On Monitoring Timing in Hierarchies*

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Abstract

The principal-agent literature has shown that the agent's incentive problems can be alleviated if the principal can hire either a supervisor or an auditor, but not much attention has been given to the choice between these two monitoring mechanisms. We analyze the optimal monitoring timing in a very simple setup with an honest monitor. This timing choice involves a trade-off. On one hand, a signal from a supervisor provides flexibility in contracting (since output can be contracted on this signal). On the other hand, a signal from an auditor can be used to punish the agent. We show that auditing is optimal when strong punishment schemes can be implemented and enforced by courts. If punishment is weak or cannot be enforced by courts, supervising (or, in general, *ex ante* monitoring) is optimal when the supervisor's signal is informative of the agent's type. The results are consistent with some stylized facts of organizational structures (auditing top-level management and supervising low-level employees) and regulation of hazardous activities (in whose case a regulatory stage is more probable when the enforcement costs are lower).

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1 Introduction

The literature on the principal-agent problem has analyzed the role that monitoring institutions play in alleviating incentive problems. Two separate branches of this literature have been studied separately. The first one analyzes the effects of hiring a supervisor on the agent's incentives and on the principal's contract design (see, for example, Tirole [14]). The supervisor obtains information about the agent's productivity *before* the agent exerts effort (we also refer to him as *ex ante* monitor).

The second branch of the literature studies the optimal contract when the principal hires an auditor (see, for example, Baron and Besanko [2]). The auditor obtains information about the agent's effort or productivity *after* the agent exerted her effort (we also refer to him as *ex post* monitor). We will refer to both of them as monitors when there is no need to distinguish them.

However, not much attention has been given to what affects the choice between the two monitoring institutions.[1] There are reasons that justify the importance of this problem. The evidence suggests the existence of both institutions, and a formal explanation is needed to rationalize their prevalence. Owners of a firm hire third parties to supervise employees, to monitor their effort or to audit their private information. In regulation, governmental agencies intervene in industries (by means of ex ante controls) or audit firms' accounting data and expenses, or the industry is subject to competition policies. Moreover, *the monitoring timing choice is not inconsequential since it has different effects on the agent's incentives, and therefore the principal's utility.* On the one hand, the supervisor's report is used to design a "flexible" contract for the agent, in which output and the agent's compensation are based on both the agent's and monitor's report. On the other hand, the principal can use the auditor's report to punish the agent (provided that a punishment scheme is available and enforceable), but she cannot make the contracting of output depend on this report. The principal faces a trade-off between flexibility and rigidity-punishment.

In order to find the optimal solution to this trade-off, we specify a general model (principal-monitor-agent hierarchy) that allows both supervising and auditing. The principal, who is uninformed about the agent's productivity and effort, hires the agent to

[1] The literature on *Law and Economics* has already considered the stage of legal intervention or (benevolent) regulation of activities that generate externalities (see Shavell [13] and Kolstad *et al.* [9]). They do not consider the trade-off analyzed in this paper.

produce a good or service. In addition, the principal may hire a monitor (whose preferences are aligned to the principal's) to extract some of the agent's private information, which can be used to reduce the agent's rents.

The solution to this trade-off is such that auditing is optimal when the principal has strong punishment schemes, when it is more probable that punishments can be applied or enforced, or when punishment instruments are weak and the monitor's signal is noisy. Otherwise, supervising is optimal when punishment schemes are weak or cannot be enforced, provided that the supervisor's signal is very informative of the agent's type. Given a low expected punishment, the supervisor is more valuable to the principal when he learns the "right" information about the agent (which is more probable when his signal is more accurate), for the principal can reduce the agent's rents when she is certain about the agent's type. The principal is more prone to select a supervisor when she anticipates a lower probability of punishment enforcement.

The formal results in this paper explain casual observations, such as auditing of top-level managers in organizations (such as CEOs, who may be more exposed to punishments), or supervising of low-level employees' activities during the production stage. Typically, low-level employees have lower incomes or are protected by minimum wage regulations). Of course, company shareholders prefer to "screen" a candidate to a high-rank (i.e., managerial) position when they cannot rely on courts as an enforcement device of an eventual punishment. These results also apply to regulation of "hazardous" activities. In particular, the determinants of optimal stage of intervention such as magnitude of possible sanctions or probability of application of sanctions arise naturally under this agency-based structure. A new important determinant is the quality of the monitor's information (measured as signal accuracy of the agent's type), which is valuable to achieve some flexibility ex ante (i.e., prevention of damages at a low cost).

This paper connects many works dedicated to monitoring in hierarchies, which apply to either supervising or auditing. Baron and Besanko [2] analyzed the optimal design of a regulatory contract when the government hires a benevolent regulator to audit a firm. They obtain a separation result that the pricing decision does not depend on the auditing decision (which means that the price and quantity when the firm is audited are the same as those when the firm is not audited), but the auditing decision depends on the pricing decision (in particular, the principal sends the auditor when she infers that the firm overstated the price). Cohen [4] characterizes the optimal enforcement for a government regulator to prevent oil spills (i.e., a kind of negative externality) in an agency-based framework with moral hazard. Tirole [14] introduces the optimal contract when a supervisor is hired, but his concern is about the effect of collusion between the supervisor and the agent on such contract (see Section 6 for a brief discussion). However, none of these works consider the optimality of supervising as compared with auditing. Finally, as we mentioned before, the Law and Economics literature (Kolstad *et al.* [9] and Shavell [13]) has analyzed the optimal stage of Law enforcement of activities that generate externalities in a benevolent-regulator framework. Neither agency problems nor imperfect signals is considered in these papers.

The paper is organized as follows. Section 2 outlines the model. Section 3 computes the optimal contract when the principal hires a supervisor or an auditor. Section 4 discuses the optimal monitoring timing. We provide some applications to organization design and regulation in Section 5. Finally, Section 6 concludes and discusses some extensions.

