Delegation to Encourage Communication of Problems [1]

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Abstract

We consider a principal-agent model where the principal and agent have conflicting preferences about the best response to an unknown state of the world. We study how those different preferences affect the principal's choice to centralize or delegate decisions when delegation can be used to encourage the agent to communicate problems. We demonstrate that the principal may choose centralization for two reasons: (i) to exercise better control over the agent's actions when the agent finds it optimal to send an inquiry, and (ii) to dissuade the agent from sending an inquiry altogether when, by doing so, she provides a stronger incentive for the agent to exert high effort to learn the true state. Delegation emerges in equilibrium only if the costs of effort to acquire information for both the principal and the agent are sufficiently high and occurs less often as the principal's and agent's preferences become better aligned. Further, the agent's information acquisition effort under delegation is always lower than under centralization.

1 Introduction

Following the collapse of Enron in 2001, the financial press reported that disagreements had arisen among partners of Arthur Andersen, Enron's auditor, regarding the appropriate accounting treatment of certain Enron transactions.[1] In particular, partners in Andersen's Professional Standards Group (PSG), financial reporting experts within the firm, questioned whether certain Enron deals had economic substance. However, whereas the PSG was once the final accounting authority in Andersen, in the Enron case the PSG's recommendations were apparently overridden by the partner-in-charge of the Enron audit. Thus, the PSG's once firm-wide authority over accounting interpretations had apparently been delegated to local partners.[2]

In this paper, we consider in a principal-agent framework when such delegation of authority is desirable, particularly when the incentives of the principal and the agent are not aligned. For example, in the case of a large audit partnership, individual audit partners typically have a small portfolio of audits out of thousands of the partnership's clients. Incentives of individual partners to retain their clients may be quite different from the incentives of the firm as a whole.[3] Further, local agents may be informationally advantaged. Continuing the Arthur Andersen analogy, while the PSG might or might not be authorized to have the final word in an accounting

[1] See, for example, McRoberts (2002).

[2] Byrne (2002) states: "An Andersen practice director in Houston ... overruled Bass [the PSG partner for Enron], who continued to object to other accounting transactions over the next couple of months. Andersen was the only one of the Big Five where a local partner could overrule the Professional Standards Group." McNamee *et al.* (2002) state: "... members of Andersen's PSG objected strongly to the Houston energy trader's accounting. Andersen's Enron audit team ... overruled those concerns on at least four occasions, siding instead with Enron on controversial accounting that hid debt and pumped up earnings." See also Morton (2002), Behr and Hilzenrath (2002), and Hamburger *et al.* (2002). For an alternative view of these events, see Morrison (2004). In an internal Arthur Andersen memo included as an exhibit in the U.S. Senate hearings on the role of the Board of Directors in Enron's Collapse, Bass wrote: "The PSG only gives advice. The engagement partners and practice directors then reach a decision based on that advice as well as other considerations ..." (U.S. Senate 2002, p. 584).

[3] For example, Kaplan (2004, p. 366) states: "While the major accounting firms have thousands of clients, individual audit partners usually have only a dozen major clients, often fewer. In that circumstance, the partner in charge of the audit is almost desperate to keep *all* of the clients in his/her stable. Losing one client over accounting irregularities would be very bad indeed; losing two would constitute professional suicide. In other words, it matters little that the accounting firm is huge with hundreds of large clients. The individual audit partner has only a few. As a consequence, at the level where the most important decisions are made regarding financial statement disclosures, the balance of power lies with the client."

dispute, such authority is moot if no inquiry about a controversial issue is forwarded to the group by a local partner. Thus, one rationale for delegation of decision authority is to encourage inquiries regarding questionable issues.

Situations where the principal and the agent disagree over the appropriate action occur routinely in various organizational settings. A plant manager may disagree with the chief operations officer over acceptable levels of product defects. A division manager may disagree with a CEO over transfer pricing policies (Kirkpatrick, 2001). A faculty member may disagree with a department chair over appropriate course content. In each of these cases the principal, by lack of proximity to the problem, may not learn of the issue if the agent believes the principal will require an action that is detrimental to the agent's interests. While, for concreteness, we frame much of our discussion in terms of an auditing organization and the relationship between the firm and a local audit partner, the issues we consider here are generic to most organizations where managers have local knowledge of problems.

The purposes of this study are to (i) characterize situations where it is optimal for the principal to delegate decision authority to the agent, (ii) investigate the effect that exogenous changes in the principal's and the agent's payoffs — e.g., resulting from regulatory or legislative initiatives — have on the actions taken by the principal and the agent and, (iii) characterize how exogenous payoff changes affect the risk of a catastrophic outcome for the firm. The answer to the first question permits us to develop a better understanding of the determinants of organizational structure, i.e., why one firm delegates authority while another centralizes. The answers to the second and third questions have implications for both managers and policymakers.

We present a one-period model of a principal-agent relationship where both the principal and the agent can acquire information about the state of the world and the agent is hired to take an action on behalf of the principal. The agent can exert costly effort to learn the true state of the world. If he fails to discover the state, he can send an inquiry to the principal who then can exert (additional) costly effort to learn the state of the world.

For convenience, we assume that the principal and the agent agree on the appropriate action if the state is known. However, if the true state is unknown, the principal's preferred action may be different from the agent's. In other words, the principal and the agent have different preferences over Type I and Type II errors. Knowing this, the agent, when uninformed, may decide not to send an inquiry (i.e., not to report a problem) if the principal is unlikely to discover the true state of the world and select a correct action.

The principal, in anticipation of the possibility of no inquiry, can provide an incentive for the agent to send an inquiry whenever the agent is uninformed by allowing the agent to ignore the principal's recommendation if the principal herself fails to learn the true state. Following the tradition established in the literature, we label this organizational arrangement *delegation*. Alternatively, the principal can choose *centralization* — an arrangement where her opinion, if issued, is always binding.

Our main result demonstrates that the principal may choose centralization for two distinct reasons: (i) to exercise better control over the agent's actions when the agent finds it optimal to send an inquiry, and (ii) to dissuade the agent from sending an inquiry altogether when, by doing so, the principal provides a stronger incentive for the agent to exert high effort.

Delegation of the sort that we study emerges in equilibrium only if the costs of effort to learn the true state for both the principal and the agent are sufficiently high, i.e., if they both are relatively unlikely to learn the state. We show that an exogenous (e.g., as a result of a legislative action) increase in the agent's penalty for failing to take a corrective action when such action is appropriate can lead to an increase in catastrophic risk for the principal, where catastrophes can be thought of as major audit failures or product failures.

The remainder of the paper is organized as follows. Prior work is discussed in the following section. The model is presented and the agent's problem is solved in Section 3. The solution to the principal's problem is derived and the main result is presented in Section 4. Section 5 investigates the effect of exogenous changes to the principal's and the agent's payoffs on catastrophic risk. Section 6 concludes.

2 Prior Work

A standard result in the principal-agent literature is that, if the Revelation Principle applies, complete centralization is always weakly preferred to any other organizational arrangement (see Myerson 1982). In order to study delegation, one thus has to dispense with one (or more) of the assumptions underlying the Revelation Principle. An incomplete contracting approach, which eliminates complete revelation, is the approach most commonly taken in the delegation literature. One strand of this literature assumes that contracts, while limited by constraints on communication or contract complexity, are relatively rich in the sense that some outcome- or message-contingent arrangements are feasible.[4] This strand includes Demski and Sappington (1987), Melumad and Reichelstein (1987), Melumad, Mookherjee and Reichelstein (1992), and Melumad, Mookherjee and Reichelstein (1997). A central theme of several of these papers is identification of conditions such that delegation performs as well as the best message-dependent contract under centralization.

An alternative approach in the delegation literature is to restrict all contracting options other than the centralization/delegation decision, consistent with DeBijl (1994), Aghion and Tirole (1997), Gautier and Paolini (2000), Dessein (2002), and Harris and Raviv (2005). Because this approach is used in this paper, we describe these papers in more detail.

