an informative report.

We now discuss the robustness of our results in a setting where the public official has some room for fabricating information. Specifically, we assume that, when the public official learns that the externalities are h, she can report the externalities to be in the interval $[h - m, h + m]$, where the parameter m is the public official's manipulation power.[34,35] When the evidence is inconclusive, the public official could fabricate evidence with probability M, which is regime dependent and may be a function of Π. We focus on the general environment without salaries of Section 3.3 and relegate the technicalities to the appendix. We provide below the main insights of this extension.

When the public official's manipulation power is not overly high, the results of our previous analysis continue to hold. In particular, an increase in the proportion of honest public officials is beneficial to welfare in a regime of lenient authorization and may hurt welfare in a regime of strict authorization. However, additional and novel mechanisms are at play. In both regimes, the strength of institutions, γ, determines which form of corruption is more relevant for investment incentives. Collusion is independent of γ because the firm would not challenge the public official's report as it stands to gain additional profits. By contrast, the impact of extortion on investment does depend on γ: when the institutions are very strong, the prospect of extortion does not significantly affect the firm's investment decision. This is because a corrupt public official will not be able to extract a large fraction of profits from the firm. It turns out that, under lenient authorization, welfare positively depends on υ when γ is high enough so that the investment decision is mostly driven by the prospect of collusion rather than the fear of extortion. In that case, an increase in υ mitigates the over-investment problem and improves the pool of projects that are approved. In a regime of strict authorization, investment will be increasing in υ unless γ is too high, where the relevant threshold is decreasing in the public official's manipulation ability. However, in this regime, the pool of projects that are approved may improve when collusion is more likely to occur. This is because collusion leads to the authorization of products for which there is insufficient evidence of their safety. This may positively impact on the desirability of corruption in strict authorization.

[34] We borrow both this concept and the terminology from the literature on corruption in procurement auctions, where it is often assumed that the assessment of the quality component of a bid can be manipulated (see Burguet and Che, 2004, and more recently Huang and Xia, 2019).

[35] In fact, once the public official has observed h, she can under-report the externalities up to $\max\{0, h - m\}$ and over-report the externalities up to $\min\{H, h + m\}$.

6.4 Taxes and regulation

In this extension, we examine how the benevolent regulator can use taxes to discipline the firm's investment and production decisions and how this affects the choice of the authorization regime. To this end, we focus on the scenario developed in Section 3.3. Because of administrative and bureaucratic distortions, levying this tax brings about an inefficiency for every dollar which is raised. We denote this inefficiency by $\lambda_t \geq 0$.[36]

Let us first suppose that the benevolent regulator can initially commit to a tax $t \geq 0$ that a firm must pay in order to undertake production. In both regimes, the regulator will set the tax to govern the firm's investment decision, taking into account ex-post efficiency as well as the direct social cost of setting the tax, $\lambda_t t$. While the technicalities are reported in the appendix, in what follows we describe the main results of this extension. In a regime of lenient authorization, when the fraction of corrupt public officials is higher, the firm has a stronger incentive to invest as unsafe products are more likely to be authorized. To counterbalance this effect, the regulator sets a higher tax when υ is lower. In a regime of strict authorization, the firm must pay an indirect tax to a corrupt public official to have production authorized. Knowing this, the regulator will impose a lower tax burden on the firm whenever corruption is more pervasive - or when the institutions are weaker or the firm's bargaining power is lower. Put differently, there is a substitution between the indirect tax paid to the public official and the direct tax paid to the regulator. Some evidence on extortion acting as an indirect tax for innovative firms operating in poor institutional environments is provided by Ayyagari et al. (2010). In the next proposition, we compare welfare under both lenient and strict authorization when the regulator can levy a tax on production.

Proposition 7. *When the regulator can set a tax on production,*

(i) when $\lambda_t = 0$, a regime of lenient authorization is (weakly) preferred to one of strict authorization if and only if:

$$(1-p)\int_0^{\Pi}(\Pi-h)g(h)dh \geq (1-p\upsilon)\int_{\Pi}^{H}(h-\Pi)g(h)dh, \tag{2}$$

where this condition is more difficult to satisfy when the activity is more harmful;

(ii) the impact of an increase in λ_t on welfare is

(a) always negative in a regime of lenient authorization where $W_G^{LA}(t^{LA}) > 0$, whenever $\lambda_t \in \left(0, \frac{1-p(1-G(\Pi))[1-(1-\upsilon)\alpha]}{2\left[1-p\upsilon(1-G(\Pi))\right]}\right)$;

(b) negative in a regime of strict authorization only if condition (1) is not satisfied;

[36] As this tax is levied on the externality-generating activity, we have added the subscript t to distinguish this shadow cost from λ used in the previous sections. That parameter was also meant to capture the inefficiencies generated by imposing a distortive tax on other sectors of the economy to finance the regulation of innovative activities.

(iii) an increase in υ may reduce welfare.

The left-hand side of Condition (2) 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 (2) 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 Condition (2). When $\lambda_t = 0$, the tax on production can be set in such a way that second-best welfare is achieved under both regimes (as we formally show in the appendix). When $\lambda_t > 0$, the regulator bears a cost to govern investment incentives. Welfare in a regime of lenient authorization always decreases in the shadow cost of raising taxes - up to the point at which it would no longer be efficient to levy a tax on production. By contrast, welfare in a regime of strict authorization may not be affected by this inefficiency as the regulator may not want to impose a tax even when it would be costless to do so. In fact, in this regime, the regulator may be willing to subsidize production. Once again, we retrieve the finding that an increase in the pervasiveness of corruption may be associated with a higher level of welfare.

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 $r \in [0, H] \bigcup \{\emptyset\}$. This more complex tax scheme does not affect welfare in the strict authorization regime. Intuitively, in this regime, the regulator prohibits production when the activity is known to be unsafe or there is no evidence, 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 different expected levels 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 $t_{\emptyset}^{LA}$ (respectively, t_h^{LA}) is the tax that the innovative firm must pay to produce the good if there is no conclusive evidence about product safety (if there is evidence that the good would generate an externality equal to some $h \in [0, H]$). The following remark shows that with such a tax schedule, there is no loss of generality in restricting attention to a lenient-authorization regime.

Remark 4. *When the tax can be made contingent on both the production decision and the signal, lenient authorization weakly dominates strict authorization, i.e., $W_G^{LA} \geq W_G^{SA}$.*

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 that state, leading to a strict social preference for a regime of lenient authorization. This subsection has provided some insights on the relation between the optimal authorization regime and the ability to tailor the tax to the outcome of the regulatory process. In particular, strict authorization may dominate only when the tax can solely depend on whether the firm undertakes production or not.

7 Conclusions

In this paper, we have developed a stylized model to analyze the different effects of corruption on the regulation of innovative activities that may exhibit negative externalities. We find that corruption leads to the adoption of stricter regulation and may turn out to be welfare improving, by alleviating the under-investment problem caused by the firms' tendency to disregard the external effects that their activities generate. It may appear unsavory that more pervasive corruption can lead to a higher level of welfare. However, one of the implications of this result is that the anticipation of corruption may steer the firm's investment decisions towards less harmful activities, that do not require a close regulatory scrutiny and the associated bribes. For example, think of a firm that may devote resources to develop a new drilling technique, which could pollute the environment. If the firm anticipates that it will likely be subject to extortion from the public official tasked with authorizing the potentially harmful activity, it may steer its investment towards less controversial technologies, like clean energy, that do not harm the environment.

It is important to stress that our conclusion on the beneficial welfare effect of corruption has been found in a model where the innovation might bring about negative externalities. If the innovative activity might generate benefits that are not reaped by the firm, it could be socially desirable to stimulate investment. In that case, extortion would not increase welfare, but collusion might. In some other cases, there is uncertainty about the sign of the externalities. For instance, there are heated debates over the pros and cons of cryptocurrencies and genetically-modified crops.[37] In these scenarios, the over-investment problem may or may not arise under strict authorization. When it does, extortion helps to mitigate it. Of course, this requires that the positive externalities, or the probability that they are generated, cannot be too large.

It is also worth remarking that throughout the paper we have maintained the assumption that the regulator is benevolent. According to the *tollbooth view* of regulation (see Djankov et al., 2002), regulators are self-interested. Then, akin to Immordino and Pagano (2010), one could assume that the regulator maximizes the expected bribes collected by the public official.

[37] Cryptocurrency enthusiasts emphasize their role in fostering trade, but there are obvious alarms over the type of transactions that are facilitated, letting alone the hefty harm to the environment that the mining of such currencies entails (e.g., see "Bitcoin's Climate Problem", on The New York Times, March 9, 2021). Genetically-modified crops require fewer pesticides and provide more nutrients (like vitamins or minerals), but there is some concern over the possibility of allergic reactions (e.g., see "Food: How Altered?" on the National Geographic Magazine, May 2002).