2 Model

Consider a hierarchy consisting of an owner (principal), a monitor (supervisor or auditor) and a manager (agent).[2] The principal hires the agent to produce a good with gross value V and production cost $C = \bar{\theta} - \theta e$. The payoff to the principal is $V - \bar{\theta} + \theta e$.[3] The cost C, which is *observed* by the principal, is reduced by a combination of agent's productivity and effort, which are *not observed* by the principal. By exerting higher effort the agent reduces the production cost, but she derives a private effort disutility or cost $\psi(e) = e^2/2$.[4] The agent's private productivity or type is $\theta \in \{\theta_L, \theta_H\}$, with $\theta_H > \theta_L > 0$. Let q be the ex ante probability that the agent's productivity is high, i.e., $q = Pr(\theta = \theta_H)$. The parameter $\bar{\theta}$ is an upper bound on the production cost.[5] The principal reimburses the cost C and pays a net transfer t to the agent. The agent's reservation utility is normalized to $U_0 = 0$.

[2]We also consider other hierarchies, such as owner-headman-worker, government-regulator-firm/contractor.

[3]This specification of the model nests regulation models (with cost function C) and organization models (with profit function $\pi \approx \theta e$).

[4]We assume a quadratic effort cost to obtain simple solutions to the optimal contract. The results can be generalized to more general (convex) functions.

[5]We show later that the effort exerted by a type-θ_H agent is $e = \theta_H$, and hence we assume that $\bar{\theta} > \theta_H^2$ for the observed cost to be positive in all the cases analyzed in this paper.

The principal also decides whether to hire a monitor who observes an imperfect signal about the agent's productivity (this signal is also observed by the agent). The monitor obtains a signal at no cost (the results extend to a costly monitor, provided that he is hired). The signal may take the following values: With probability $1-p$ the monitor learns nothing about the agent's type ($\sigma = 0$). Otherwise he gets an imperfect observation of the agent's type ($\sigma \in \{L, H\}$), which is correct with probability $\alpha > 1/2$. This assumption satisfies the monotone likelihood ratio property that a correct signal is more probable. Table 1 summarizes the possible signals and their corresponding probabilities.

Table 1: **Monitor's Signal of Agent's Type**

σ	Probability	Observation	θ
0	$1-p$	0	θ_H
H	$p\alpha$	θ_H	θ_H
L	$p(1-\alpha)$	θ_L	θ_H
0	$1-p$	0	θ_L
H	$p(1-\alpha)$	θ_H	θ_L
L	$p\alpha$	θ_L	θ_L

With the new information, the principal may set a fine or reduce the agent's wage whenever she finds that the agent misreported her type or shirked. The agent is protected by limited liability when punished: an eventual fine z^r set by the principal (depending on the monitor's report r) must be up to some liability maximum z. The liability bound may be interpreted as exogenous wealth constraints or exogenous maximum legal punishment. To introduce some uncertainty in the enforcement of the penalties, we assume that the agent is punished with some probability $\phi \in [0, 1]$, so the expected punishment is ϕz^r.

The monitor sends a report $r \in \{0, L, H\}$ to the principal, who pays him a wage w. He is protected by limited liability ($w \geq 0$). His reservation utility is normalized to 0.

In addition, the principal has to decide whether to send the monitor *before* or *after* the agent exerted effort. In the first case, the monitor supervises the agent and obtains a signal about the agent's productivity (effort has not been exerted yet). In the second case, the monitor may either audit the agent's productivity or monitor effort. Given the cost structure ($C = \bar{\theta} - \theta e$), the information obtained by the principal is the same whether monitoring generates a signal σ on productivity or effort, provided that the informativeness of signals and the cost of observing them are the same. Whether monitoring is ex ante or ex post (on effort or productivity), we assume the same distribution of signal (same p and α) and the same cost ($c = 0$) to eliminate a possible source of timing preference. Hence we concentrate on (ex ante or ex post) productivity monitoring for convenience in the exposition.

In order to make the timing decision, the principal compares costs and benefits under each alternative. If she hires a supervisor, she obtains a report that can be used to contract both output and wage. This gives some flexibility to the output choice, for the principal can create output distortions according to the probability of the events in order to reduce the agent's rent. On the other hand, when the principal hires an auditor, she does not benefit from the flexibility in contracting output, but she can punish (up to some point) the agent when she finds that the agent misreported her type (or shirked). There is a trade-off: flexibility in contracting vs. rigidity and punishment.

The timing of the game is as follows.

1. Nature chooses the agent's type θ. The agent learns her type.
2. The principal decides the monitoring timing.
3. The principal offers a set of contracts: $t(C, r)$ to the agent ($\{t(C, r), z^r\}$ if the agent is audited) and $w(C, r)$ to the monitor. The three parties sign the contract.
4. *IF* a supervisor is hired, he observes a signal σ, and sends a report r to the principal.
5. The agent chooses effort e. The cost C is realized.
6. *IF* an auditor is hired, he observes a signal σ, and sends a report r to the principal.
7. Transfers are realized.

We assume that the three parties are risk neutral. Since there are both moral hazard and adverse selection, a transfer of the hierarchy from the principal to the agent is not optimal.[6] The principal, agent and monitor's utility is $U_P = V - [t + w + C]$, $U_A = t - e^2/2$ (minus an expected punishment, when it applies) and $U_M = w$, respectively.