Private pre-contractual information may be given exogenously, as in Dessein (2002) and Harris and Raviv (2005). In Dessein (2002) noisy communication arises endogenously as a consequence of strategic information transmission by an informed agent. As a result, the principal may find it optimal to delegate authority to the agent in order to avoid noisy communication and the resulting loss of information. The principal's delegation–centralization decision involves a trade-off between a decision based on perfect information taken by an agent who has preferences that are different from the principal versus noisy information supplied by the agent and an unbiased decision taken by the principal. Harris and Raviv (2005) study optimal communication and allocation of authority in an organization where *both* the principal and the agent are privately (and costlessly) informed. Under centralization, the agent sends a noisy message to the principal who then decides, whereas under delegation, the principal sends a noisy message to the agent who decides. Harris and Raviv (2005) show that the probability of delegation increases with the importance of the agent's information and decreases with the importance of the principal's information. A similar example is Hvide and Kaplan (2003), who demonstrate that delegation may enable high-ability workers to signal their ability by choosing difficult tasks.

In a study that is somewhat related to ours, Gautier and Paolini (2000) investigate a signaling game with post-contractual information asymmetry where the principal can use delegation as a mechanism to allow the agent to signal his private information. In their model, the principal extracts the agent's information by

[4] Alternatively, the principal may be able to commit to a decision rule based on a message but not a transfer of resources, as in Melumad and Shibano (1991).

giving up control rights over some immediate decisions, in order to use the information so obtained in subsequent periods. In our model, information asymmetry arises endogenously, and thus the principal's problem is to strike a balance between motivating the agent to discover a correct action and inducing him to report his private information if he fails.

On the other hand, private information can also arise endogenously, but at a cost. Here the theme is one of using delegation to provide incentives to become informed. The incentive view of delegation is developed in Aghion and Tirole (1997) [hereafter, AT]. AT investigate an organizational arrangement where the principal can overrule her subordinate's decision and always does so if she is informed (the situation that AT label *formal authority*). If, however, the subordinate is better informed and preferences are not too incongruous, then the principal chooses to rubber-stamp the subordinate's proposal. In this case, the subordinate has *real authority* even though formal authority still resides with the principal.[5] As a result, the principal's loss of control is offset by an increase in the subordinate's initiative. AT formulate their model in terms of (new) projects that may or may not be implemented: if both the principal and the agent fail to learn the true state of the world, they agree that no project should be undertaken in a given period (i.e., a "zero project" is implemented). In contrast, we study an ongoing business process where taking a "zero action" is not an option. That is, one cannot "skip" the current period as if it did not occur at all (an assumption made by AT) — instead, one has to purposefully take an action and face the consequences. To contrast our results with those of AT, we find that the agent's information acquisition effort under delegation is *always lower* than under centralization, while AT find that the agent always has more incentives to become informed under delegation. In addition, the type of delegation that we study occurs *less* often as the principal's and the agent's preferences become better aligned, whereas in AT the opposite is true.

Results similar in spirit to those obtained by AT are reported in De Bijl (1994). He explores a principal-agent relationship in which the agent derives private benefits from exerting effort and, therefore, exerts higher effort when given more discretion. With an assumption that the agent will always become informed if he has complete discretion, the optimal mechanism derived by De Bijl balances centralization, which decreases the agent's motivation but keeps the principal in control, and delegation,

[5] Baker, Gibbons, and Murphy (1999) extend the framework proposed by AT and show that informal delegation may be supported by reputation concerns.

which results in initiative but decreases the principal's real authority. The situation that we study here is different in the sense that delegation may be chosen by the principal even though it always reduces the agent's incentives to acquire information. Furthermore, centralization may be used as a motivating device when the principal prefers to forego her control (i.e., when the agent will not send an inquiry) in favor of providing a strong incentive for the agent.

The key feature that distinguishes our model from prior work is the type of delegation that we study. Unlike most of the studies in the delegation literature, we assume that the organizational structure allowing the agent to take an action on behalf of the principal (the firm) is exogenously fixed — that is, delegation of this decision right is given. Further, we suppose that the environment is such that unless the agent communicates with the principal, the principal is unaware of any potential problem. We then study the allocation of one specific decision right — the right to disregard the principal's recommendation. Several themes mentioned above are present in our model: the agent acquires private information, communication is noisy in the sense that the agent may or may not report a problem to the principal, and the organizational arrangement may be chosen by the principal to motivate the agent to exert effort (or, alternatively, to motivate him to communicate his private information).

3 The Model

Consider a firm composed of a principal and an agent. The firm has to take one of two possible actions, labeled g and b, that result in different payoffs to the principal and the agent depending on the realized state of the world, which is unknown *ex ante*. There are two possible states of the world drawn from the set $\{G, B\}$; the probability that state B is realized, $\lambda = \Pr\{B\}$, is common knowledge. We can think of state G as a "good" state that requires, say, zero action g, and of state B as a "bad" state that requires a (costly) corrective action b. The principal hires the agent to discover the true state of the world and take an appropriate action on behalf of the firm.

Following AT, we assume that information is acquired in a binary form. That is, the agent exerts effort, p, at private cost $c(p)$, and learns the true state of the world with probability p. With probability $1-p$, he does not learn anything. We assume that the agent's cost of effort, $c(p)$, is increasing, strictly convex, and satisfies

$c(0) = 0$, $c'(0) = 0$, and $c'(1) = \infty$. The agent's information about the state of the world is neither observable nor verifiable. If the agent does not learn anything, he can either take his preferred action or send an inquiry to the principal, who, then, discovers the true state of the world with probability q, at private cost $C(q)$ (where $C(\cdot)$ satisfies the same conditions as $c(\cdot)$), and learns nothing with probability $1-q$.

If the action taken by the agent "matches" the realized state of the world — i.e., if the pair (*State*, *Action*) belongs to the set $\{(G, g), (B, b)\}$ — both parties receive their highest possible payoff, which is normalized to 0 (i.e., in this case their preferences are perfectly aligned). If a "mismatch" occurs — i.e., if the pair (*State*, *Action*) belongs to the set $\{(G, b), (B, g)\}$ — then both parties are penalized. This payoff structure guarantees that the "matching" action is always taken by the agent if either he or the principal succeeds in discovering the true state of the world.

3.1 Payoffs

We study an organizational structure where the agent is authorized to undertake an action on behalf of the firm. In particular, the agent can take an action without consulting the principal even if he fails to discover the true state of the world. Such an arrangement may result from conditions that make the principal's intervention impossible or impractical. Some degree of autonomy granted to the agent is descriptive of many organizations where local offices, especially in remote locations, have considerable discretion over which potential problems get reported to the headquarters and which are not, presumably in the hope that if a problem ever occurs, it can be dealt with locally and adverse consequences will not transpire.

The parties' payoffs, exclusive of the cost of effort, under four possible combinations of the realized state of the world and the action taken by the firm are given in Table 1. We assume that $S > s > 0$ and $T > t > 0$; that is, the principal and the agent disagree about the appropriate action when the realized state of the world is unknown.

To illustrate the payoffs, consider an audit client who proposes an "aggressive" accounting treatment for a transaction. The proposed treatment may either be in compliance with applicable standards (state G) or not in compliance (state B). The actions available to the audit firm are "do nothing" (i.e., accept the proposal — action g) or require an alternative, more conservative, treatment (action b). By assumption, the parties' payoffs are maximized if the true state of the world is discovered. If it is known that the SEC will reject the treatment, then the more

Probability of occurring	State of the world	Action	Principal's payoff	Agent's payoff
λ	B	b	0	0
		g	$-S$	$-t$
$1-\lambda$	G	b	$-s$	$-T$
		g	0	0

Table 1: The payoffs.

conservative treatment spares the auditor and the client adverse publicity and possible fines. On the other hand, if the SEC will accept the treatment, the auditors generate goodwill from the client by allowing the more aggressive treatment.

However, if an unwarranted rejection is taken (case (G, b)), the principal's (audit firm's) penalty s may represent the loss of a single client among many, while the agent's (partner's) penalty T is the loss of a substantial part of his client portfolio with the accompanying loss of prestige and revenue. Likewise, if the treatment is incorrectly accepted (case (B, g)), the principal faces a loss of S, which can represent millions in legal penalties and reputational losses, while the agent's loss of T is more limited.