We leave the analysis of the self-interested regulator's choice of the authorization regime for future research.

Empirically determining the relationship between corruption, regulation, and welfare is a fascinating research question that warrants an in-depth analysis which goes beyond the scope of the present paper. However, we find some suggestive evidence of the positive association between corruption and regulation by correlating 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,[38] 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).[39] 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. They are also consistent with the strong positive correlation between measures of distrust and indicators of regulation documented by Aghion et al. (2010).

In our analysis, we have not followed a specific real-world regulatory procedure. Thus, the insights of our model might be valid for the regulation of all those activities where there might be uncertainty about the social repercussions ensuing their adoption: from the approval process of drugs, vaccines, and dietary supplements to the authorization of new production technologies that are suspected of adversely affecting the environment, like drilling techniques, and even financial regulation, since most customers may have difficulty understanding features of more sophisticated financial products.

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

[39] 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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A Appendix A

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 has a positive impact on welfare. 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:

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

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,

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

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

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

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 has a positive impact on welfare 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:

$$\Pi \geq \frac{2}{G(\Pi)}\int_0^{\Pi} hg(h)dh = 2E_g(h|h \leq \Pi). \tag{A2}$$

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 $G(\cdot) \geq F(\cdot)$. 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

First, note that $W^{LA} \geq W^{SA}$ if and only if:

$$\Pi - 2\left(\frac{(1 - p + pG(\Pi))E_g(h) + p\int_0^{\Pi} hg(h)dh}{1 - p + 2pG(\Pi)}\right) \geq 0, \tag{A3}$$

which may or may not hold.

Point (a). Taking the derivative of the lhs of (A3) with respect to Π, we obtain: $1 - p + 2p\Big[G(\Pi) - g(\Pi)E_g(h)\Big]$, which is positive only if $E_g(h) < \frac{1-p+2pG(\Pi)}{g(\Pi)}$.

Point (b). As for the effect of p on inequality (A3), note that the derivative of the lhs with respect to p yields:

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

which is positive if and only if $G(\Pi)\int_{\Pi}^{H} hg(h)dh \geq [1-G(\Pi)]\int_{0}^{\Pi} hg(h)dh$. This is always satisfied as $E_g(h|h \geq \Pi) > \Pi > E_g(h|h < \Pi)$.

Point (c). Consider two distributions of harm on $[0, H]$: $F(\cdot)$ and $G(\cdot)$ where $F(h) \leq G(h)$ for all h. Let us determine whether the condition (A3), under which lenient authorization is preferred to strict authorization, is more likely to be satisfied under distribution $G(\cdot)$ than $F(\cdot)$. 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:

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

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 inequality (A3) to be less likely to be satisfied when activities are more harmful is $\int_0^{\Pi} hf(h)dh \geq \int_0^{\Pi} hg(h)dh$. $\square$

Proof of Proposition 2

Welfare under strict authorization can be written as:

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

We first prove that 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:

$$\Pi \geq \frac{2}{2 - [\gamma + \alpha(1-\gamma)]} E_g(h|h \leq \Pi). \tag{A4}$$

Note that $\frac{2}{2-[\gamma+\alpha(1-\gamma)]} < 2$ and, as a result, the condition under which p positively affects welfare in a regime of strict authorization is easier to satisfy when public officials are corrupt than when they are honest - to see this, compare (A4) with (A2).

By comparing W_C^{LA} and W_C^{SA}, we can determine that the regulator prefers a regime of lenient authorization to one of strict authorization if and only if the following inequality holds:

$$\Pi - 2\frac{[1 - p(1-G(\Pi))(1-\alpha)]E_g(h) + p^2[\gamma + \alpha(1-\gamma)]G(\Pi)\int_0^{\Pi} G(h)dh}{1 - p^2\Big[(G(\Pi))^2 + (1-\alpha)^2[1 - (2-\gamma)G(\Pi)][1 - \gamma G(\Pi)]\Big]} \geq 0.$$

Taking the derivative of its lhs with respect to p, we find that an increase in the precision of the signal makes the inequality more likely to be satisfied only if

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

It is immediate to see that $W^{LA} \geq W_C^{LA}$, whereas it holds that $W_C^{SA} \geq W^{SA}$ iff:

$$\begin{aligned} \frac{c}{2}\left[(I^{SA})^2-(I_C^{SA})^2\right] \geq & \quad \left(I^{SA}-I_C^{SA}\right)w^{SA} \\ \Leftrightarrow \frac{c}{2}\left(I^{SA}+I_C^{SA}\right) \geq & \quad w^{SA}, \end{aligned}$$

which is verified whenever $\frac{E_g(h|h<\Pi)}{\Pi} \geq \frac{(1-\gamma)(1-\alpha)}{2}$.

□

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:

$$\frac{\partial W_G^{LA}}{\partial \upsilon} = \frac{\partial I_G^{LA}}{\partial \upsilon}\left[w_G^{LA}-cI_G^{LA}\right]+I_G^{LA}\frac{\partial w_G^{LA}}{\partial \upsilon}.$$

Notice that

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

since $h \geq \Pi$ for any $h \in [\Pi, H]$. Moreover,

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

and

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

Hence, $\frac{\partial W_G^{LA}}{\partial \upsilon} > 0$.

Consider 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:

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

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 distributions 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 $G(\cdot)$. □

Proof of Lemma 3

We denote the solutions by the subscript G as we continue to focus on the general scenario. First, we show that the regulator prefers to prevent collusion for levels of h closer to H. 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

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

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.

We now determine 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

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

Henceforth, we do not report the argument of the functions to save on notation. 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.[40] First-order necessary condition for a maximum requires that:

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

This can be rearranged as:

$$\begin{aligned} h_L = & \Pi + \frac{\lambda}{1-\upsilon}\Pi + \frac{\alpha}{c}\Pi \frac{\left(w_G^{LA} - c I_G^{LA}\right)}{I_G^{LA}} \\ = & \Pi \left[1 + \frac{\lambda}{1-\upsilon} + \frac{\alpha}{c} \frac{\left(w_G^{LA} - c I_G^{LA}\right)}{I_G^{LA}} \right], \end{aligned} \tag{A5}$$

where:

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

[40] Because of that, there is no distinction between h_L and $\hat{h}_L$. In general, there can be a corner solution which is why we distinguish between these two thresholds in the statement of the proposition.

For the threshold h_L determined in (A5) to be a maximum, it must be that the second-order condition is also satisfied. This condition is:

$$\frac{\partial I_G^{LA}}{\partial h_L}\frac{\partial w_G^{LA}}{\partial h_L} + \frac{\partial^2 w_G^{LA}}{\partial h_L^2} I_G^{LA} + \frac{\partial^2 I_G^{LA}}{\partial h_L^2}(w_G^{LA} - cI_G^{LA}) + \frac{\partial I_G^{LA}}{\partial h_L}\frac{\partial (w_G^{LA} - cI_G^{LA})}{\partial h_L} < 0.$$

As $\frac{\partial w_G^{LA}}{\partial h_L} = -\frac{\partial I_G^{LA}}{\partial h_L}\frac{(w_G^{LA} - cI_G^{LA})}{I_G^{LA}}$, the second-order condition holds if:

$$\left(\frac{\partial I_G^{LA}}{\partial h_L}\right)^2 \left(\frac{(2w_G^{LA} - cI_G^{LA})}{I_G^{LA}}\right) - I_G^{LA}\frac{\partial^2 w_G^{LA}}{\partial h_L^2} - \frac{\partial^2 I_G^{LA}}{\partial h_L^2}(w_G^{LA} - cI_G^{LA}) > 0.$$

Note that the last two terms reduce to $p(1-\upsilon)g(h_L)I_G^{LA}$. Thus, the second-order condition holds if:

$$I_G^{LA} + \frac{\partial I_G^{LA}}{\partial h_L}\alpha\Pi\left(\frac{(2w_G^{LA} - cI_G^{LA})}{cI_G^{LA}}\right) > 0,$$

and it is always satisfied when α is small enough or when $2w_G^{LA} - cI_G^{LA} > 0$.