When the principal observes both agent's effort and type, the problem simplifies to choose effort and transfers in order to maximize $V - \bar{\theta} + [\theta e - t]$, for $\theta \in \{\theta_L, \theta_H\}$, subject to the agent's interim participation constraint $t - e^2/2 \geq 0$. The solution to this problem is: $e_j^{FB} = \theta_j$, $t_j^{FB} = \theta_j^2/2$, for $j = L, H$. The principal's expected utility is

[6] Limited liability to the monitor ensures that a transfer of the hierarchy from the principal to the monitor is not possible.

$$EU_P^{FB} = V - \bar{\theta} + \left[q\theta_H^2 + (1-q)\theta_L^2\right]/2 \tag{1}$$

Suppose that the principal does not observe either agent's effort or type. The contract offered by the principal should be conditioned only on the observable C. Because of the binary nature of the problem and the fact that C is deterministic for a given agent's type, we can concentrate on forcing contracts. As it is well known from revelation principle, the principal can restrict herself to Bayesian direct mechanisms based on an agent's truthful report. For a report $\hat{\theta}$ there is an effort recommendation $e(\hat{\theta})$ to achieve a production cost $C(\hat{\theta}) = \bar{\theta} - \hat{\theta}e(\hat{\theta})$. When the agent reports that his type is $\hat{\theta} = \theta_L$ ($\hat{\theta} = \theta_H$) and the principal observes a cost C_L (C_H), the principal pays the agent a transfer t_L (t_H) and recommends to exert effort e_L (e_H). Let $\Delta\theta = (\theta_L/\theta_H)^2 < 1$ and $R = 1 - \Delta\theta < 1$. A feasible contract to the agent must satisfy the individual rationality (IR) and incentive compatibility (IC) constraints

$$\begin{array}{ll} IR(L):\ t_L \geq e_L^2/2 & \qquad IC(L):\ t_L - e_L^2/2 \geq t_H - e_H^2/2\Delta\theta \\ IR(H):\ t_H \geq e_H^2/2 & \qquad IC(H):\ t_H - e_H^2/2 \geq t_L - e_L^2\Delta\theta/2 \end{array}$$

A standard result is that when the constraints IR(L) and IC(H) are binding, IC(L) and IR(H) are not binding (the proof is standard and hence omitted). The principal's problem with the binding constraints IR(L) and IC(H) is to choose e_L and e_H to maximize

$$V - \bar{\theta} + q\left[\theta_H e_H - \frac{e_H^2}{2} - R\frac{e_L^2}{2}\right] + (1-q)\left[\theta_L e_L - \frac{e_L^2}{2}\right]$$

The solution to this problem and the principal's utility are:

$$\begin{array}{ll} e_L^{NM} = \dfrac{(1-q)\theta_L}{(1-q)+qR} & \qquad e_H^{NM} = \theta_H \\ t_L^{NM} = \dfrac{e_L^2}{2} & \qquad t_H^{NM} = \dfrac{e_H^2}{2} + R\dfrac{e_L^2}{2} \end{array}$$

$$EU_P^{NM} = V - \bar{\theta} + q\frac{\theta_H^2}{2} + \frac{(1-q)^2\theta_L^2}{2\left[(1-q)+qR\right]} \tag{2}$$

where the superscript NM stands for no-monitor. In order to elicit high effort from the high-productivity agent (who has incentives to claim that she is inefficient), the principal pays her an information rent. Eliciting lower effort from the low-productivity agent reduces this rent, which depends on the high-productivity agent's gains from misreporting.

To avoid paying rents, the principal may offer a No-Rent contract to be accepted only by the high-productivity agent: $t = \theta_H^2/2$ if the observed production cost is $C_H = \bar{\theta} - \theta_H^2$, and nothing otherwise. The principal's utility is $EU_P^{NR} = q\left\{V - \bar{\theta} + \theta_H^2/2\right\}$. We assume that the principal prefers to hire both types of agents (it is sufficient to assume a high V).

3 Optimal Contract with a Monitor

The monitor's signal adds information about the agent's type that can be used in the main contract. We solve for the contract with a supervisor or an auditor separately, and show the conditions such that the principal chooses either of them.[7]

3.1 Contract with a Supervisor

The supervisor reports her signal ($r = \sigma$) to the principal before the agent exerts effort. The principal can use this report to contract agent's effort and wage. Let agent's effort be e_{jr} and her compensation be t_{jr} when the agent reports $\hat{\theta} \in \{\theta_L, \theta_H\}$ and the monitor reports $r \in \{0, L, H\}$ in a direct mechanism. The relevant constraints for a feasible contract are

$$\begin{array}{ll} \text{IR(jr)}: & t_{jr} \geq e_{jr}^2/2 \\ \text{IC(Hr)}: & t_{Hr} - e_{Hr}^2/2 \geq t_{Lr} - e_{Lr}^2 \Delta\theta/2 \end{array} \quad \text{for } j \in \{L, H\},\ r \in \{0, L, H\}$$

Let π_{jr} denote the probability of occurrence of each state, where $j \in \{L, H\}$ and $r \in \{0, L, H\}$.[8] Given that the supervisor reports to the principal honestly, the latter can set $w_{jr} = 0$.[9] As in the case without monitor, if constraints IR(Lr) and IC(Hr) are binding, the other constraints are non-binding. The principal's problem with the binding constraints is to choose $\{e_{jr}\}$ to maximize

$$V - \bar{\theta} + \sum_{r \in \{0,L,H\}} \pi_{Hr} \left\{ \theta_H e_{Hr} - \frac{e_{Hr}^2}{2} - R\frac{e_{Lr}^2}{2} \right\} + \sum_{r \in \{0,L,H\}} \pi_{Lr} \left\{ \theta_L e_{Lr} - \frac{e_{Lr}^2}{2} \right\}$$

The optimal effort and compensation are:

$$\begin{array}{ll} e_{H0} = e_{HL} = e_{HH} = \theta_H & e_{L0} = \dfrac{(1-q)\theta_L}{(1-q) + qR} \\ e_{LL} = \dfrac{(1-q)\alpha\theta_L}{(1-q)\alpha + q(1-\alpha)R} & e_{LH} = \dfrac{(1-q)(1-\alpha)\theta_L}{(1-q)(1-\alpha) + q\alpha R} \end{array} \tag{3}$$

[7] The optimal contract for a given monitoring stage has been analyzed elsewhere and we compute it with the assumptions made in this paper. We acknowledge the original author in each case.