We investigate two organizational arrangements, centralization and delegation. Under centralization, the agent is required to follow the principal's directive whenever it is issued. Under delegation, following the principal's recommendation is voluntary: the agent is free to ignore it if the principal has not been able to discover the true state of the world. The principal's action space over her strategic decision is thus {*Centralization*, *Delegation*}.[6]

3.2 Regions of agreement and disagreement

We assume that the information communicated by the principal can be costlessly verified by the agent. The agent, when he does not discover the true state of the world, chooses whether or not to send an inquiry to the principal given the organizational arrangement in effect. Notice that, because the agent can determine his preference in advance given the exogenous parameters, his effort level is predicated on his choice of whether or not to send an inquiry. The agent's action space over

[6] We assume that the principal can credibly commit to following the policy she chooses. The model can be extended to the case where delegation is informal and is supported by reputation concerns — see Baker *et al.* (1999).

his strategic decision is thus {*Inquiry*, *No Inquiry*}. The game is sequential, with the principal making the first move. The timing is as follows:

$\tau = 0$ Nature chooses the state of the world.

$\tau = 1$ The principal chooses an organizational arrangement.

$\tau = 2$ The agent solves the game by backward induction: given the organizational arrangement, he decides whether or not it will be in his interest to send an inquiry should he fail to discover the true state of the world. He then chooses his effort level accordingly, exerts the effort, and observes the outcome. If he succeeds in discovering the true state, he takes a matching action (i.e., g if G is observed and b if B is observed), and the game ends. Failing that, he either sends an inquiry (according to his decision made earlier) or chooses his preferred action, and the game ends.

$\tau = 3$ If the principal receives the agent's inquiry, she chooses her effort level, exerts her effort, observes the outcome, and sends her recommendation with the action that matches the true state of the world (if she succeeds in discovering it) or her preferred action (if she fails) to the agent. The agent follows the recommendation if it is correct (in the sense explained above) or if he is required to do so by organizational arrangement; otherwise, he chooses his preferred action, and the game ends.

Knowing the probability of state B, the parties determine their preferred actions when the true state of the world is unknown. The principal's expected penalty if she chooses action g is λS; her penalty if she chooses action b is $(1-\lambda)s$. The principal, therefore, will choose action g if (and only if)

$$\lambda S \leq (1-\lambda)s \Leftrightarrow \lambda \leq \frac{s}{S+s} \equiv \underline{\lambda}\,.$$

In a similar fashion, one can show that, when the state of the world is unknown, the agent will choose action g if (and only if)

$$\lambda t \leq (1-\lambda)T \Leftrightarrow \lambda \leq \frac{T}{T+t} \equiv \overline{\lambda}\,.$$

It follows that for $\lambda \in [0, \underline{\lambda}]$ — call it Region 1 — the parties' preferences are congruent; i.e., both, when uninformed, prefer that the firm take action g. The immediate implication is that, when the probability of the state B is sufficiently small, there is no strategic conflict: the agent always sends an inquiry. As a result, the principal's choice of organizational arrangement has no effect on the payoffs. For the sake of determinacy, we will assume that, if centralization and delegation yield the principal identical expected payoffs, she always prefers centralization — that is, that the principal does not voluntarily surrender her authority to the agent. This assumption is consistent with the notion that the ultimate authority always resides with the principal (the viewpoint advocated by Baker *et al.* 1999). Notice that $0 < \underline{\lambda} < \frac{1}{2} < \overline{\lambda} < 1$; hence the size of Region 1 is determined solely by the principal's payoffs (because $\underline{\lambda}$ is a function of S and s only).

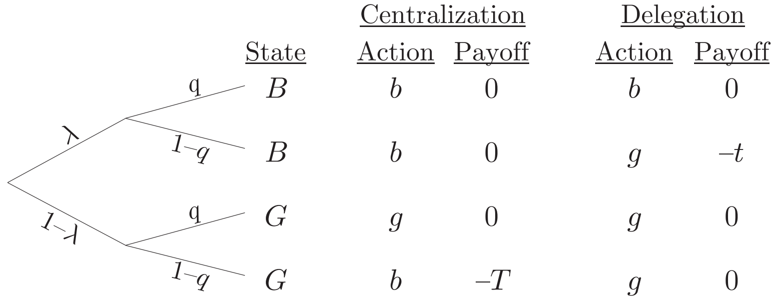
If $\lambda \in \left[\underline{\lambda}, \overline{\lambda}\right]$ (labeled Region 2), the principal and the agent have conflicting preferences: when uninformed, the principal prefers action b while the agent prefers action g. But the agent has an informational advantage and is allowed to take his preferred action without informing the principal; hence it is, ultimately, the agent's choice that determines the optimal organizational arrangement in Region 2. The size of this region is, therefore, a function of both the principal's and the agent's payoffs. In particular, as the principal's and the agent's preferences become better aligned, then both "agree" more often — i.e., Region 2 shrinks. As we shall see presently, delegation of the sort that we study here can only occur in this region, which is the focus of our study; hence, in our model, delegation occurs more often the higher the divergence in the principal's and the agent's preferences.

If the probability of state B is sufficiently high (i.e., when $\lambda \in \left[\overline{\lambda}, 1\right]$ — call it Region 3), the principal's and the agent's preferences are again aligned: this time, they both prefer to err on the side of caution and take action b if the state of the world is unknown. There is no strategic conflict: the agent always sends an inquiry and the principal chooses centralization (by the assumption stated above).[7]

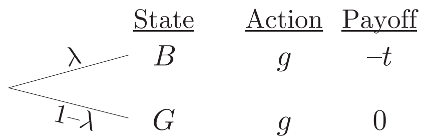
3.3 Agent's inquiry decision

We now investigate the agent's inquiry decision. As noted above, we solve the game by backward induction. First, we consider the agent's decision if he fails to discover the true state of the world. At that stage of the game, the cost of the agent's effort is sunk and thus does not enter his calculations. The agent's decision tree at this juncture is depicted in Figure 1.

[7] The tie-breaking rule that we use in Regions 1 and 3 is not critical for our results and is adopted for convenience only. Within Region 2, which is the focus of our study, equilibria that we characterize are unique almost everywhere.



(a) with inquiry



(b) with no inquiry

Figure 1: The agent's payoffs provided he fails to discover the true state of the world (ignoring the cost of effort).

The expected benefit to the agent from sending an inquiry arises from the probability that the principal discovers the true state of the world; this probability is always positive. Under centralization, the expected cost of sending an inquiry is the expected loss from the agent being forced to take his less preferred action when the principal fails to discover the true state. Under delegation, the agent is free to choose the action he takes, and therefore his expected loss from sending an inquiry is zero. Thus under delegation he always sends an inquiry.

Under centralization, the agent who fails to discover the true state of the world will send an inquiry if his expected loss from doing so, denoted ℓ_{ci} (where the subscript denotes centralization, inquiry), is at least as low as his expected loss from sending no inquiry, ℓ_{cn} (centralization, no inquiry), where:

$$\ell_{ci} = (1-\lambda)(1-q_{ci})T\,, \text{ and}$$
$$\ell_{cn} = \lambda t\,.$$

Thus, the agent sends an inquiry if the following condition is satisfied:

$$(1-\lambda)(1-q_{ci})T \leq \lambda t,$$

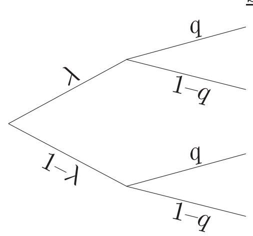
or, equivalently, if

$$q_{ci} \geq 1 - \frac{\lambda}{1-\lambda}\frac{t}{T} \equiv q_0 \,. \tag{1}$$

Intuitively, the agent will send an inquiry if the probability that the principal will discover the true state is sufficiently high.[8]

3.4 The principal's effort

If the principal receives the agent's inquiry, she determines her optimal effort level by solving the problem depicted in Figure 2.



	Centralization		Delegation	
State	Action	Payoff	Action	Payoff
B	b	0	b	0
B	b	0	g	$-S$
G	g	0	g	0
G	b	$-s$	g	0

Figure 2: The principal's payoffs provided she receives the agent's inquiry (ignoring the cost of effort).