To study the impact of the parameters on the optimal value of h_L, consider the following implicit function obtained from the first order condition:

$$\begin{aligned} Z_L(h_L) :=\ & \frac{\partial I_G^{LA}}{\partial h_L}(w_G^{LA} - cI_G^{LA}) + \frac{\partial w_G^{LA}}{\partial h_L} I_G^{LA} \\ =\ & \frac{p(1-\upsilon)\alpha}{c}\Pi g(h_L)(w_G^{LA} - cI_G^{LA}) + \Big[p(1-\upsilon)(\Pi - h_L)g(h_L) + \lambda p g(h_L)\Pi\Big] I_G^{LA} = 0. \end{aligned}$$

As the second-order condition is satisfied, the sign of $\frac{\partial h_L}{\partial \lambda}$ coincides with the sign of $\frac{\partial Z_L(h_L)}{\partial \lambda}$:

$$\frac{\partial I_G^{LA}}{\partial h_L}\frac{\partial w_G^{LA}}{\partial \lambda} + \frac{\partial^2 w_G^{LA}}{\partial h_L \partial \lambda} I_G^{LA}.$$

The above derivative is always positive if:

$$p\Big[1 - G(\Pi)\Big]\Big[1 + (1-\upsilon)\alpha\Big] < 1,$$

which is more likely to be the case when p, α are small and υ and Π are higher.

As for the effect of an increase in υ on h_L, this is positive as:

$$\frac{\partial Z_L(h_L)}{\partial \upsilon} = \frac{\partial^2 I_G^{LA}}{\partial h_L \partial \upsilon}(w_G^{LA} - cI_G^{LA}) + \frac{\partial I_G^{LA}}{\partial h_L}\frac{\partial w_G^{LA}}{\partial \upsilon} - c\frac{\partial I_G^{LA}}{\partial h_L}\frac{\partial I_G^{LA}}{\partial \upsilon} + \frac{\partial^2 w_G^{LA}}{\partial h_L \partial \upsilon} I_G^{LA} + \frac{\partial w_G^{LA}}{\partial h_L}\frac{\partial I_G^{LA}}{\partial \upsilon} > 0,$$

since $\frac{\partial^2 I_G^{LA}}{\partial h_L \partial \upsilon} < 0$, $\frac{\partial w_G^{LA}}{\partial \upsilon} > 0$, $\frac{\partial I_G^{LA}}{\partial \upsilon} < 0$, $\frac{\partial^2 w_G^{LA}}{\partial h_L \partial \upsilon} > 0$.

Considering the marginal impact of α on the threshold h_L, we obtain

$$\frac{\partial Z_L(h_L)}{\partial \alpha} = \frac{\partial^2 I_G^{LA}}{\partial h_L \partial \alpha}(w_G^{LA} - cI_G^{LA}) + \frac{\partial I_G^{LA}}{\partial \alpha}\left(\frac{\partial w_G^{LA}}{\partial h_L} - c\frac{\partial I_G^{LA}}{\partial h_L}\right).$$

Note that $\frac{\partial^2 I_G^{LA}}{\partial h_L \partial \alpha} > 0$ and $\frac{\partial I_G^{LA}}{\partial \alpha} > 0$. The impact is positive if and only if:

$$\begin{aligned} \lambda p[2G(h_L) - 1 - G(\Pi)]\Pi >\ & 2(1-\alpha)p(1-\upsilon)[G(h_L) - G(\Pi)]\Pi + p(1-\upsilon)\int_\Pi^{h_L} hg(h)dh \\ & + \int_0^\Pi hg(h)dh + (1-p)\int_\Pi^H hg(h)dh. \end{aligned}$$

Thus the impact may be positive only for λ very high and α close to 1. □

Proof of Lemma 4

Suppose that $s_h - R \geq s_\emptyset$ for $h \in [0,\Pi)$. Then if, in the extortion subgame, the parties do not reach an agreement, the public official would report $r = h$ and the firm would be allowed to produce. The threat points for the public official and the firm are $s_h - R$ and Π, respectively. The bribe would be determined by the following:

$$b^{Noeq} \in \arg\max_{b\in\mathbb{R}} \quad (b+R)^{1-\alpha}(-b)^{\alpha}.$$

This yields $b^{Noeq} = -\alpha R$, and the utility of the public official in the extortion subgame would be $s_h - \alpha R$ which is always smaller or equal than the $\max\{s_h, s_\emptyset\}$, that the public official could secure by not engaging in extortion. $\square$

Proof of Lemma 5

We denote the solutions by the subscript G as we continue to focus on the general scenario. The regulator would always set $s_h^{SA} = 0$ for $h \geq \Pi$, since $\lambda \geq 0$ and there are no corruption opportunities when the activity is unsafe under strict authorization. Similarly, setting $s_\emptyset > 0$ would not be beneficial: if extortion is to be prevented, a positive payment for $r = \emptyset$ would only increase the cost of doing so; if extortion is not prevented, there is no need to pay the public official a positive salary. For $h < \Pi$, $s_h^{SA} = 0$ if the regulator does not want to prevent extortion at that h. By contrast, if the regulator wants to prevent extortion at that $h < \Pi$, $s_h^{SA} = \min\{R, \frac{(1-\alpha)}{\alpha}(1-\gamma)\Pi\}$ to minimize the wage bill. That is, the regulator chooses to either make blackmail non credible or extortion non profitable, depending on which one is the cheapest.

The regulator chooses the threshold $h_S \in [0,\Pi)$ above which extortion is prevented in order to maximize 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:

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

Ex-post surplus if a breakthrough is achieved is:

$$w_G^{SA} = p\int_0^\Pi (\Pi - h)g(h)dh - p\left(\int_{h_S}^\Pi g(h)dh\right)\lambda s_h.$$

First-order condition yields:

$$Z_S(h_S) := -\frac{p}{c}(1-\upsilon)(1-\gamma)(1-\alpha)\Pi g(h_S)[w_G^{SA} - cI_G^{SA}] + pg(h_S)I_G^{SA}\lambda s_h. \tag{A6}$$

When $w_G^{SA} - cI_G^{SA} \leq 0$, the regulator wants to increase h_S and $h_S^{SA} \to \Pi$. When $w_G^{SA} - cI_G^{SA} > 0$ the regulator may want to decrease h_S and an interior solution may occur.

Let us call $\hat{h}_S^{SA}$ the value of h_S for which $Z_S(h_S) = 0$. With some abuse of notation, the optimal threshold is $h_S^{SA} = \min\{\hat{h}_S^{SA}, \Pi\}$. $\hat{h}_S^{SA}$ depends on the parameter values. By using the

Implicit Function Theorem, we can perform some comparative statics. First, see the effect of an increase in λ on $\hat{h}_S^{SA}$: $\frac{\partial \hat{h}_S^{SA}}{\partial \lambda} = -\frac{\frac{\partial Z_S}{\partial \lambda}}{\frac{\partial Z_S}{\partial h_S}}$. Since $\frac{\partial Z_S}{\partial h_S} < 0$ for the second-order condition to be satisfied, the sign coincides with that of the numerator:

$$\frac{\partial Z_S}{\partial \lambda} = \frac{p^2}{c}(1-\upsilon)(1-\gamma)(1-\alpha)\Pi g(\hat{h}_S^{SA})\left(\int_{\hat{h}_S^{SA}}^{\Pi} g(h)dh\right) s_h + pg(\hat{h}_S^{SA})I_G^{SA}s_h > 0.$$

An increase in R weakly increases s_h and, as a result, weakly rises $\hat{h}_S^{SA}$:

$$\frac{\partial Z_S}{\partial R} = \frac{p^2}{c}(1-\upsilon)(1-\alpha)(1-\gamma)g(\hat{h}_S^{SA})\Pi[G(\Pi)-G(\hat{h}_S^{SA})]\lambda\frac{\partial s_h}{\partial R} + pg(\hat{h}_S^{SA})I_G^{SA}\lambda\frac{\partial s_h}{\partial R} \geq 0.$$

An increase in υ has a positive effect on the threshold $\hat{h}_S^{SA}$, as:

$$\begin{aligned}\frac{\partial Z_S}{\partial \upsilon} =& \frac{p}{c}(1-\gamma)(1-\alpha)g(\hat{h}_S^{SA})\Pi[w_G^{SA} - cI_G^{SA}]\\ &+ \frac{p^2}{c}(1-\gamma)^2(1-\alpha)^2(1-\upsilon)g(\hat{h}_S^{SA})G(\hat{h}_S^{SA})\Pi^2\\ &+ p(1-\gamma)(1-\alpha)s_h g(\hat{h}_S^{SA})G(\hat{h}_S^{SA})\Pi > 0.\end{aligned}$$

The sign of the impact of an increase in α corresponds with that of $\frac{\partial Z_S}{\partial \alpha}$, which is positive when

$$\lambda < \frac{\alpha^2(1-\upsilon)[(w_G^{SA}-cI_G^{SA}) + (1-\alpha)(1-\upsilon)(1-\gamma)pG(\hat{h}_S^{SA})\Pi]}{p[(1-\alpha)(1-\upsilon)(1-\gamma)(G(\Pi)-G(\hat{h}_S^{SA})) + G(\Pi) - (1-\alpha^2)(1-\upsilon)(1-\gamma)G(\hat{h}_S^{SA})]}.$$

Note that both the numerator (for the relevant values of the parameters for an interior solution, i.e., when $w_G^{SA} - cI_G^{SA} > 0$) and the denominator are positive.