[8] There are six states whose probabilities are $\pi_{L0} = (1-q)(1-p)$, $\pi_{LL} = (1-q)p\alpha$, $\pi_{LH} = (1-q)p(1-\alpha)$, $\pi_{H0} = q(1-p)$, $\pi_{HL} = qp(1-\alpha)$, and $\pi_{HH} = qp\alpha$. We will use this simplification throughout the paper.

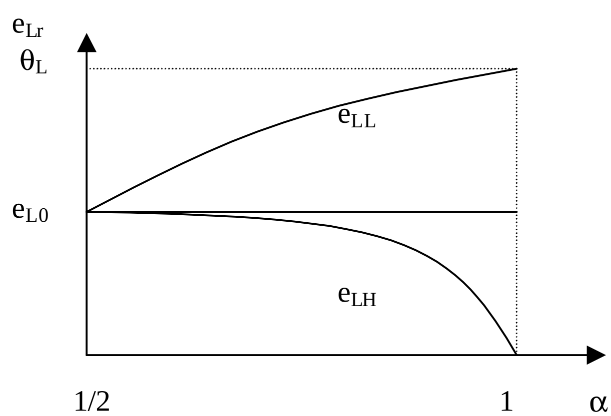
[9] When there are no incentive problems between the principal and the supervisor, the former only compensates the supervisor for the search costs.

$$t_{Lr} = \frac{e_{Lr}^2}{2}, \quad t_{Hr} = \frac{\theta_H^2}{2} + R\frac{e_{Lr}^2}{2}, \qquad w_{jr} = 0, \qquad j \in \{L, H\} \text{ and } r \in \{0, L, H\} \qquad (4)$$

The next Proposition summarizes this result (see Tirole [14]).[10]

Proposition 1 *The optimal contract when the principal hires an honest supervisor satisfies (3)-(4). The supervisor is hired always.*

Figure 1: **Effort as a Function of Supervisor's Signal Accuracy** (α)



We can observe the benefits of flexibility in contracting from equations (3)-(4) and Figure 1. The principal pays only the effort cost to the type-θ_L agent for any monitor's report, but cannot eliminate the rents to the type-θ_H agent. Let the agent's rents in state Hr be $R_{Hr} = Re_{Lr}^2/2$. The optimal contract is such that $e_{LL} > e_{L0} > e_{LH}$ and $R_{HL} > R_{H0} > R_{HH}$. By obtaining the signal before the agent exerts effort, the principal finds it profitable to create higher distortions in the low-probability state LH (she reduces e_{LH}) when the signal is more accurate, which allows her to pay lower rents R_{HH} in the high-probability state HH. Also, the principal reduces distortions in the high-probability state LL (she increases e_{LL}) when the signal is more accurate, which leads to higher rents R_{HL} in the low-probability state HL. In the limiting case of perfectly informative signal ($\alpha = 1$), the high inefficiencies and rents are ex ante costless (states LH and HL have probability 0).

[10]If the cost of supervising is positive, the contract should be corrected to internalize this cost. The results in Proposition 1 still hold, provided that the supervisor is hired.

3.2 Contract with an Auditor

By the time the principal sends the auditor to obtain information about the agent's type, the agent has already exerted effort and the outcome realized. Hence, the principal can use the auditor's report only to adjust compensations to the agent. From the Revelation Principle, the principal can relate a low production cost (or high output) to a type-θ_H agent. In this case there is no need to perform an audit, and the agent is paid t_h. When the production cost is high (or output is low), the principal cannot infer whether this is because the type-θ_L agent has exerted the right effort or the type-θ_H agent has shirked (the agent is paid t_l). In this case the principal sends the auditor (with probability $\delta \in [0,1]$) and penalizes the agent when the auditor's report does not match with the agent's type report. We include an uncertainty component in the punishment stage reflecting the possibility that such punishment may not be enforced (for instance, by the courts). Therefore, the fines are z^0 if $r = 0$ and z^H if $r = H$, which can be imposed with probability $\phi \in [0,1]$. Using these results, the agent's participation and incentive constraints are

$$
\begin{array}{ll}
\text{IR(L)}: & t_l - \delta\left[(1-p)\phi z^0 + p(1-\alpha)\phi z^H\right] \geq e_l^2/2 \\
\text{IC(L)}: & t_l - \delta\left[(1-p)\phi z^0 + p(1-\alpha)\phi z^H\right] - e_l^2/2 \geq t_h - e_h^2/2\Delta\theta \\
\text{IR(H)}: & t_h \geq e_h^2/2 \\
\text{IC(H)}: & t_h - e_h^2/2 \geq t_l - \delta\left[(1-p)\phi z^0 + p\alpha\phi z^H\right] - e_l^2\Delta\theta/2
\end{array}
\tag{5}
$$

The principal pays $w^r = 0$ to the auditor for any report (since there is no incentive problem), and sends him whenever the production cost is high (i.e., she sets $\delta = 1$). Let - $_{ep}$ $= \{e_h, e_l, t_h, t_l, z^0, z^H\}$ be the set of choice variables. The principal's problem is to choose - $_{ep}$ to maximize

$$
V - \bar{\theta} + q\{\theta_H e_h - t_h\} + (1-q)\left\{\theta_L e_l - t_l + \left[(1-p)\phi z^0 + p(1-\alpha)\phi z^H\right]\right\} \tag{6}
$$

subject to constraints (5) and the limited liability constraints $z^r \leq z$ for $r \in \{0, H\}$. Let α_1^* denote the value of α such that IR(H) is non-binding for $\alpha < \alpha_1^*$, and α_2^* the value of α such that IC(H) is non-binding for $\alpha > \alpha_2^*$ (from equations (11) and (12) in the Appendix, respectively), where

$$
\alpha_1^* = \frac{1}{2} + \frac{(1-q)^2\theta_L^2 R}{4p\phi z\left[(1-q) + qR\right]^2} \qquad\qquad \alpha_2^* = \frac{1}{2} + \frac{\theta_L^2 R}{2p\phi z}
$$