Under centralization, she solves

$$\min_{q_{ci}\in(0,1)} (1-\lambda)(1-q_{ci})s + C(q_{ci}).$$

Her optimal effort, q_{ci}, satisfies $C'(q_{ci}) = (1-\lambda)s$; it is monotonically decreasing in λ and attains its maximum value on the interval $\left[\underline{\lambda}, \overline{\lambda}\right]$ at $\lambda = \underline{\lambda}$. Intuitively, the principal's effort is decreasing in the probability of state B because, as this probability decreases, so does the expected cost of an incorrect action.

[8]Notice that the principal's effort is itself a function of probability λ; this is the primary reason why later we need to specify functional forms for the costs of effort.

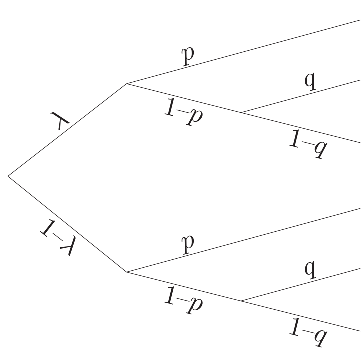
If the principal receives an inquiry under delegation, her optimization problem is given by

$$\min_{q_d \in (0,1)} \lambda(1 - q_d)S + C(q_d).$$

The principal's optimal effort under delegation, q_d, satisfies $C'(q_d) = \lambda S$; it is monotonically increasing in λ and attains its minimum on the interval $\left[\underline{\lambda}, \overline{\lambda}\right]$ at $\lambda = \underline{\lambda}$: now that the cost of making an error increases with probability λ, so does the principal's optimal effort. It follows immediately that $q_{ci} \leq q_d$ for all $\lambda \in \left[\underline{\lambda}, \overline{\lambda}\right]$, with strict inequality if $\lambda > \underline{\lambda}$. That is, in the interior of Region 2 the principal's effort is always strictly greater under delegation than it is under centralization (with inquiry) because in the former case her cost of error is higher. This result is what one would expect because the principal's maximum loss is higher under delegation and, furthermore, is increasing in probability λ.

3.5 The agent's effort

For the agent, the opposite is true: his effort under delegation is lower than under centralization. In effect, under delegation the principal substitutes her effort for the agent's. To see this, consider the agent's decision when he chooses the level of his effort (see Figure 3).



	Centralization		Delegation	
State	Action	Payoff	Action	Payoff
B	b	0	b	0
B	b	0	g	0
B	b	0	g	$-t$
G	g	0	g	0
G	g	0	g	0
G	b	$-T$	g	0

Figure 3: The agent's payoffs provided he sends an inquiry (ignoring the cost of effort).

If it is optimal for the agent to send an inquiry, then, under centralization, he solves

$$\min_{p_{ci}\in(0,1)} L_{ci}^a \equiv (1-\lambda)(1-p_{ci})(1-q_{ci})T + c(p_{ci}).$$

His optimal effort under centralization with inquiry, p_{ci}, is a solution to

$$c'(p_{ci}) = (1-\lambda)(1-q_{ci})T.$$

Under delegation (where he always sends an inquiry), the agent solves

$$\min_{p_d\in(0,1)} L_d^a \equiv \lambda(1-p_d)(1-q_d)t + c(p_d).$$

The optimal effort, p_d, is determined from

$$c'(p_d) = \lambda(1-q_d)t.$$

It follows from the assumption that $c(p)$ is a monotonically increasing function that

$$\begin{aligned} p_{ci} > p_d &\Leftrightarrow c'(p_{ci}) > c'(p_d) \\ &\Leftrightarrow (1-\lambda)(1-q_{ci})T \geq \lambda(1-q_d)t \end{aligned}$$

or

$$\lambda < \frac{(1-q_{ci})T}{(1-q_{ci})T + (1-q_d)t}.$$

Because $q_{ci} \leq q_d$, we have

$$\frac{(1-q_{ci})T}{(1-q_{ci})T + (1-q_d)t} > \frac{T}{T+t} \equiv \overline{\lambda} > \lambda.$$

Thus, $p_{ci} > p_d$.

If the agent does not send an inquiry (which, as noted above, can only happen under centralization), he solves

$$\min_{p_{cn}\in(0,1)} L_{cn}^a \equiv \lambda(1-p_{cn})t + c(p_{cn}).$$

His optimal effort, which is given by

$$c'(p_{cn}) = \lambda t,$$

always exceeds his effort under delegation (since $0 < q_d < 1$).

To summarize, in the interior of Region 2 the following inequalities are always satisfied:

$$\begin{aligned} p_{cn} &> p_d \, , \text{ and} \\ p_{ci} &> p_d \, . \end{aligned} \tag{2}$$

Intuitively, if the agent sends an inquiry, then centralization provides a stronger incentive for him to exert effort because if he fails to discover the true state of the world, he stands to lose more under centralization than under delegation. But if he does not send an inquiry, the incentive to find the true state of the world under centralization is still stronger than under delegation — because now the agent knows that he cannot rely on the principal's expertise. As a result, the principal can use centralization for two distinct reasons: (i) to exercise better control over the agent's actions when he sends an inquiry, or (ii) to provide the agent with an incentive to exert effort when he does not send an inquiry. In other words, in the latter case the principal could use delegation to make sure that the agent sends an inquiry, but under delegation the agent's effort is so much lower that the principal is better off if the inquiry is never sent.

Notice that, although it is conceivable that the principal can motivate the agent by promising not to respond to his inquiries, it will be impossible to make a credible commitment of this sort (it is easy to check that should the principal receive an inquiry, she will always respond to it). Thus, in our setting, centralization can be used as a commitment device.

We next investigate the principal's choice in more detail. Before we proceed, however, we state a result that will be useful in the following analysis.

Remark. *If $\lambda \in [\underline{\lambda}, \overline{\lambda}]$, then $\ell_{ci} < \ell_{cn}$ implies that (Centralization, Inquiry) is the unique equilibrium of the game.*[9]

In other words, the principal always chooses centralization in Region 2 whenever the conditions are such that the agent will send an inquiry. To solve the game, we now have to answer the question: when does the agent choose to send an inquiry? Given that he always prefers to learn the true state of the world, it seems reasonable to expect that the agent will always send an inquiry if the principal is very likely

[9]All proofs are given in the Appendix.

to discover the true state. Conversely, he will probably not send an inquiry if the chances of the principal's discovering the true state are small. As it turns out, this intuition is correct under a very weak assumption about the functional form of the principal's cost of effort (recall that the agent's cost of effort does not affect his decision at this juncture). We summarize this argument in the following lemma.

Lemma. *Suppose the principal's cost of effort is given by $C(q) = hf(q)$, where $h \in (0, \infty)$ and $f(q)$ is increasing, strictly convex, and satisfies $f(0) = 0$, $f'(0) = 0$, and $f'(1) = \infty$. Then the following statements are true:*

i. *For all $\lambda \in \left(0, \overline{\lambda}\right)$ there exists some sufficiently low principal's cost-of-effort parameter $h_0(\lambda)$, given by*

$$h_0(\lambda) = \frac{s(1-\lambda)}{f'\left(1 - \frac{\lambda}{1-\lambda}\frac{t}{T}\right)}, \tag{3}$$

such that $h \leq h_0(\lambda)$ implies $\ell_{ci} \leq \ell_{cn}$ and $h \leq h_0(\underline{\lambda})$ implies $\ell_{ci} \leq \ell_{cn}$ for all $\lambda \in \left[\underline{\lambda}, \overline{\lambda}\right)$.

ii. *If $h > h_0(\underline{\lambda})$, then there exists $\lambda_0 \in \left(\underline{\lambda}, \overline{\lambda}\right)$, which is a unique solution to*

$$h_0(\lambda_0) = q_0,$$

such that $\lambda < \lambda_0$ implies $\ell_{cn} < \ell_{ci}$.

Call the subset of Region 2 where (*Centralization, Inquiry*) is the equilibrium, Region 2_{CI}. Further, denote the subset of Region 2 in which delegation occurs as Region 2_D, and the subset in which (*Centralization, No Inquiry*) occurs as Region 2_{CN}. The Lemma states that if the principal's cost-of-effort parameter does not exceed a certain cut-off value of $h_0(\underline{\lambda})$, which is determined by both parties' payoffs, then the problem of the agent's withholding information never arises, i.e., the equilibrium is in Region 2_{CI}.[10] If, on the other hand, the principal's cost of effort is sufficiently high, then there always exists a subset of Region 2, call it Region 2_j, $j \in \{CN, D\}$, where the agent never sends an inquiry under centralization (he

[10] The result stated in the Lemma follows, *inter alia*, from the assumption that the principal's and the agent's preferences are congruent with respect to either state of the world whenever it is known. In the case where the preferences over the known states also differ, the region where the agent does not send an inquiry may not vanish.

always sends an inquiry under delegation). It can be shown that $h_0(\lambda)$ is monotonically increasing in λ, and it follows directly from the inspection of (3) that $h_0(0) = 0$ and $\lim_{\lambda\to\overline{\lambda}} h_0(\lambda) = \infty$.