As for the effect of an increase in γ on the threshold $\hat{h}_S^{SA}$, note that $\frac{\partial Z_S}{\partial \gamma}$ is positive when

$$\lambda < \frac{(1-\alpha)(1-\upsilon)[(w_G^{SA}-cI_G^{SA}) + (1-\alpha)(1-\upsilon)(1-\gamma)pG(\hat{h}_S^{SA})\Pi]}{p[(1-\alpha)(1-\upsilon)(1-\gamma)(G(\Pi)-G(\hat{h}_S^{SA})) + G(\Pi) - 2(1-\alpha)(1-\upsilon)(1-\gamma)G(\hat{h}_S^{SA})]}.$$

Note that the denominator may be negative. Hence, the effect is inconclusive.

Consider now the second order condition. For a maximum, this requires that:

$$\begin{aligned}&-\frac{p^2\Pi}{c}(1-\upsilon)(1-\gamma)(1-\alpha)[2\lambda s_h + (1-\upsilon)(1-\gamma)(1-\alpha)\Pi][g(h_S)]^2\\ &+\frac{p^2\Pi}{c}g'(h_S)\left[(1-\upsilon)(1-\gamma)(1-\alpha)\int_0^{\Pi} hg(h)dh + [1+(1-\upsilon)(1-\gamma)(1-\alpha)]G(\Pi)\lambda s_h\right]\\ &-\frac{p^2\Pi}{c}g'(h_S)G(h_S)(1-\upsilon)(1-\gamma)(1-\alpha)[2\lambda s_h + (1-\upsilon)(1-\gamma)(1-\alpha)\Pi] < 0.\end{aligned} \tag{A7}$$

Note that, at the candidate interior optimum, the threshold would be obtained from:

$$G(h_S^{SA}) = \frac{G(\Pi)\lambda s_h + (1-\upsilon)(1-\gamma)(1-\alpha)\left[G(\Pi)\lambda s_h + \int_0^{\Pi} hg(h)dh\right]}{(1-\upsilon)(1-\gamma)(1-\alpha)[2\lambda s_h + (1-\upsilon)(1-\gamma)(1-\alpha)\Pi]}.$$

Substituting the interior optimum into condition (A7), the terms in the second and third lines exactly cancel out and the second order condition amounts to:

$$-\frac{p^2\Pi}{c}(1-\upsilon)(1-\gamma)(1-\alpha)[2\lambda s_h + (1-\upsilon)(1-\gamma)(1-\alpha)\Pi][g(h_S^{SA})]^2 < 0,$$

which always holds. □

Proof of Proposition 4

As for the negative impact of an increase in λ on welfare under lenient authorization, see that:

$$\frac{\partial W_G^{LA}(h_L^{LA})}{\partial \lambda} = -I_G^{LA}(h_L^{LA})p[1-G(h_L^{LA})]\Pi < 0,$$

whenever $h_L^{LA} < H$. Consider now a regime of strict authorization. Suppose that $\lambda = 0$. The first-order condition of the welfare maximization problem with respect to h_S under strict authorization yields:

$$-\frac{p}{c}(1-\upsilon)(1-\gamma)(1-\alpha)\Pi g(h_S)[w_G^{SA} - cI_G^{SA}].$$

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:

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

The optimal threshold is then given by:

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

That is, the regulator will increase h_S up to the point at which $w_G^{SA} = cI_G^{SA}$, if such $h_S < \Pi$, and second-best welfare is obtained. Otherwise, the regulator will increase h_S up to Π. The latter is the case if Condition 1 holds. If this inequality holds and λ takes any positive value, the regulator will continue to tolerate extortion. That is, the value of λ will not affect welfare. If condition (1) does not hold, $h_S^{SA} < \Pi$ and an increase in λ will have a negative impact on welfare:

$$\frac{\partial W_G^{SA}(h_S^{SA})}{\partial \lambda} = -I_G^{SA}(h_S^{SA})p\left(\int_{h_S^{SA}}^{\Pi} g(h)dh\right)s_h < 0.$$

□

Proof of Proposition 5

It is immediate to see the effect of an increase in υ on welfare under lenient authorization:

$$\frac{\partial W_G^{LA}(h_L^{LA})}{\partial \upsilon} = \underbrace{\frac{\partial I_G^{LA}(h_L^{LA})}{\partial \upsilon}}_{<0}\underbrace{[w_G^{LA}(h_L^{LA}) - cI_G^{LA}(h_L^{LA})]}_{<0} + \underbrace{\frac{\partial w_G^{LA}(h_L^{LA})}{\partial \upsilon}}_{>0} I_G^{LA}(h_L^{LA}) > 0.$$

As for $W_G^{SA}(h_S^{SA})$, note that if υ increases, Condition (1) is more likely to hold, so that second-best will not be achieved when $\lambda = 0$. When Condition (1) holds, $W_G^{SA}(h_S^{SA}) = W_G^{SA}$ and, as shown in the Proof of Proposition 3, an increase in υ has a negative impact on welfare exactly when Condition (1) holds. When Condition (1) does not hold and $\lambda > 0$, an increase in υ reduces welfare because $\frac{\partial I_G^{SA}(h_S^{SA})}{\partial \upsilon} > 0$ and $[w_G^{SA}(h_S^{SA}) - cI_G^{SA}(h_S^{SA})] < 0$, where the latter inequality owes to welfare falling short of second-best when $\lambda > 0$. □

B Appendix B

Proof of Remark 1

Recall that preventing collusion in a regime of lenient authorization entails paying the public official $s_r = \Pi$ for $r \in [h_L, H]$. Ex-post welfare is:

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

The regulator maximizes ex-post welfare with respect to h_L. The first-order condition is:

$$p(1-\upsilon)(\Pi - h_L^{LAexpost})g(h_L^{LAexpost}) + \lambda p \Pi g(h_L^{LAexpost}) = 0.$$

From this, we can recover:

$$h_L^{LAexpost} = \Pi + \frac{\lambda}{1-\upsilon}\Pi.$$

Note that the second order condition with respect to h_L gives $-p(1-\upsilon g(h_L) < 0$.

In a regime of strict authorization, the regulator chooses the threshold h_S below which extortion occurs, with $0 \leq h_S \leq \Pi$:

$$w_{SA} = p\int_0^{\Pi}(\Pi - h)g(h)dh - p\lambda s_h \int_{h_S}^{\Pi} g(h)dh.$$

The derivative with respect to h_S gives $\lambda p \Pi g(h_S) > 0$. The regulator would like to set h_S as large as possible, i.e. $h_S^{SAexpost} = \Pi$. The second order condition requires $g'(h_S) \leq 0$.

Comparing the two ex-post welfare expressions, we find that $w_{LA} > w_{SA}$ if and only if:

$$\Pi - E_g(h) > \frac{p}{1-p}\left[\lambda\Pi\left[1 - G\left(\Pi + \frac{\lambda}{1-\upsilon}\Pi\right)\right] - (1-\upsilon)\int_{\Pi}^{\Pi\left(1+\frac{\lambda}{1-\upsilon}\right)}(\Pi - h)g(h)dh\right].$$

□

Proofs of Proposition 6 and Remark 2

We start by showing that under modified lenient authorization the regulator prefers to authorize production if $h \in [0, \bar{h}]$ and prohibit production if $h > \bar{h}$, where $\bar{h} \in (0, H]$. This implies that our problem reduces to determining two thresholds $\bar{h}$ and h_L.