The optimal effort and compensation are (this is a simplified version of Baron and Besanko [2]):

$$
\begin{array}{llll}
 & \alpha < \alpha_1^* & \alpha_1^* \le \alpha \le \alpha_2^* & \alpha_2^* < \alpha \\
e_l: & \dfrac{(1-q)\theta_L}{(1-q)+qR} & \sqrt{\dfrac{2p(2\alpha-1)\phi z}{R}} & \theta_L \\
t_h: & \dfrac{\theta_H^2}{2}+\dfrac{e_l^2 R}{2}-p(2\alpha-1)\phi z & \dfrac{\theta_H^2}{2} & \dfrac{\theta_H^2}{2}
\end{array} \tag{7}
$$

$$
e_h=\theta_H, \qquad t_l=\frac{e_l^2}{2}+(1-p\alpha)\phi z, \qquad z^0=z^H=z, \qquad w^0=w^L=w^H=0 \tag{8}
$$

The next Proposition summarizes the optimal contract.

Proposition 2 *The optimal contract when the principal hires an honest auditor satisfies (7)-(8). The auditor is hired always.*

Proof: See Appendix.

This contract displays some rigidity compared with the contract with a supervisor since the agent's effort is not affected directly by the auditor's report. This report is used to punish the agent (which affects the agent's net compensation) when the principal obtains no favorable information about the agent's type. In particular, for a given informativeness α of the monitor's signal, and a given uncertainty ϕ about the enforceability of the punishment, the threat of punishment is enough to deter the type-θ_H agent from misreporting when the liability bound is high enough, and the principal achieves first-best utility.[11] This result is summarized in the next Corollary.

Corollary 1 *For any degree informativeness of the signal α and any level ϕ of uncertainty of the enforceability of punishment, the principal achieves first-best utility when the punishment bound z is sufficiently high.*

Proof: Fix a value of α and some $\phi > 0$. The principal achieves first-best utility if $\alpha > \alpha_2^*$, which is satisfied when $z > z_B$, and $z_B = \theta_L^2 R/p\phi(2\alpha-1)$. *Q.E.D.*

Conversely, the agent receives some positive rent (and as a consequence the principal's utility is lower than the first-best one) if there is enough uncertainty. For any given accuracy of the signal α, this holds if $\alpha_1^* > 1$, i.e., $\phi < \min\{1, (1-q)^2\theta_L^2 R/2pz\,[(1-q)+qR]^2\}$.

[11] Note, however, that the principal punishes the type-θ_L agent in equilibrium. When the type-θ_H agent reports truthfully, she is not audited (see Kofman and Lawarrée [8]). This result of punishment in equilibrium is common in the literature on collusion under uncertainty (see, for example, Green and Porter [7]), in which the colluding parties use a self-policing instrument that triggers when a bad outcome occurs (which can be caused by nature or by other party's deviation).

4 Optimal Timing

In this section we discuss the principal's monitoring timing decision with an honest monitor. When the principal hires a supervisor, she finds profitable to distort allocations and minimize the agent's expected rents depending on the supervisor's signal. On the other hand, the auditor's signal cannot be used to modify allocations, but can be used to punish the agent.

Not surprisingly, the information of an auditor is very useful to the principal when the latter can punish the agent strongly and the punishment can be enforced (i.e., high z and ϕ). As we show in the Appendix (Proof of Theorem 1), there exists a minimum liability bound $\bar{z}$ such that an auditor is optimal for $z > \bar{z}$ for any degree of informativeness of his signal.[12]

However, when the punishment cannot be perfectly enforced (for instance, when there is long delay in expedition by the courts, in whose case ϕ means the discount value of a future punishment, or when there is uncertainty about the courts' decisions, in whose case ϕ is the probability of a favorable decision by the courts), a supervisor may be optimal even under very strong punishment (in particular, $\bar{z}$ decreases in ϕ).

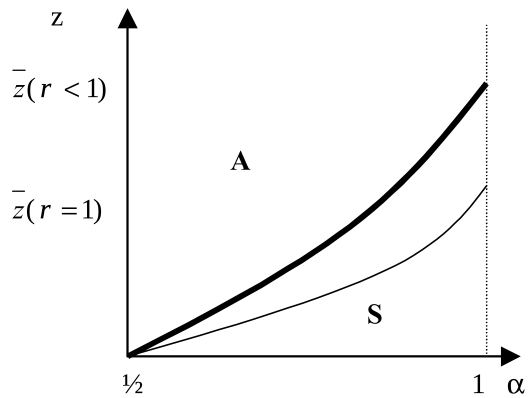
For a given punishment instrument $z < \bar{z}$, the principal hires the monitor to supervise the agent when his signal is informative of the agent's type, and to audit the agent when his signal is noisy (See Figure 2). This is so because the type-θ_H agent's rents are reduced when the supervisor observes a "correct" signal (that is, $\sigma = H$, which is more probable when α is high), while the type-θ_L agent is punished when the auditor obtains a "wrong" signal (that is, $\sigma \in \{0, H\}$, which is more probable when α is low). The next Theorem emphasizes the importance of monitoring timing.

Theorem 1 *Suppose that the principal hires an honest monitor.*
• *Auditing is optimal when the principal's punishment instrument is strong (z is relatively high) and it can be enforced (ϕ is high), or when punishment is weak or difficult to enforce (i.e., z low or ϕ low) as long as the monitor's signal of the agent's type is noisy (low α).*
• *Supervising is optimal when the punishment instrument is weak (low z) or difficult to enforce (low ϕ) as long as the monitor's signal is informative (high α).*

Proof: See Appendix.

[12] In a paper on Law enforcement, Shavell [13] shows that the availability of harm-based sanctions is an important determinant of the (ex post) legal intervention stage.