Region 2_j, $j \in \{CN, D\}$, is characterized by $\lambda \in (\underline{\lambda}, \lambda_0)$, where λ_0 is defined in the Lemma; it increases in size as the principal's cost-of-effort parameter increases because the agent stands to gain less from consulting a less efficient principal. In the limit, as the principal's cost of effort tends to infinity, the agent never sends an inquiry in Region 2. It also follows from the Lemma that the agent does not send an inquiry only if the probability λ is neither too low nor too high. Thus an exogenous increase in λ may suffice to compel the agent to report the information that he would otherwise withhold. Figure 4 illustrates the results of the Lemma in (λ–h)-space. The shaded area represents the region where the agent always sends an inquiry and the principal always chooses centralization.

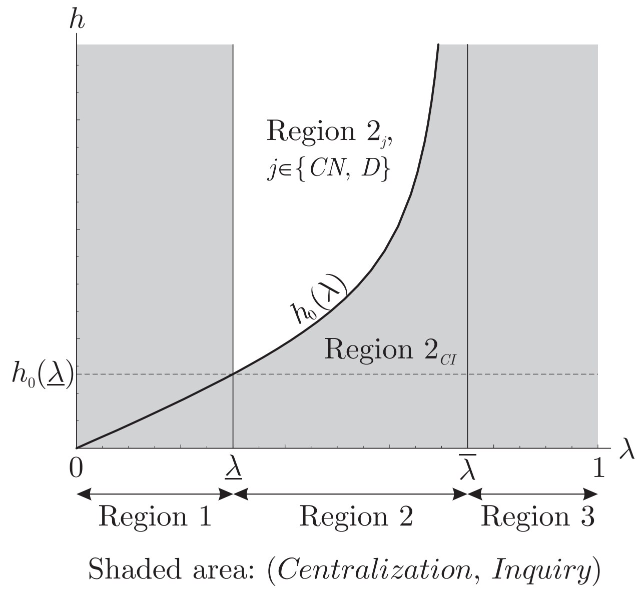


Figure 4: The regions in (h–λ)-space.

To summarize, the game has a unique equilibrium (Centralization, Inquiry) if one of the following conditions hold:

i. The probability of state B is in Regions 1 or 3, i.e., $\lambda \in [0, \underline{\lambda}] \cup [\overline{\lambda}, 1]$;

ii. The principal's cost-of-effort parameter is below the cut-off value of $h = h_0(\underline{\lambda})$;

iii. The principal's cost-of-effort parameter exceeds $h_0(\underline{\lambda})$ *and* probability λ exceeds the cut-off value of λ_0.

4 Optimal Organizational Arrangements

We can now fully characterize the principal's centralization–delegation decision. To do so, it is convenient to make assumptions about the functional forms of the agent's and the principal's costs of effort. For tractability, we assume that the agent's cost of effort has the form $c(p) = \frac{k}{2}p^2$, where $k \in (0, \infty)$ is the agent's cost-of-effort parameter.[11]

In this section we only investigate the case where the principal's cost of effort is "sufficiently" high (in the sense defined in the Lemma). We can, therefore, simplify the computations further by assuming that the principal's cost function is also quadratic; specifically, $C(q) = \frac{h}{2}q^2$.[12] With these cost functions, we can express in closed form the agent's and principal's effort choices for various scenarios, which are given in Table 2.

Region	Principal	Agent
Centralization, Inquiry	$q_{ci} = \dfrac{(1-\lambda)\,s}{h}$	$p_{ci} = \dfrac{(1-\lambda)\,(1-q_{ci})\,T}{k}$
Centralization, No Inquiry	None	$p_{cn} = \dfrac{\lambda t}{k}$
Delegation	$q_d = \dfrac{\lambda S}{h}$	$p_d = \dfrac{\lambda\,(1-q_d)\,t}{k}$

Table 2: The parties' effort choices

The principal's problem is to choose an organizational arrangement given the agent's decision to send (or not to send) an inquiry and his anticipated effort level. As shown by (2), if the agent sends an inquiry, his effort under delegation is always lower than under centralization. Despite that, the principal may choose delegation as a means of encouraging the agent to send an inquiry — if her expected gain

[11] We use this function for tractability although it does not satisfy our requirement that $c'(1) = \infty$. We must, therefore, impose a restriction to ensure interior solutions (specifically, $p \leq 1$).

[12] To guarantee an interior solution we will, again, have to impose an additional restriction on the admissible values of the parameter h.

from an increased probability of discovering the true state of the world offsets her expected loss from taking effort to do it. If, on the other hand, the decrease in the agent's effort under delegation is sufficiently high, the principal may choose centralization as an incentive device, even though as a result the agent never sends an inquiry. The following proposition characterizes the principal's choice and the corresponding equilibria (in this and the following proposition we assume that p and q are interior solutions).

Proposition 1. *Suppose that $\lambda \in \left(\underline{\lambda}, \overline{\lambda}\right)$, the principal's cost of effort is given by $C(q) = \frac{h}{2}q^2$, $h > 0$, and the agent's cost of effort is given by $c(p) = \frac{k}{2}p^2$, $k > 0$. Then there exist cut-off values h_0 and k_d, given by*

$$h_0 = \frac{(1-\lambda)^2 sT}{(1-\lambda)T - \lambda t}, \text{ and} \tag{4}$$

$$k_d = \lambda t \left(3 - \frac{S\lambda}{h}\right) \tag{5}$$

such that the following statements are true:

i. *If $h < h_0$, then the unique equilibrium of the game is (Centralization, Inquiry) for all admissible values of k.*

ii. *If $h > h_0$ and $k < k_d$, then the unique equilibrium of the game is (Centralization, No Inquiry).*

iii. *If $h > h_0$ and $k > k_d$, then the unique equilibrium of the game is (Delegation, Inquiry).*

Proposition 1 indicates that delegation is optimal only if both the principal's and the agent's cost-of-effort parameters are sufficiently high. The cost-of-effort parameter may be (relatively) high if, for example, the agent (the principal) is responsible for several projects, has duties other than investigating the true state of the world, or is particularly scrupulous about carrying out his (her) duties. Centralization with no inquiry will be optimal if the agent's cost-of-effort parameter is relatively low (provided that the principal's cost-of-effort parameter is relatively high). Figure 5 illustrates the principal's choice of organizational arrangement in (h–k)-space.

Alternatively, to parallel Figure 4, we illustrate the principal's choice of organizational arrangements in (λ–h)-space. To do so, we restate equation (5) in terms of

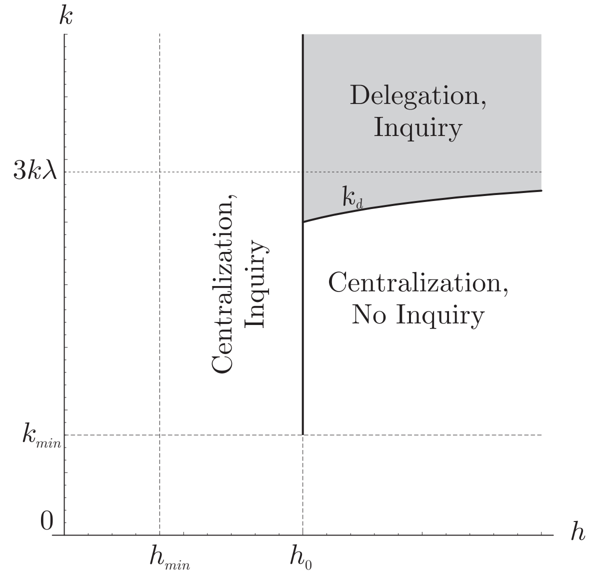


Figure 5: Equilibria in Region 2. Additional constraints, $h > h_{min} \equiv S\lambda$ and $k > k_{min} \equiv t\lambda$, are required to guarantee an interior solution.

h such that

$$h_d = \frac{St\lambda^2}{3t\lambda - k}\,. \tag{6}$$

Figure 6 permits a characterization of the principal's choice in Region 2 for a given value of λ. It shows that the set of values of h for which delegation is chosen becomes smaller as λ increases. In particular, when the agent's cost-of-effort parameter, k, is not too high (i.e., when $k < 3t\lambda$ — see (6)), a (small) increase in λ may cause the principal to switch from delegation to centralization with no inquiry — but when k is sufficiently high, the (*Centralization, No Inquiry*) subset of Region 2 vanishes.