In a regime of modified lenient authorization, compare the following two intervals of allowable projects: $[0, \bar{h}]$ and $[l_1, l_2]$ with $0 < l_1 < \bar{h} < l_2 < h_L$ and such that $G(\bar{h}) = G(l_2) - G(l_1)$, so that the ex-ante probability that the firm will be allowed to produce is the same and does not affect investment incentives. Comparing ex-post welfare under the two intervals, we obtain that: $w^{MLA}([0, \bar{h}]) > w^{MLA}([l_1, l_2])$ if and only if $\int_{\bar{h}}^{l_2} hg(h)dh > \int_0^{l_1} hg(h)dh$ which is always the case as $\int_{\bar{h}}^{l_2} hg(h)dh \geq \bar{h}[G(l_2) - G(\bar{h})] > l_1 G(l_1) \geq \int_0^{l_1} hg(h)dh$ because $\bar{h} > l_1$ and $G(l_1) = G(l_2) - G(\bar{h})$. If ex-post welfare is different, the regulator would like to set different investment levels. However, as $w^{MLA}([0,\bar{h}]) > w^{MLA}([l_1,l_2])$, it cannot be that $\max_I Iw^{MLA}([l_1,l_2]) - \frac{cI^2}{2} > \max_I Iw^{MLA}([0,\bar{h}]) - \frac{cI^2}{2}$. In a similar fashion, it can be shown that the regulator does not want to prohibit any project within the interval $[0,\bar{h}]$. With a similar approach, one could show that the interval $[0,\bar{h}]$ dominates other intervals $[l_1,l_2]$ with $l_2 > h_L$ and/or $l_1 > \bar{h}$.

We now go on to set up and solve the regulator's optimization problem under modified lenient authorization. We have already shown that preventing collusion for $h \geq h_L$ requires a bonus equal to Π and that there is no need to pay a positive bonus, otherwise. Therefore, the wage scheme will be:

$$s_h^{MLA} = \begin{cases} \Pi, & \text{for any } h \in [h_L, H] \\ 0, & \text{for any } h \in [0, h_L), \end{cases}$$

and $s_\emptyset^{MLA} = 0$. The regulator chooses $\bar{h}$, h_L, and I to maximize welfare subject to the firm's incentive compatibility constraint. As the firm's payoff function is strictly concave in I, we can use the first-order condition of the firm's maximization problem:

$$I^{MLA} = \frac{p\int_0^{\bar{h}} \Pi g(h)dh + p(1-\upsilon)\alpha\int_{\bar{h}}^{h_L} \Pi g(h)dh + (1-p)\int_0^H \Pi g(h)dh}{c}.$$

If there is a breakthrough, ex-post welfare is:

$$w^{MLA} = p\int_0^{\bar{h}} (\Pi - h)g(h)dh + p(1-\upsilon)\int_{\bar{h}}^{h_L} (\Pi - h)g(h)dh + (1-p)\int_0^H (\Pi - h)g(h)dh - \lambda p\int_{h_L}^H \Pi g(h)dh.$$

Note that the difference $w^{MLA} - cI^{MLA}$ is:

$$-p\int_0^{\bar{h}} hg(h)dh + p(1-\upsilon)(1-\alpha)\int_{\bar{h}}^{h_L} \Pi g(h)dh - p(1-\upsilon)\int_{\bar{h}}^{h_L} hg(h)dh - (1-p)\int_0^H hg(h)dh - \lambda p\int_{h_L}^H \Pi g(h)dh,$$

that is negative for any $\bar{h}$ and h_L.

We now look for the interior solution. In what follows, we assume that the second order conditions hold. The first-order conditions with respect to h_L and $\bar{h}$ are, respectively:

$$\frac{\partial I}{\partial h_L}(w - cI) + \frac{\partial w}{\partial h_L}I = 0; \quad \frac{\partial I}{\partial \bar{h}}(w - cI) + \frac{\partial w}{\partial \bar{h}}I = 0.$$

We obtain the following implicit functions:

$$h_L^{MLA} = \Pi\left[1 + \frac{\lambda}{1-\upsilon} + \frac{\alpha}{c}\frac{(w^{MLA} - cI^{MLA})}{I^{MLA}}\right]; \tag{B1}$$

$$\bar{h}^{MLA} = \Pi\left[1 + \frac{1-\alpha(1-\upsilon)}{\upsilon}\frac{(w^{MLA} - cI^{MLA})}{cI^{MLA}}\right]. \tag{B2}$$

It is easy to see that $\bar{h}^{MLA} < \Pi$ and that $h_L^{MLA} > \bar{h}^{MLA}$ for any λ, implying that some collusion always occurs in equilibrium. As for the impact of λ on welfare, for the Envelope Theorem, this is simply given by:

$$\frac{\partial W^{MLA}}{\partial \lambda} = -I^{MLA}p\int_{h_L^{MLA}}^H \Pi g(h)dh \leq 0,$$

and the inequality is strict whenever $h_L^{MLA} < H$.

If $\upsilon = 1$, it is easy to show that $\bar{h}$ can be implicitly determined from the next equation and is lower than Π:

$$\bar{h}^{MLA} = \Pi - \frac{p\int_0^{\bar{h}^{MLA}} hg(h)dh + (1-p)E_g(h)}{pG(\bar{h}^{MLA}) + (1-p)}.$$

Consider now modified strict authorization. Again, the regulator prefers to authorize production if $h \in [0, \bar{h}]$, and prohibit production if $h > \bar{h}$, where $\bar{h} \in (0, H]$. This implies that our problem reduces to determining two thresholds $\bar{h}$ and h_S. Compare the two intervals $[0, \bar{h}]$ and $[l_1, l_2]$ with $0 < l_1 < \bar{h} < l_2$. The thresholds above which extortion is prevented are h_S^1 and h_S^2 respectively and suppose that are set in such a way as to guarantee the same investment. That is, $G(h_S^1) = G(h_S^2) - G(l_1)$ and $G(\bar{h}) = G(l_2) - G(l_1)$. Comparing ex-post welfare under the two intervals, under the assumption that $\bar{h} > h_S^2$, we obtain that $w^{MSA}([0, \bar{h}]) > w^{MSA}([l_1, l_2])$ if $\int_{\bar{h}}^{l_2} hg(h)dh > \int_0^{l_1} hg(h)dh$. This is always the case because $\int_{\bar{h}}^{l_2} hg(h)dh \geq \bar{h}[G(l_2) - G(\bar{h})] > l_1 G(l_1) \geq \int_0^{l_1} hg(h)dh$, as $\bar{h} = l_1$ and $G(l_2) - G(\bar{h}) = G(l_1)$. If ex-post welfare is different, the regulator would like to set different investment levels. However, as $w^{MSA}([0, \bar{h}]) > w^{MSA}([l_1, l_2])$, it cannot be that $\max_I Iw^{MSA}([l_1, l_2]) - \frac{cI^2}{2} > \max_I Iw^{MSA}([0, \bar{h}]) - \frac{cI^2}{2}$. In a similar fashion, it can be shown that the regulator does not want to prohibit any project within the interval $[0, \bar{h}]$. With a similar approach, one could show that the interval $[0, \bar{h}]$ dominates other intervals $[l_1, l_2]$ with h_S^1 and/or h_S^2 are greater than $\bar{h}$.

We now go on to set up and solve the regulator's optimization problem under modified strict authorization. Preventing extortion for $h \in [h_S, \bar{h}]$ requires a positive bonus, whereas there is no need to pay a positive bonus, otherwise. Therefore, the wage scheme will be:

$$s_h^{MSA} = \begin{cases} \min\left\{R, \frac{(1-\alpha)(1-\gamma)\Pi}{\alpha}\right\}, & \text{for any } h \in [h_S, \bar{h}] \\ 0, & \text{for any } h \in [0, h_S) \bigcup (\bar{h}, H], \end{cases}$$

and $s_\emptyset^{MSA} = 0$. The regulator chooses $\bar{h}$, h_S, and I to maximize welfare subject to the firm's incentive compatibility constraint. As before, we can replace the firm's incentive compatibility constraint with the first-order condition of the firm's maximization problem:

$$I^{MSA} = \frac{p\upsilon\int_0^{\bar{h}} \Pi g(h)dh + p(1-\upsilon)(\gamma + \alpha(1-\gamma))\int_0^{h_S} \Pi g(h)dh + p(1-\upsilon)\int_{h_S}^{\bar{h}} \Pi g(h)dh}{c}.$$

If there is a breakthrough, ex-post welfare is:

$$w^{MSA} = p\int_0^{\bar{h}} (\Pi - h)g(h)dh - \lambda p\int_{h_S}^{\bar{h}} s_h g(h)dh.$$

Note that the difference $w - cI$ is:

$$-p\int_0^{\bar{h}} hg(h)dh - \lambda p\int_{h_S}^{\bar{h}} s_h^{MSA} g(h)dh + (1-\upsilon)(1-\gamma)(1-\alpha)pG(h_S)\Pi.$$

We now look for the interior solution. In what follows, we assume that the second order conditions hold. The first-order conditions with respect to h_S and $\bar{h}$ are, respectively:

$$\frac{\partial I}{\partial h_S}(w - cI) + \frac{\partial w}{\partial h_S}I = 0; \quad \frac{\partial I}{\partial \bar{h}}(w - cI) + \frac{\partial w}{\partial \bar{h}}I = 0.$$