Figure 2: **Optimal Monitoring Timing**



Suppose now that principal is constrained to monitor the agent's type (because, say, it is too costly to monitor effort), so that the problem is when to obtain information that is available at the outset. Another interpretation of Theorem 1 is that *the principal can strategically delay the gathering of relevant information*. In particular, this is so when the punishment instrument is sufficient to deter the agent, so that the deterrent effect offsets the benefits of flexibility cum uncertainty in punishment enforcement.

Next, we present the principal's response to changes in the environment. Assume that the liability bound z is such that $z < \bar{z}$, so that there exists a cut-off $\alpha^C \in (1/2, 1]$ of the monitor's signal informativeness for which a supervisor is optimal when $\alpha > \alpha^C$ and an auditor is optimal otherwise. Then, we have the following

Result 1 *Consider as reference the informativeness of the monitor's signal α.*
- *The cut-off α^C increases in z. Auditing is optimal for a broader region of the informativeness of the monitor's signal as the liability bound increases.*
- *The cut-off α^C decreases in ϕ. Suervising is optimal for a broader region of the informativeness of the monitor's signal as the punishment is more difficult to enforce.*
- *The cut-off α^C decreases in R. The region of optimality of a supervisor expands out as the adverse selection problem is more severe.*[13]

Proof: See Appendix.

[13]This result applies to the case in which the agent still earns some rent when audited (i.e., parameters are such $\alpha_1^* \geq 1$ in equation (7)), and for $q \leq 1/(1+R)$.

The first two results are a direct implication of Theorem 1. The third result is a consequence of the way the principal designs the contract. The supervisor's signal is useful to reduce the agent's rent in the more probable state ($R_{HH} < R_{H0}$). The auditor's signal is only useful to punish the agent (whose rents are the rents under the No-Monitor contract net of the expected punishment, see t_h in (7)). When the type distribution is more disperse, which implies a more severe adverse selection problem (captured by a higher R), the first contract is more suitable to control the agent's rent. For a given α, ϕ and z, the decrease in the principal's utility with a supervisor is lower than that in the utility with an auditor, and the intersection occurs at a lower α. Therefore, the region of optimality of a supervisor expands out.

5 Applications

5.1 Organization of the Firm

From our discussion in the previous sections, we conclude that auditing is optimal when the punishment instrument is strong. Instead, a supervisor is optimal when his information is very informative about the agent's type and a punishment instrument (to be used if an auditor is hired) is weak or difficult to enforce.

These results are consistent with typical organizational structures, in which low-level workers (typically with lower incomes or protected by minimum wages) are supervised during production stage, while top-level managers (such as CEOs or top-level managers, who typically are able to respond to fines up to some level) are exposed to audits. Moreover, screening is a better instrument when the court's response to complaints is lenghty or very uncertain.

5.2 Regulation

The literature on regulation and information (Laffont and Tirole [11] and others) has studied ex ante and ex post regulation separately (which provides the building blocks for this paper). The theoretical framework in this paper nests both stages of regulations.

The Law and Economics literature (see Shavell [13], Kolstad *et al.* [9]) has studied the optimal regulatory stage of activities that generate externalities with a benevolent regulator. In this paper, we provide a conceptual agency-based framework to explain the implications of regulatory timing on the society welfare. Consider, for example, the case of a hazardous activity with "disastrous" consequences. From Section 3.1 (in which we add incentives), and in accordance with the standard recommendation, the government should put all the efforts in ex ante regulation whenever the liability faced by the injurer is low (as it is the case when the bad outcome involves irremediable consequences).[14] Ex post regulation is recommended when the injurer can be strongly punished.

6 Conclusion

In this paper we study the case of one-time monitoring in hierarchies. We provide insights on the optimality to the principal of using monitoring timing as a choice variable. Previous literature on the principal-agent model has analyzed both monitoring cases separately, while the literature on Law and Economics has studied the timing of legal intervention. We show that the principal faces a trade-off in the monitoring decision (an early report provides some flexibility in contracting, while a later report can be used to punish the agent), and provide the solution to this trade-off. An auditor is optimal when the principal can expose the agent to severe fines. When the punishment is weak or difficult to enforce, the timing choice depends on the monitor's signal accuracy. In this case, the principal chooses a supervisor when his signal is informative of the agent's type, and an auditor otherwise.

The literature on collusion (Tirole [14, 15], Baliga [1], Faure Grimaud *et al.* [6]) analyzes the effects of collusion on the principal's contract design. In a work in progress, we analyze the monitoring timing under different collusion environments, related to de degree of information manipulation, such as hard but non-forgeable information, hard and forgeable information or soft information (see Cont [5]).

In this paper we assume that the principal has to decide between ex ante or ex post monitoring. However, when the principal has access to both monitors who are not related and do not share information, there is no reason for the principal not to choose both monitors if gathering information is costless.[15] An interesting extension is to consider that the principal may want to hire both monitors, and allow for costly collection of

[14]For example, Cohen [4], pp. 45-46, shows estimates of very low penalties compared to the environmental damage done by oil spills.

[15]There has been some progress along these lines (with a benevolent regulatory agency). For example, Kolstad *et al.* [9] show that ex ante and ex post regulation may be complements depending on the injurer's uncertainty of his potential liability.

signals, or information sharing and collusion between monitors (in the same lines as those mentioned in the previous paragraph). Under these circumstances, the principal may find optimal to discard one of the monitors.

There is a more general question of strategic timing. In our framework, the principal optimally chooses to delay the monitoring to later stages when she hires an auditor (in particular, when effort monitoring is not available). This result is a case of strategic timing, since under some circumstances the principal delays the gathering of relevant information that is available in the beginning of the game. Along these lines, there is a broader question that has to do with strategic contracting. Theoretical models assume that grand contracts are designed at the beginning of a general game. By constraining the set of decisions at some period of the game, the parties may get some benefit at later stages. For example, in a paper on collusion and delegation, Laffont and Martimort [10] show that a principal finds profitable to delegate to the supervisor the direct contracting with an agent.