It also follows from Proposition 1 that, when the equilibrium of the game is (*Centralization, No Inquiry*), an exogenous increase in the agent's cost of effort may compel the principal to switch to delegation. In an audit setting, the agent's cost of effort may increase if mandatory rotation of engagement partners were implemented, since not all client-specific information can be transferred to a new partner. It also follows that an exogenous increase in the principal's cost of effort (which may occur in an audit setting if, for example, the Professional Standards Group is downsized) can result in the agent not sending an inquiry. The effects of exogenous changes in

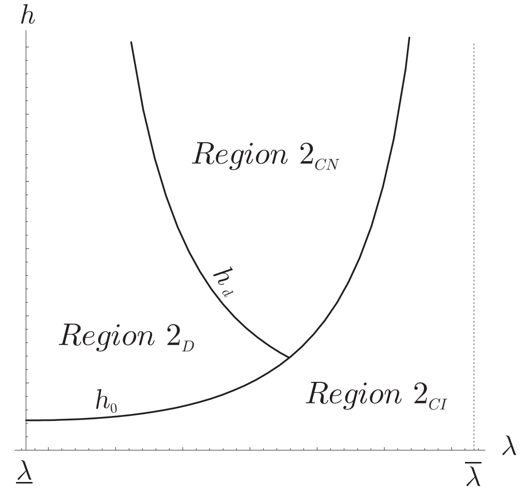


Figure 6: Equilibria in (h–λ)-space.

the remaining parameters of the model are summarized in the following corollary.

Corollary 1. *Assume that $\lambda \in (\underline{\lambda}, \overline{\lambda})$ (Region 2). Then the effects of exogenous increases in the penalty parameters, in (h–k)-space, are as indicated in Table 3.*

Region	s	S	t	T
Centralization, Inquiry	Increases	No effect	Increases	Decreases
Centralization, No Inquiry	Decreases	Decreases	Either[13]	Increases
Delegation	Decreases	Increases	Decreases	Increases

Table 3: The effects of increases in the penalty parameters on the size of the regions (within Region 2).

Suppose, for example, that h and k are randomly distributed in an economy. Then the probability that (*Centralization, Inquiry*) is the observed organizational choice is given by $\Pr(h < h_0)$. Changes in parameters that increase h_0 increase the probability that (*Centralization, Inquiry*) is observed. Similarly, changes in para-

[13]However, since $\frac{\partial k_d}{\partial t} > 0$, we know that the size of Region 2_{CN} increases in t relative to the size of Region 2_D.

meters that increase k_d increase the probability that (*Centralization, No Inquiry*) will be observed and decrease the probability of delegation.

Note from Corollary 1 that an increase in S (the principal's penalty when the action g is taken when the state is B — analogous in an audit setting to incorrectly accepting a deficient financial report) *increases* the likelihood of delegation of authority to the agent. Similarly, increasing the agent's penalty T (which arises when the action b is taken when the state is G — e.g., incorrectly rejecting a client's financial statements) increases the likelihood of delegation. Larger values of T in an audit setting could be associated with partners who have fewer but larger clients, where the loss of a single client could have severely negative effect on a partner.

To facilitate the interpretation of Corollary 1, it is useful to introduce congruence parameters similar to those used in AT: $\alpha = \frac{s}{S}$ and $\beta = \frac{t}{T}$, both in $(0, 1)$. Such a substitution allows us to decompose the payoffs into their incentive (S and T) and goal-congruence (α and β) components.[14] In particular, the opposite effects of s and S, as well as t and T, on the size of the Delegation region indicate that, as the player's interests become better aligned (i.e., as either of the congruence parameters increases), the agent sends an inquiry more often and the need for (costly) delegation diminishes.[15]

Changes in the principal's payoffs also have both incentive and goal-congruence effects. An increase in penalty s (i) provides an incentive for the principal to work harder and thus induces the agent to send an inquiry more often, and (ii) makes it less likely that the agent "disagrees" with the principal. An increase in penalty S makes the agent's withholding information about a potential problem particularly costly for the principal and makes it more likely that she chooses delegation so that she will have an opportunity to learn the true state. Therefore, even though the agent's efforts under delegation and centralization with inquiry decrease in s and S (as shown in Table 2), an increase in the principal's penalties can, nonetheless, have a positive effect on the agent, in the sense of inducing him to send an inquiry. In fact, it turns out that an increase in both types of penalties imposed on the principal (s and S) can leave her better off, as the following numerical example demonstrates.

[14]Notice that the cut-off probabilities with the new formulation take the form $\underline{\lambda} = \frac{\alpha}{1+\alpha}$ and $\overline{\lambda} = \frac{1}{1+\beta}$; thus both depend on the congruence parameters only — and, hence, so does the size of Region 2.

[15]This can also be shown directly by solving the model with $s = \alpha S$ and $t = \beta T$.

Example 1. *Let* $s_1 = 2$, $S_1 = 6$, $t = 3.8$, $T = 4$, $h = 3$, $k = 2$, *and* $\lambda = 0.35$ *(Case 1). Then, since* $h_{0_1} \approx 2.66 < h$, *the agent does not send an inquiry, and, since* $k < k_d \approx 3.06$, *the principal chooses centralization. The principal's expected loss is (see Table 2)*

$$L^p_{cn} = S_1 \lambda (1 - p_{cn}) \approx 0.70 \,.$$

Suppose now that the principal's penalties are increased to $s_2 = 2.5$ *and* $S_2 = 7.5$ *(Case 2). We have* $h < h_{0_2} \approx 3.33$*: the agent chooses to send an inquiry, and the principal chooses centralization. Her expected loss is given by*

$$L^p_{ci} = s_2 (1 - \lambda)(1 - q_{ci_2})(1 - p_{ci_2}) + (1 - p_{ci_2}) \frac{h}{2} q^2_{ci_2} \approx 0.48 \,.$$

In Example 1, the increase in the principal's penalties induce the agent to send an inquiry, which in equilibrium makes the principal better off even after considering the cost of the principal's effort.

5 Catastrophic Risk

In this section we investigate the effect that different organizational arrangements have on the likelihood of a catastrophic failure, or the probability that no corrective action is taken given that the "bad" state is realized, $\Pr\{g|B\} \equiv R$.[16] We describe such an outcome as "catastrophic" because it can lead to large lawsuits or firm bankruptcy. This circumstance yields the highest losses for the firm (the principal).

Catastrophic risk is (identically) zero if action b is taken by the firm whenever the true state of the world is unknown. Recall that in Regions 2 and 3 (i.e., for $\lambda > \underline{\lambda}$) the principal always prefers taking action b. As shown above, action g is never taken in Region 2 when (*Centralization, Inquiry*) is the equilibrium of the game; hence catastrophic risk in this part of Region 2 is zero. It is, however, always positive in Region 2_{CN} and Region 2_D. Under centralization with no inquiry catastrophic risk is determined by probability λ and the agent's effort only, because the principal is never called into action and thus her expertise remains unused. Under delegation, with probability $1 - p_d$ the principal learns about the problem, and with probability $1 - q_d$ fails to discover the true state of the world — in which case the agent takes his preferred action g.

[16] In the acceptance sampling literature, this circumstance is known as *consumer's risk*, that is, the risk of accepting a defective product (see, e.g., Duncan 1974, p. 165).

The values of R for the three organizational arrangements are given in Table 4. Proposition 2 characterizes the relative magnitudes of R_{cn} and R_d.