We obtain the following implicit functions:

$$G(h_S^{MSA}) = \frac{(1-\upsilon)(1-\gamma)(1-\alpha)\int_0^{\bar{h}^{MSA}} hg(h)dh + \lambda[1+(1-\upsilon)(1-\gamma)(1-\alpha)]G(\bar{h}^{MSA})s_h}{[(1-\upsilon)(1-\gamma)(1-\alpha)]^2\Pi + 2(1-\upsilon)(1-\gamma)(1-\alpha)\lambda s_h^{MSA}}; \tag{B3}$$

$$\bar{h}^{MSA} = \Pi + \lambda s_h^{MSA}\left[\frac{1-(1-\upsilon)(1-\gamma)(1-\alpha)}{(1-\upsilon)(1-\gamma)(1-\alpha)}\right]. \tag{B4}$$

The interior solution is obtained when the following condition holds:

$$\frac{1}{G(\bar{h})}\int_0^{\bar{h}^{MSA}} hg(h)dh \leq (1-\upsilon)(1-\gamma)(1-\alpha)\Pi - \lambda\frac{(1-(1-\upsilon)(1-\gamma)(1-\alpha))}{(1-\upsilon)(1-\gamma)(1-\alpha)}s_h^{MSA}. \tag{B5}$$

Note that when $\lambda = 0$, $\bar{h}^{MSA} = \Pi$ which means there is no distortion in ex-post allocative efficiency, and Condition (B5) boils down to Condition (1) with the opposite sign. Importantly, h_S^{MSA} is set in such a way so as to guarantee second-best investment. Therefore, at the interior solution, welfare in a regime of modified strict authorization is:

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

When Condition (B5) is not satisfied, we are at a corner solution as $h_S = \bar{h}$. Then, the latter is found to be:

$$\bar{h} = \Pi\left(1+(\upsilon+(1-\upsilon)(\gamma+(1-\gamma)\alpha))\left[\frac{(xG(\bar{h})\Pi - \int_0^{\bar{h}} hg(h)dh)}{(\upsilon+(1-\upsilon)(\gamma+\alpha(1-\gamma)))G(\bar{h})\Pi}\right]\right),$$

which can be greater or smaller than Π. When we are at the corner solution, it is immediate to see that an increase in λ does not have any effect on welfare.

If $\upsilon = 1$, it is easy to show that $\bar{h}$ can be implicitly determined from the next equation and is lower than Π: $\bar{h}^{MSA} = \Pi - E_g(h|h < \bar{h}^{MSA})$. □

Proof of Corollary 3

The effect of an increase in υ on welfare under lenient authorization is ambiguous. This is because $\frac{\partial W^{MLA}}{\partial \upsilon} = -p\int_{\bar{h}^{MLA}}^{h_L^{MLA}}(\Pi-h)g(h)dh$ which can be negative as $h^{MLA} < \Pi$.

As for W^{MSA}, bear in mind that welfare is higher when Condition (B5) is satisfied (indeed, if $\lambda = 0$ second-best is achieved). Note that an increase in υ makes it more likely that Condition (B5) does not hold, leading to lower social welfare. Moreover, when second-best is not achieved, $w^{MSA} < cI^{MSA}$, and an increase in υ increases investment, regardless of whether Condition (B5) is satisfied or not, reducing social welfare. □

Proof of Remark 3

Consider a regime of lenient authorization (solutions will be denoted by the superscript LAq). Equilibrium investment is:

$$I_G^{LAq} = \frac{p[qG(\Pi)+(1-q)(1-G(\Pi)]\Pi + (1-p)\Pi + p(1-\upsilon)\alpha[q(1-G(\Pi))+(1-q)G(\Pi)]\Pi}{c}.$$

Equilibrium ex-post welfare is:

$$w_G^{LAq} = \int_0^H (\Pi - h)g(h)dh - pv\left((1-q)\int_0^\Pi (\Pi - h)g(h)dh + q\int_\Pi^H (\Pi - h)g(h)dh\right).$$

The effect of v on W_G^{LAq} is

$$I_G^{LAq}\frac{\partial w_G^{LAq}}{\partial v} + \frac{\partial I_G^{LAq}}{\partial v}\Big[w_G^{LAq} - cI_G^{LAq}\Big].$$

Notice that $\frac{\partial I_G^{LAq}}{\partial v} < 0$, and that

$$\begin{aligned} w_G^{LAq} - cI_G^{LAq} = &-\int_0^H hg(h)dh + pv\left[q\int_\Pi^H hg(h)dh + (1-q)\int_0^\Pi hg(h)dh\right] \\ &+ p(1-\alpha)(1-v)\left[q\int_\Pi^H \Pi g(h)dh + (1-q)\int_0^\Pi \Pi g(h)dh\right] < 0. \end{aligned}$$

To see this note that the above expression is negative if

$$-\int_0^H hg(h)dh + pv\int_0^\Pi hg(h)dh + p(1-\alpha)(1-v)\int_0^\Pi \Pi g(h)dh + pq[\Psi] < 0,$$

where

$$\Psi := v\int_\Pi^H hg(h)dh + (1-\alpha)(1-v)\int_\Pi^H \Pi g(h)dh - v\int_0^\Pi hg(h)dh - (1-\alpha)(1-v)\int_0^\Pi \Pi g(h)dh.$$

If $\Psi > 0$, then $\partial(w_G^{LAq} - cI_G^{LAq}) > 0$. But then we have already shown in the Proof of Proposition 3 that $w_G^{LAq} - cI_G^{LAq} < 0$ when $q = 1$. If $\Psi < 0$, then for any $q > 1/2$, $w_G^{LAq} - cI_G^{LAq} < 0$. Thus, a sufficient condition for welfare to be increasing in v in a regime of lenient authorization is that $\frac{\partial w_G^{LAq}}{\partial v} > 0$, which is the case if:

$$q > \frac{\int_0^\Pi (\Pi - h)g(h)dh}{\int_0^\Pi (\Pi - h)g(h)dh - \int_\Pi^H (\Pi - h)g(h)dh}.$$

Consider a regime of strict authorization (solutions will be denoted by the superscript SAq). Equilibrium investment is:

$$I_G^{SAq} = \frac{p\Gamma\Big[qG(\Pi) + (1-q)(1-G(\Pi)\Big]\Pi}{c}.$$

Equilibrium ex-post welfare is:

$$w_G^{SAq} = p\left(q\int_0^\Pi (\Pi - h)g(h)dh + (1-q)\int_\Pi^H (\Pi - h)g(h)dg\right).$$

Note that $\frac{\partial w_G^{SAq}}{\partial v} = 0$ and $\frac{\partial I_G^{SAq}}{\partial v} > 0$, whereas

$$w_G^{SAq} - cI_G^{SAq} = p\left(q\int_0^\Pi (\Pi - h)g(h)dh + (1-q)\int_\Pi^H (\Pi - h)g(h)dg\right) - p\Gamma\Big[qG(\Pi) + (1-q)(1-G(\Pi)\Big]\Pi < 0$$

when

$$\Gamma > \frac{q\int_0^\Pi (\Pi - h)g(h)dh + (1-q)\int_\Pi^H (\Pi - h)g_(h)dh}{\Big[qG(\Pi) + (1-q)(1-G(\Pi)\Big]\Pi},$$

that can be rewritten as reported in the text of the remark. □

Corruption opportunities and manipulation power

For both regimes, we make the assumption that $0 < \Pi - m$ and $\Pi + m < H$ and we focus on the general environment without salaries of Section 3.3.