Finally, a new line of research is under project. The intuition in this paper extends to the stage of control (if necessary) of competing firms, where regulation (interpreted as ex ante control) and competition policy (which triggers after some incorrect behavior is detected) interact with each other. This discussion has gained room in situatuins (such as Internet), where there are many providers (multiple agents), it involves many countries (multiple principals) and many regulators. For example, ex post control (competition policy) may be optimal when it is difficult to coordinate or organize interaction among the agents (see Laffont and Tirole [12]).

Appendix

Proof of Proposition 2: When the principal hires a benevolent auditor, she pays $w^r = 0$ for $r \in \{0, L, H\}$. Constraint IC(L) is non-binding when the others are satisfied. The Lagrangean to problem (6) is

$$\begin{aligned}
\mathcal{L} &= V - \bar{\theta} + q\{\theta_H e_h - t_h\} + (1-q)\left\{\theta_L e_l - t_l + \left[(1-p)\phi z^0 + p(1-\alpha)\phi z^H\right]\right\} \\
&+ \lambda_1\left\{t_l - \left[(1-p)\phi z^0 + p(1-\alpha)\phi z^H\right] - \frac{e_l^2}{2}\right\} + \lambda_2\left\{t_h - \frac{e_h^2}{2}\right\} \\
&+ \lambda_3\left\{t_h - \frac{e_h^2}{2} - t_l + \left[(1-p)\phi z^0 + p\alpha\phi z^H\right] + \frac{e_l^2\Delta\theta}{2}\right\}
\end{aligned}$$

The Kuhn-Tucker conditions are

$$\begin{array}{lll}
\mathcal{L}_{e_h} = q\theta_H - (\lambda_2 + \lambda_3)\, e_h \leq 0, & e_h \geq 0, & \mathcal{L}_{e_h} e_h = 0 \\
\mathcal{L}_{e_l} = (1-q)\theta_L - (\lambda_1 - \lambda_3\Delta\theta)\, e_l \leq 0, & e_l \geq 0, & \mathcal{L}_{e_l} e_l = 0 \\
\mathcal{L}_{t_h} = -q + \lambda_2 + \lambda_3 \leq 0, & t_h \geq 0, & \mathcal{L}_{t_h} t_h = 0 \\
\mathcal{L}_{t_l} = -(1-q) + \lambda_1 - \lambda_3 \leq 0, & t_l \geq 0, & \mathcal{L}_{t_l} t_l = 0
\end{array}$$

$$\begin{aligned}
\mathcal{L}_{z^0} &= (1-q) - \lambda_1 + \lambda_3 = 0;\ \text{if } \mathcal{L}_{z^0} < 0,\ z^0 = 0;\ \text{if } \mathcal{L}_{z^0} > 0,\ z^0 = z \\
\mathcal{L}_{z^H} &= (1-q)(1-\alpha) - \lambda_1(1-\alpha) + \lambda_3\alpha = 0 \\
&\quad \text{if } \mathcal{L}_{z^H} < 0,\ z^H = 0;\ \text{if } \mathcal{L}_{z^H} > 0,\ z^H = z
\end{aligned}$$

together with the participation and incentive compatibility constraints. The solution involves positive e_l and e_h. From the participation constraints, t_l and t_h are both positive. Then $\mathcal{L}_{e_h} = \mathcal{L}_{t_h} = 0$, which implies that the type-θ_H agent exerts first-best effort $e_h = \theta_H$. Also, $\mathcal{L}_{e_l} = \mathcal{L}_{t_l} = 0$ and

$$(1-q)\theta_L = [\lambda_1 - \lambda_3\Delta\theta]\, e_l \tag{9}$$

$$(1-q) = \lambda_1 - \lambda_3 \tag{10}$$

Using (10), $\mathcal{L}_{z^0} = 0$ and hence $z^0 = z$ without loss of generality. Also, $\mathcal{L}_{z^H} = \lambda_3(2\alpha - 1) \geq 0$ and then $z^H = z$. This is a maximum deterrence result (see Baron and Besanko [2]).

Next we consider the three possible cases for the relationship between IC(H) and IR(H) (from (5)): either of them or both of them are binding.

<u>Case 1:</u> $\lambda_2 = 0$ and $\lambda_3 = q$. IR(H) is non-binding and IC(H) is binding. Using equations (9) and (10), $e_l = (1-q)\theta_L / [(1-q) + qR]$. Using the IR and IC constraints,

$t_l = e_l^2/2 + (1-p\alpha)\phi z$, $t_h = \theta_H^2/2 + e_l^2 R/2 - p(2\alpha-1)\phi z$. This is the solution if IR(H) is non-binding (i.e., $e_l^2 R/2 > p(2\alpha-1)\phi z$), which is satisfied for $\alpha < \alpha_1^*$, where

$$\alpha_1^* = \frac{1}{2} + \frac{(1-q)^2\theta_L^2 R}{4p\phi z\left[(1-q)+qR\right]^2} \tag{11}$$

<u>Case 2:</u> $\lambda_2 = q$ and $\lambda_3 = 0$. IR(H) is binding and IC(H) is non-binding. Using (10) in (9) we have $e_l = \theta_L$. From the IC and IR constraints, $t_l = \theta_L^2/2 + (1-p\alpha)\phi z$, $t_h = \theta_H^2/2$, and IC(H) must hold as inequality (i.e., $\theta_L^2 R/2 < p(2\alpha-1)\phi z$), which is satisfied for $\alpha > \alpha_2^*$, where

$$\alpha_2^* = \frac{1}{2} + \frac{\theta_L^2 R}{2p\phi z} \tag{12}$$

<u>Case 3:</u> Both λ_2 and λ_3 are non-negative (and both less than or equal to q). Using IR and IC constraints, the type-θ_H agent's rent must be zero, i.e., $e_l^2 R/2 = p(2\alpha-1)\phi z$. Hence, $e_l = \sqrt{2p(2\alpha-1)\phi z/R}$. Using equations (9) and (10), $\lambda_3 = (1-q)\left(\theta_L/e_l - 1\right)/R$. The agent compensation is $t_l = e_l^2/2 + (1-p\alpha)\phi z$ and $t_h = \theta_H^2/2$.