Region	Catastrophic Risk, R
Centralization, Inquiry	0
Centralization, No Inquiry	$\lambda\left(1-p_{cn}\right)$
Delegation	$\lambda\left(1-p_d\right)\left(1-q_d\right)$

Table 4: Catastrophic risk for each organizational structure.

Proposition 2. *Suppose that $\lambda \in \left(\underline{\lambda}, \overline{\lambda}\right)$ and the following condition is satisfied:*

$$k > k_R \equiv \lambda t \left(2 - \lambda \frac{S}{h}\right), \tag{7}$$

where $k_R < k_d$. Then in Region 2 catastrophic risk is strictly higher under centralization with no inquiry than under delegation.

Proposition 2 states that delegation results in a *lower* risk of a catastrophic outcome if the agent's cost of effort is not too low. This result may seem counterintuitive in the light of the Enron scandal, where a catastrophe (for Enron and Andersen) happened in part because the recommendations of the Andersen's Professional Standards Group were ignored. In our model, however, catastrophic risk may be reduced (albeit not eliminated) when the principal chooses delegation.

Nonetheless, there always exists a region, characterized by $k \in (k_R, k_d) \neq \varnothing$, where the principal prefers centralization with no inquiry. In this region, the principal is better off inducing the agent to exert his highest level of effort than providing him with incentives to report a problem. Table 2 shows why this is the case: it is easy to see that, as t increases, the agent's effort under centralization with no inquiry, p_{cn}, increases at a faster rate then his effort under delegation, p_d, causing the principal to choose Centralization (with no inquiry) more often.[17]

An increase in t is equivalent to a decrease in $\Delta T = T - t$, the agent's personal benefit from taking the client's side when uninformed. This is precisely what a regulator intent on reducing catastrophic risk would try to accomplish in order to

[17] See Footnote 13.

induce the agent to take a more conservative stance. The rule prohibiting audit partners from accepting jobs at their former clients for one year after leaving the audit firm can be seen as an example of such a policy. And, as shown in Table 3, an increase in t can, indeed, shift the equilibrium to the (*Centralization, Inquiry*) Region, with the attendant reduction of catastrophic risk (to zero). But, if the principal's cost of effort, h, is sufficiently high, an increase in t may leave the agent's preference for not sending an inquiry intact — but induce the principal to switch from delegation to centralization, with a resultant increase in catastrophic risk. The following proposition formalizes this argument.

Proposition 3. *Suppose that* $\lambda \in \left(\underline{\lambda}, \overline{\lambda}\right)$. *Then there exist sets of parameters* $(S, s, T, t, h, k, \lambda)$ *satisfying* $h > h_0$ *and* $k > k_d$ *as defined by (4) and (5) such that an increase in* t *results in an increase in catastrophic risk.*

Thus, when certain conditions (given in the Appendix) are satisfied, an attempt by the regulator to increase the agent's penalty for erring on the side of the client may result in an increased probability of a catastrophe. Our model predicts that this effect can take place when the principal's cost of effort is sufficiently high, and the agent's cost of effort is just above the cut-off level that justifies the use of delegation. The following example illustrates Proposition 3.

Example 2. *Let* $s = 2$, $S = 6$, $t_1 = 2$, $T = 2.5$, $h = 2.5$, $k = 1.7$, *and* $\lambda = 0.35$ *(Case 1). We have* $h_{0_1} \approx 2.03 < h$ *and* $k_{d_1} \approx 1.51 < k$, *hence the principal chooses delegation. Catastrophic risk is given by*

$$R_{d_1} = \frac{\lambda}{h^2 k} (h - S\lambda) \left(St\lambda^2 + h (k - t_1\lambda)\right) \approx 0.052 .$$

Now let $t_2 = 2.4$ *(Case 2). We have* $h_{0_2} \approx 2.28 < h$ *and* $k < k_{d_2} \approx 1.81$, *hence the principal chooses centralization and the agent does not send an inquiry. Catastrophic risk is given by*

$$R_{cn_2} = \lambda \left(1 - \frac{t_2\lambda}{k}\right) \approx 0.177 .$$

Example 1 and Proposition 3 together demonstrate that a firm's ability to adapt its organizational design to the changes in its legal and business environment may yield unintended consequences to legislation designed to achieve certain social policy objectives.

6 Conclusions

In this study we present a one-period model of a hierarchy where the agent, who acquires private information, is authorized to take an action on behalf of the principal. We study a setting where both the principal and agents are capable of acquiring needed information but are not necessarily equally efficient at it — a situation typical of many professional firms and organizations with divisions in remote locations. We use the model to characterize conditions under which the principal will allow the agent to disregard her directive and show that the principal may delegate the right to disagree with her recommendation in order to encourage the agent to report a problem, but only if the costs of effort for both the principal and the agent are sufficiently high and the principal's and the agent's preferences are not too closely aligned.

When the principal's cost of effort is sufficiently low, the agent always reports the problem and the principal always chooses centralization — i.e., the organizational arrangement where her recommendations are binding for the agent. When the principal's cost of effort is relatively high and the agent's cost of effort is relatively low, the principal may choose centralization as a motivational device to discourage the agent from relying on the principal's expertise, even though by doing so the principal relinquishes control over the agent's actions. Thus in our model centralization may be used by for two different reasons: (i) to ensure that the principal retains control over the actions taken by the agent, provided he sends an inquiry, and (ii) to encourage the agent to exert higher effort, provided he does not. We also show that exogenous increases in penalties — e.g, by legislation — can lead to unexpected and unintended increases in catastrophic risk (e.g., audit failure).

The partial-equilibrium nature of our model does not allow us to address a number of questions. Further, a richer contracting setting available to the principal would likely alter some of our conclusions.

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Appendix

Proof of Remark

Let L_r , where $r \in \{ci, cn, d\}$, denote the principal's expected penalty under regimes "Centralization with Inquiry," "Centralization with No inquiry," and "Delegation" respectively. First we show that $L_{ci} < L_d$. To see this, notice that L_{ci} is given by

$$L_{ci} = (1 - p_{ci})[(1 - \lambda)(1 - q_{ci})s + C(q_{ci})] \,.$$

Define $A_{ci} = (1 - \lambda)(1 - q_{ci})s + C(q_{ci})$. We have

$$\begin{aligned} \frac{\partial A_{ci}}{\partial \lambda} &= -(1 - q_{ci})s + \left[-(1 - \lambda)s + C'(q_{ci})\right] \frac{\partial q_{ci}}{\partial \lambda} \\ &= -(1 - q_{ci})s < 0 \end{aligned}$$

because $-(1-\lambda)s + C'(q_{ci}) = 0$ by the principal's first order condition on effort. L_d is given by

$$L_d = (1 - p_d)[\lambda(1 - q_d)S + C(q_d)] \,.$$

Define $A_d = \lambda(1 - q_d)S + C(q_d)$. We have

$$\frac{\partial A_d}{\partial \lambda} = (1 - q_d)S > 0 \,.$$

A_{ci} is decreasing in λ and A_d is increasing in λ. Therefore, if $A_{ci} < A_d$ at $\underline{\lambda}$, then $L_{ci} < L_d$ because $p_{ci} > p_d$. Since

$$\underline{\lambda} = \frac{s}{S + s} \text{ and } 1 - \underline{\lambda} = \frac{S}{S + s} \,,$$

we can write

$$\begin{aligned} A_{ci}\left(\underline{\lambda}\right) &= \frac{Ss}{S + s}\left(1 - q_{ci}\right) + C\left(q_{ci}\right) \text{ , and} \\ A_d\left(\underline{\lambda}\right) &= \frac{Ss}{S + s}\left(1 - q_d\right) + C\left(q_d\right) \,. \end{aligned}$$

We know that $q_{ci} \leq q_d$ for all $\lambda \in \left[\underline{\lambda}, \overline{\lambda}\right]$. By the principal's first-order conditions for effort, we have:

$$\begin{aligned} C'(q_{ci}) &= (1-\lambda)s = \frac{Ss}{S+s} \quad \text{at } \underline{\lambda}\text{ , and} \\ C'(q_d) &= \quad \lambda S \quad = \frac{Ss}{S+s} \quad \text{at } \underline{\lambda}\text{ .} \end{aligned}$$