In a regime of lenient authorization, collusion occurs when there is evidence that the activity is unsafe and the firm will be allowed to produce, after paying a bribe $b = (1-\alpha)\Pi$ to a corrupt public official. When the corrupt public official has collected a signal that would be favorable to the firm, she might be able to engage in extortion. If the public official learns that $h \in (\Pi - m, \Pi)$, she can threaten to report $h \geq \Pi$, so that the activity would be banned. Moreover, if the signal is uninformative, the public official can forge evidence that the activity is unsafe with probability M_L, that is decreasing in Π: intuitively, the higher Π, the more difficult it is to report that the damages would be weakly higher than Π. Whenever the threat of extortion is credible, the firm will have to pay a bribe $b = (1-\alpha)(1-\gamma)\Pi$ to be authorized to produce. We denote the equilibrium expressions by the superscript LAS. Equilibrium investment is:

$$I_G^{LAS} = \frac{p\Big[\Gamma G(\Pi) + (1-\upsilon)\Big(\alpha[1-G(\Pi)] + (1-\gamma)(1-\alpha)G(\Pi-m)\Big)\Big]\Pi}{c} + \frac{(1-p)\Big[\Big(\upsilon + (1-\upsilon)[1 - M_L(1-\gamma)(1-\alpha)]\Big)\Big]\Pi}{c},$$

whereas $w_G^{LAS} = w_G^{LA}$. We now study the impact of a change in υ on W_G^{LAS}:

$$\frac{\partial W_G^{LAS}}{\partial \upsilon} = \frac{\partial I_G^{LAS}}{\partial \upsilon}(w_G^{LAS} - cI_G^{LAS}) + \frac{\partial w_G^{LAS}}{\partial \upsilon} I_G^{LAS}.$$

The second term is positive. As for the first term:

$$\frac{\partial I_G^{LAS}}{\partial \upsilon} = \frac{(1-\alpha)(1-\gamma)p\int_{\Pi-m}^{\Pi} \Pi g(h)dh + (1-p)M_L(1-\gamma)(1-\alpha)\Pi - p\alpha[1-G(\Pi)]\Pi}{c}.$$

We can find a threshold value of γ above which $\frac{\partial I_G^{LAS}}{\partial \upsilon} < 0$:

$$\gamma_1 := \frac{(1-\alpha)\left[p\int_{\Pi-m}^{\Pi} g(h)dh + (1-p)M_L\right] - p\alpha[1-G(\Pi)]}{(1-\alpha)\left[p\int_{\Pi-m}^{\Pi} g(h)dh + (1-p)M_L\right]},$$

where it is easy to see that γ_1 is increasing in m and M_L. The difference $w_G^{LAS} - cI_G^{LAS}$ can be rewritten as:

$$-E_g(h) + p\upsilon\int_{\Pi}^{H} hg(h)dh + (1-\upsilon)(1-\alpha)\Big(p[1-\gamma G(\Pi)] + (1-\gamma)[(1-p)M_L - pG(\Pi-m)]\Big)\Pi.$$

We can find a threshold value of γ above which $w_G^{LAS} - cI_G^{LAS} < 0$:

$$\gamma_2 := \frac{-E_g(h) + p\upsilon\int_{\Pi}^{H} hg(h)dh + (1-\upsilon)(1-\alpha)\Big(p[1-G(\Pi-m)] + (1-p)M_L\Big)\Pi}{(1-\upsilon)(1-\alpha)p[G(\Pi)-G(\Pi-m)]\Pi + (1-p)M_L\Pi}.$$

Notice that $\gamma_1 > \gamma_2$:

$$0 > -E_g(h) + p\left[\upsilon\int_{\Pi}^{H} hg(h)dh + (1-\upsilon)(1-G(\Pi))\Pi\right].$$

To sum up:

Remark 5. *In a regime of lenient authorization, when information is soft, a sufficient condition for welfare to be strictly increasing in υ is that $\gamma \geq \gamma_1$ or $\gamma \leq \gamma_2$. When $\gamma \in (\gamma_2, \gamma_1)$, the sign of $\frac{\partial W_G^{LAS}}{\partial \upsilon}$ is ambiguous.*

Strong enough institutions dampen the effect of extortion on investment incentives, whereas they do not alter the impact of collusion on investment. As a consequence, for γ high enough, an increase in the fraction of honest public officials is welfare increasing as it mitigates the over-investment problem. In this case, we retrieve a result similar to that of Section 3.3. The threshold value of γ above which an increase in υ positively affects welfare is increasing in the public official's manipulation ability. Stated differently, corruption is more likely to be beneficial, thanks to its investment-dampening effect, when the public official has more leeway in fabricating evidence. As m and M_L take values close to 0, the threshold γ_1 also goes to zero, implying that, when the public official has little manipulation power, it is almost always desirable to have more honest public officials. When the institutional strength is very low (below γ_2), the firm invests too little because of the anticipation of extortion. In that range, an increase in υ reduces the likelihood of blackmail, fostering investment, thereby increasing welfare.

Consider now a regime of strict authorization. As with hard information, extortion will occur when there is evidence that the activity is safe and the public official will collect a bribe $b = (1-\alpha)(1-\gamma)\Pi$. Collusion will occur when there is no conclusive evidence with probability M_S, or the evidence reveals that the activity is unsafe up to a bound $\Pi + m$. In that case, the bribe will be $b = (1-\alpha)\Pi$. The probability M_S may be increasing in Π since it is easier to forge evidence favorable to the firm when the benefits of production are relatively larger. We denote the equilibrium expressions by the superscript SAS. Equilibrium investment is:

$$I_G^{SAS} = \frac{p\Gamma G(\Pi)\Pi + (1-\upsilon)\alpha\left(p\int_{\Pi}^{\Pi+m}\Pi g(h)dh + (1-p)M_S\Pi\right)}{c}.$$

To understand the above expression, note that the first term refers to the profits that the firm gets also when information is hard. The new term represents the expected profits from collusion: when the public official is corrupt, the firm obtains a fraction α of the gains from production (i) when there is evidence that the activity is not excessively unsafe and (ii) when there is no conclusive evidence but a favorable report can be fabricated. Ex-post welfare:

$$w_G^{SAS} = p\int_0^{\Pi}(\Pi - h)g(h)dh + (1-\upsilon)\left[p\int_{\Pi}^{\Pi+m}(\Pi-h)g(h)dh + (1-p)M_S\int_0^H(\Pi-h)g(h)dh\right].$$

We now study the impact of a change in υ on W_G^{SAS}:

$$\frac{\partial W_G^{SAS}}{\partial \upsilon} = \frac{\partial I_G^{SAS}}{\partial \upsilon}(w_G^{SAS} - cI_G^{SAS}) + \frac{\partial w_G^{SAS}}{\partial \upsilon}I_G^{SAS}.$$

Note that:

$$\frac{\partial w_G^{SAS}}{\partial \upsilon} = -p\int_{\Pi}^{\Pi+m}(\Pi-h)g(h)dh - (1-p)M_S\int_0^H(\Pi-h)g(h)dh.$$

This is negative if $\Pi > E_g(h)$ and:

$$p \leq \frac{M_S \int_0^H (\Pi - h)g(h)dh}{-\int_{\Pi}^{\Pi+m}(\Pi - h)g(h)dh + M_S \int_0^H (\Pi - h)g(h)dh}.$$

The effect on investment is:

$$\frac{\partial I_G^{SAS}}{\partial \upsilon} = \frac{p(1-\gamma)(1-\alpha)G(\Pi)\Pi - \alpha\left(p\int_{\Pi}^{\Pi+m}\Pi g(h)dh + (1-p)M_S\Pi\right)}{c};$$

This is positive if

$$\gamma < 1 - \frac{\alpha}{1-\alpha}\frac{p[G(\Pi+m) - G(\Pi)] + (1-p)M_s}{pG(\Pi)} := \gamma_3.$$

This is more likely to be the case if α is small. When public officials are corrupt, the firm suffers from extortion and benefits from collusion. The relative magnitude of these gains depends on the bargaining power. An increase in the proportion of honest public officials is beneficial to the firm if its bargaining power is low enough, so that the gains from collusion it pockets would be minor. Note that γ_3 is decreasing in both m and M_S. When m and M_S tend to 0, γ_3 goes to 1.

As for $w - cI$, this is negative if:

$$\begin{aligned}\gamma > & 1 + \frac{p[G(\Pi+m) - G(\Pi)] + (1-p)M_S}{pG(\Pi)} \\ & - \frac{p\int_0^{\Pi} hg(h)dh + (1-\upsilon)p\int_{\Pi}^{\Pi+m} hg(h)dh + (1-\upsilon)(1-p)M_S E_g(h)}{p(1-\alpha)(1-\upsilon)G(\Pi)\Pi} := \gamma_4.\end{aligned}$$

The threshold γ_4 is always decreasing in m and in M_S when $E_g(h) > (1-\alpha)\Pi$. It is easy to see that $\gamma_3 > \gamma_4$ when $E_g(h) \geq \Pi$. If $E_g(h) < \Pi$, this may not be the case. To summarize the results, we obtain:

Remark 6. *In a regime of strict authorization, when there is soft information, a sufficient condition for welfare to be strictly decreasing in* υ *is* $\gamma \in \Big[\min\{\gamma_3, \gamma_4\}, \max\{\gamma_3, \gamma_4\}\Big]$ *when* $\Pi > E_g(h)$ *and*

$$p \leq \frac{M_S \int_0^H (\Pi - h)g(h)dh}{-\int_{\Pi}^{\Pi+m}(\Pi - h)g(h)dh + M_S \int_0^H (\Pi - h)g(h)dh}.$$

When m and M_S take low values, we retrieve the condition of Proposition 3 and welfare is negatively affected by an increase in the presence of honest public officials whenever γ is high enough. Conversely, when m and M_S takes high values, collusion is also a concern in this authorization regime. In that case, when γ is large enough, an increase in the fraction of honest public officials improves welfare as it lowers the detrimental effect of collusion.