The Lagrangean is concave since it is linear in compensations and punishments, there are no cross terms among them and efforts, and the second derivative with respect to effort is negative. The summary of effort and compensations is presented in equations (7)-(8). *Q.E.D.*

Proof of Theorem 1: Define $U_H = V - \bar{\theta} + q\frac{\theta_H^2}{2}$. The principal's utility with a supervisor is

$$EU_P(S) = U_H + \frac{(1-q)^2\theta_L^2}{2}\left\{\frac{p\alpha^2}{(1-q)\alpha + q(1-\alpha)R} + \frac{p(1-\alpha)^2}{(1-q)(1-\alpha)+q\alpha R} + \frac{1-p}{(1-q)+qR}\right\} \tag{13}$$

$EU_P(S)$ is increasing and convex in α. The principal's utility with an auditor is

$$EU_P(A) = \begin{cases} U_H + \dfrac{(1-q)^2\theta_L^2}{2\left[(1-q)+qR\right]} + qp(2\alpha-1)\phi z = EU_P^{NM} + qp(2\alpha-1)\phi z & \text{if } \alpha < \alpha_1^* \\ U_H + (1-q)\left\{\sqrt{\dfrac{2p(2\alpha-1)\phi z}{R}}\theta_L - \dfrac{p(2\alpha-1)\phi z}{R}\right\} & \text{if } \alpha_1^* \le \alpha \le \alpha_2^* \\ EU_P^{FB} & \text{if } \alpha > \alpha_2^* \end{cases} \tag{14}$$

where α_1^* is from (11), α_2^* is from (12), EU_P^{NM} is equation (2) and EU_P^{FB} is equation (1). The first part of this utility function is increasing and linear in α, the second part is concave and the last part is constant. By construction, the principal's utility is continuous in all parameters.

If $z = 0$, $EU_P(A) = EU_P^{NM}$, while $EU_P(S) > EU_P^{NM}$. On the other hand, when z is very high and ϕ is positive, $EU_P(A) > EU_P(S)$ for all α. So, for intermediate values of z and positive ϕ, $EU_P(S)$ intersects $EU_P(A)$ at some cut-off value α^C such that $EU_P(A) > EU_P(S)$ for $\alpha < \alpha^C$, and $EU_P(A) < EU_P(S)$ for $\alpha > \alpha^C$. This intersection must happen when effort is distorted or the agent receives some positive rent when audited (that is, cases 1 or 2 in the Proof of Proposition 2).

When the intersection exists, if z increases given ϕ and α, $EU_P(A)$ increases (until it reaches EU_P^{FB}) while $EU_P(S)$ remains the same. Therefore the cut-off α^C increases in z (implying that auditing is optimal for a broader range of the signal informativeness $(1/2, \alpha^C])$.[16] In particular, there exists a critical liability bound $\bar{z}$ (which corresponds to the punishment z for which $\alpha^C = 1$) such that $EU_P(A) > EU_P(S)$ for all α when $z > \bar{z}$. Note that this critical bound is higher when the uncertainty of the punishment enforcement is higher (i.e., $\bar{z}$ decreases in ϕ). On the other hand, when the intersection exists, if ϕ decreases given z and α, $EU_P(A)$ decreases (until it reaches EU_P^{NM}) while $EU_P(S)$ remains the same. Therefore the cut-off α^C decreases in ϕ (implying that supervising is optimal for a broader range of the signal informativeness $(\alpha^C, 1])$. *Q.E.D.*

Proof of Result 1: The region of optimality of a supervisor expands out as adverse selection is more severe (i.e., R increases, caused by an increase in θ_H). The proof is done assuming that parameters are such that $\alpha_1^* \geq 1$ (from equation (11)) and $q \leq 1/(1+R)$. We show that $EU_P^{NC}(S)$ decreases less than $EU_P^{NC}(A)$ does as R increases. When this is the case, the new cut-off α^C corresponds to a lower value of α (keeping all the other parameters fixed). From equations (13) and (14), eliminate the common parts U_H and $(1-q)^2\theta_L^2/2$ to get that

$$\frac{\partial}{\partial R}\left(\frac{p\alpha^2}{(1-q)\alpha + q(1-\alpha)R} + \frac{p(1-\alpha)^2}{(1-q)(1-\alpha)+q\alpha R} + \frac{1-p}{(1-q)+qR}\right) > \frac{\partial}{\partial R}\left(\frac{1}{[(1-q)+qR]}\right) \quad (15)$$

which, after several steps (omitted for convenience), simplifies to

$$\begin{aligned}&\alpha(1-\alpha)\left\{\left[2\left(\alpha^2+(1-\alpha)^2\right) - 4\alpha(1-\alpha)\right](1-q)^3 + \left[\alpha(1-\alpha) - \alpha^3 - (1-\alpha)^3\right]q^3R^3\right\} \\ &+ \left[\alpha^4 + (1-\alpha)^4 + 2\alpha^2(1-\alpha)^2 - \alpha(1-\alpha)\right](1-q)^2 qR > 0\end{aligned}$$

The first term is positive, the second term is non-negative and the third term is non-positive. But note that $(1-q)^2q^2 \geq q^3R^3$ and $(1-q)^3 \geq q^3R^3$ when $q \leq 1/(1+R)$, and

[16] We prove this straight result assuming that the intersection exists. The more general result is that the cut-off α^C is non-decreasing in z, which corresponds to including the case of no intersection. This generalization holds throughout the proof.

that the sum of all brackets simplifies to $1 - 4\alpha + 4\alpha^2 > 0$, for $\alpha > 1/2$. Hence, inequality (15) is satisfied. *Q.E.D.*

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