Taxes and regulation

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

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

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

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

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. We assume that the second-order condition for a maximum is satisfied, which sets an upper bound to the value that λ_t can take.

Lemma 6. *In a regime of lenient authorization, the tax on production is:*

$$t^{LA} = \frac{E_g(h) - p\upsilon \int_\Pi^H hg(h)dh - p(1 - G(\Pi))(1 - \upsilon)(1 - \alpha)\Pi - \lambda_t \Pi\Big[1 - p\upsilon(1 - G(\Pi))\Big]}{1 - p(1 - G(\Pi))[1 - \alpha(1 - \upsilon)] - 2\lambda_t\Big[1 - p\upsilon(1 - G(\Pi))\Big]}. \quad \text{(B6)}$$

Equilibrium investment and ex-post welfare are:

$$\begin{aligned} I_G^{LA}(t^{LA}) &= \max\left\{(\Pi - t^{LA})\left[\frac{1 - (1 - G(\pi))p[1 - (1 - \upsilon)\alpha]}{c}\right], 0\right\} \\ w_G^{LA}(t^{LA}) &= \max\left\{(\Pi - t^{LA})\Big[1 - (1 - G(\pi))p[1 - (1 - \upsilon)\alpha] - \lambda_t[1 - p\upsilon(1 - G(\Pi))]\Big], 0\right\}, \end{aligned} \quad \text{(B7)}$$

where

$$\Pi - t^{LA} = \frac{\int_0^H (\Pi(1 - \lambda_t) - h)g(h)dh - p\upsilon \int_\Pi^H (\Pi(1 - \lambda_t) - h)g(h)dh}{1 - 2\lambda_t - p(1 - G(\Pi))[1 - (1 - \upsilon)\alpha - 2\lambda_t \upsilon]}.$$

Proof. 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 is:

$$\frac{\partial I_G^{LA}(t)}{\partial t}\left[2\frac{\partial w_G^{LA}(t)}{\partial t} - c\frac{\partial I_G^{LA}(t)}{\partial t}\right],$$

which is negative if and only if λ_t is sufficiently small:

$$\lambda_t < \frac{1 - p(1 - G(\Pi))[1 - (1 - \upsilon)\alpha]}{2\Big[1 - p\upsilon(1 - G(\Pi))\Big]}.$$

Given t^{LA}, the firm will invest only if $\Pi > t^{LA}$. If $\Pi \leq t^{LA}$, then $I_G^{LA}(t^{LA}) = w_G^{LA}(t^{LA}) = 0$.

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

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

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

$$\frac{[1 - p(1 - \alpha)(1 - G(\Pi))]}{\alpha(1 - G(\Pi))} > p\upsilon.$$

Lastly, note that when $\lambda_t = 0$, $I_G^{LA}(t^{LA}) = \max\{w_G^{LA}/c, 0\}$ and $W_G^{LA}(t^{LA}) = \max\{(w_G^{LA})^2/2c, 0\}$. □

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

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

The tax is chosen in Stage 0 to maximize $W_G^{SA}(t)$. The solution is characterized in the following lemma. We assume that the second-order condition for a maximum is satisfied.

Lemma 7. *In a regime of strict authorization, the tax on production is:*

$$t^{SA} = \max\left\{\frac{\int_0^{\Pi}\Big[h - \Pi(1 + \lambda_t - \Gamma)\Big]g(h)dh}{G(\Pi)(\Gamma - 2\lambda_t)}, 0\right\}, \tag{B8}$$

and $t^{SA} > 0$ *only if* $\lambda_t < \frac{E_g(h|h\leq\Pi)}{\Pi} - (1-\upsilon)(1-\gamma)(1-\alpha)$*. For* $t^{SA} > 0$*, the firm will invest*

$$I_G^{SA}(t^{SA}) = \frac{p\Gamma\Big[\int_0^{\Pi}(\Pi(1-\lambda_t) - h)g(h)dh\Big]}{c(\Gamma - 2\lambda_t)}$$

and ex-post surplus is:

$$w_G^{SA}(t^{SA}) = \frac{p(\Gamma - \lambda_t)\Big[\int_0^{\Pi}(\Pi(1-\lambda_t) - h)g(h)dh\Big]}{(\Gamma - 2\lambda_t)}$$

Welfare in a regime of strict authorization is:

$$W_G^{SA}(t^{SA}) = \frac{p^2\Gamma\Big[\int_0^{\Pi}(\Pi(1-\lambda_t) - h)g(h)dh\Big]^2}{2c(\Gamma - 2\lambda_t)} \tag{B9}$$

Welfare decreases in υ*,* γ*, and* α*.*

Proof. The equilibrium tax is derived from the first-order condition of the maximization problem. Note that the second order condition holds if and only if $2\lambda_t < \Gamma$. Given t^{SA}, the firm will always invest a positive amount. Consider that the second-order condition is satisfied at $\lambda_t \to \frac{E_g(h|h<\Pi)}{\Pi} - (1-\upsilon)(1-\gamma)(1-\alpha))$ (which is the highest value of λ_t such that the non-negativity constraint on t^{SA} is satisfied) requires that:

$$2 - 2\frac{E_g(h|h<\Pi)}{\Pi} > \Gamma.$$

Note that the numerator of $I_G^{SA}(t^{SA})$ is positive for any $\lambda_t \in \Big[0, \frac{E_g(h|h<\Pi)}{\Pi} - (1-\upsilon)(1-\gamma)(1-\alpha)\Big)$ if exactly the same inequality holds.

To see that an increase in Γ increases the equilibrium tax, notice that:

$$\frac{\partial t^{SA}}{\partial\Gamma} = \frac{\int_0^{\Pi}\Big(\Pi(1-\lambda_t) - h\Big)g(h)dh}{G(\Pi)(\Gamma - 2\lambda_t)^2},$$

which is positive for $I_G^{SA}(t^{SA}) > 0$.

To see that an increase in Γ reduces welfare, consider the following derivative:

$$\frac{\partial W_G^{SA}(t^{SA})}{\partial \Gamma} = -\frac{p^2\lambda_t\Big[\int_0^{\Pi}(\Pi(1-\lambda_t)-h)g(h)dh\Big]^2}{c(\Gamma-2\lambda_t)^2} < 0.$$

Note that if Condition (1) does not hold, the regulator would not use a tax to discourage investment even for $\lambda_t = 0$. In that case,

$$W_G^{SA}(t^{SA}) = \frac{p^2\Gamma G(\Pi)\Pi\Big[\int_0^{\Pi}(\Pi-h)g(h)dh\Big]}{c} - \frac{(p\Gamma G(\Pi)\Pi)^2}{2c},$$

and the effect of an increase in Γ is:

$$\frac{\partial W_G^{SA}(t^{SA})}{\partial \Gamma} = -\frac{p^2 G(\Pi)\Pi\int_0^{\Pi} hg(h)dh}{c} < 0.$$

Lastly, note that when $\lambda_t = 0$, $I_G^{SA}(t^{SA}) = w_G^{SA}/c$ and $W_G^{SA}(t^{SA}) = (w_G^{LA})^2/2c$.

□

Proof of Proposition 7

Condition (2) is straightforwardly derived by comparing welfare under the two authorization regimes when $\lambda_t = 0$. To see that (2) is more difficult to satisfy for distribution $F(\cdot)$ which conditionally stochastically dominates distribution $G(\cdot)$, note that after some computations (2) 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 (2) is satisfied for distribution $G(\cdot)$, it may not hold for distribution $F(\cdot)$. When λ_t takes positive values and increases, it reduces the value of $w_G^{LA}(t)$ and $w_G^{SA}(t)$ for any positive value of t. Hence, it cannot be that $W_G^{LA}(t^{LA})$ and $W_G^{SA}(t^{SA})$ increase when λ_t goes up. However, if $W_G^{LA}(t^{LA}) = 0$, welfare does not decrease when λ_t increases. If Condition (1) does not hold, $t^{SA} = 0$ and, as a result, an increase in λ_t does not affect welfare in a regime of strict authorization. Lastly, welfare in strict authorization was found to be decreasing in Γ, which, in turn, is increasing in v. □

Proof of Remark 4

To illustrate the proof, we set $\lambda_t = 0$. 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 $t_{h}^{LA} = t_{\emptyset}^{LA} = t^{LA}$. $\square$