Therefore, $q_{ci} = q_d$ and $A_{ci} = A_d$ at $\underline{\lambda}$. So $A_{ci} < A_d$ for $\lambda > \underline{\lambda}$ implies $L_{ci} < L_d$ for $\lambda > \underline{\lambda}$. If $\ell_{ci} < \ell_{cn}$, then the agent will send an inquiry under centralization (and will always send an inquiry under delegation). By the argument above, centralization with inquiry is preferred by the principal. □

Proof of Lemma

As argued in the text, $\ell_{ci} \leq \ell_{cn}$ iff the principal's effort, $q(\lambda)$, is greater than or equal to the value given by (1), i.e., for all $\lambda \in \left[\underline{\lambda}, \overline{\lambda}\right)$,

$$q(\lambda) = \left(f'\right)^{-1}\left(\frac{s}{h}(1-\lambda)\right) \geq 1 - \frac{\lambda}{1-\lambda}\frac{t}{T} \equiv q_0(\lambda)\,. \tag{A.1}$$

Since $f'(\cdot)$ is convex and increasing in λ, its inverse is concave and increasing in λ and, therefore, $(f')^{-1}\left(\frac{s}{h}(1-\lambda)\right)$ is concave and decreasing in λ. Notice that $q_0\left(\overline{\lambda}\right) = 0$, $q_0(0) = 1$, and $q(1) = 0$. But $\overline{\lambda} < 1$ and $q(0) = (f')^{-1}\left(\frac{s}{h}\right) < 1$. Since $q_0(\lambda)$ and $q(\lambda)$ are continuous and monotone, their graphs intersect (by connectedness, which follows from continuity) exactly once (by monotonicity) at a point $\lambda_0 < \overline{\lambda}$. Furthermore,

$$q_0'(\lambda_0) < q'(\lambda_0)\,. \tag{A.2}$$

Hence $\lambda \leq \lambda_0$ implies $q(\lambda) \geq q_0(\lambda)$. Since $f'(\cdot)$ is monotonically decreasing in h, we can always find $h = h_0$ such that (A.1) is satisfied for any given $\lambda \in \left(0, \overline{\lambda}\right)$. It follows directly from (A.2) that $\lambda_0 = \underline{\lambda}$ implies $q(\lambda) \geq q_0(\lambda)\ \forall \lambda \in \left(0, \overline{\lambda}\right)$. This proves part (i). Part (ii) follows immediately from the fact that $q(\lambda)$ is monotonically decreasing in h for all $\lambda \in \left(0, \overline{\lambda}\right)$. □

Proof of Proposition 1

If the principal receives the agent's inquiry under centralization, she solves

$$\min_{q_{ci}\in(0,1)} (1-\lambda)(1-q_{ci})s + \frac{h}{2}q_{ci}^2\,, \tag{A.3}$$

which yields the optimal effort level of $q_{ci} = \frac{s}{h}(1-\lambda)$. As argued in the text (p. 12), the agent will send an inquiry (under centralization) iff $q_{ci} \geq q_0$, where q_0 is defined by (1). Substituting q_{ci} above into (1), solving for h, and simplifying yields the value of h_0 such that $h < h_0$ implies $\ell_{ci} < \ell_{cn}$, that is, the agent sends an inquiry and the principal chooses centralization by assumption. This proves part (i).

Under delegation, the principal's choice of effort is a solution to

$$\min_{q_d\in(0,1)} \lambda\,(1-q_d)\,S + \frac{h}{2}q_d^2\,,$$

which yields the optimal effort level of $q_d = \frac{S\lambda}{h}$.

The agent determines whether, given the principal's optimal effort level, it is in his best interest to send an inquiry should he fail to discover the true state of the world. Assume that $h > h_0$. Then under centralization, the agent does not send an inquiry. He solves (see Figure 1 panel (b))

$$\min_{p_{cn}\in(0,1)} \lambda\,(1-p_{cn})\,t + \frac{k}{2}p_{cn}^2\,,$$

and his optimal effort level is $p_{cn} = \frac{t\lambda}{k}$. Under delegation, the agent always sends an inquiry. His optimal effort level, p_d, is determined from (see Figure 1 panel (a))

$$\min_{p_d\in(0,1)} \lambda\,(1-p_{cn})\,(1-q_d)\,t + \frac{k}{2}p_d^2\,,$$

and is given by $p_d = \frac{t\lambda}{k}\left(1-\frac{S\lambda}{h}\right)$.

The principal's expected loss under centralization is given by

$$\begin{aligned} L_{cn}^p &= \lambda\,(1-p_{cn})\,S \\ &= S\lambda\left(1-\frac{t\lambda}{k}\right). \end{aligned} \tag{A.4}$$

Her expected loss under delegation is given by

$$\begin{aligned} L_d^p &= \lambda\left(1-p_d\right)\left(1-q_d\right)+\left(1-p_d\right)\frac{h}{2}q_d^2 \\ &= \frac{S\lambda}{2h^2k}\left(2h-S\lambda\right)\left(St\lambda^2+h\left(k-t\lambda\right)\right). \end{aligned} \tag{A.5}$$

The principal will choose delegation iff $L_{cn}^p > L_d^p$. Substituting (A.4) and (A.5) into $L_{cn}^p = L_d^p$ and solving for h establishes the result. □

Proof of Corollary 1

The results follow from the following observations.

a. $\dfrac{\partial h_0}{\partial s} = \dfrac{T\left(1-\lambda\right)^2}{T\left(1-\lambda\right)-t\lambda} > 0$ because the denominator is positive for $\lambda < \overline{\lambda}$.

b. $\dfrac{\partial h_0}{\partial T} = -\dfrac{st\lambda\left(1-\lambda\right)^2}{\left(T\left(1-\lambda\right)-t\lambda\right)^2} < 0.$

c. $\dfrac{\partial h_0}{\partial t} = \dfrac{sT\lambda\left(1-\lambda\right)^2}{\left(T\left(1-\lambda\right)-t\lambda\right)^2} > 0.$

d. $\dfrac{\partial k_d}{\partial t} = \lambda\left(3-\dfrac{S\lambda}{h}\right) = \lambda\left(3-q_d\right) > 0.$

e. $\dfrac{\partial k_d}{\partial S} = -\dfrac{t\lambda^2}{h} < 0.$

f. $\dfrac{\partial k_d}{\partial \lambda} = t\left(3-\dfrac{2S\lambda}{h}\right) = \lambda\left(3-2q_d\right) > 0.$

Proof of Proposition 2

Catastrophic risk under centralization with no inquiry is given by

$$\begin{aligned} R_{cn} &= \lambda\left(1-p_{cn}\right) \\ &= \lambda\left(1-\frac{t}{k}\lambda\right); \end{aligned}$$

catastrophic risk under delegation is given by

$$\begin{aligned} R_d &= \lambda\left(1-p_d\right)\left(1-q_d\right) \\ &= \frac{\lambda}{h^2k}\left(St\lambda^2+h\left(k-t\lambda\right)\right)\left(h-S\lambda\right). \end{aligned}$$

We have

$$R_{cn} \geq R_d \Leftrightarrow \frac{S\lambda^2}{h^2 k}\left(St\lambda^2 + h\left(k - 2t\lambda\right)\right) \geq 0$$
$$\Leftrightarrow St\lambda^2 + h\left(k - 2t\lambda\right) \geq 0$$
$$\Leftrightarrow k \geq \lambda t\left(2 - \frac{S\lambda}{h}\right) \equiv k_R\,.$$

The result follows. □

Proof of Proposition 3

We want to find a pair (x, δ), where $x = (S, s, T, t, h, k, \lambda)$ is a point in the parameter space and $\delta > 0$, such that the equilibrium at x is (*Delegation*, *Inquiry*) and the equilibrium at $y = (S, s, T, t + \delta, h, k, \lambda)$ is (*Centralization*, *No Inquiry*). The proof is by construction.

Pick any S, s, T, t, h, λ satisfying the following conditions:

$$\frac{s}{S+s} < \lambda < \frac{T}{T+t}\,,$$

$$h > \max\left\{\frac{sT\left(1-\lambda\right)^2}{T\left(1-\lambda\right) - t\lambda} \equiv h_0\left(x\right),\, S\lambda\right\}\,,$$

where $h > S\lambda \Leftrightarrow q_d < 1$. Let

$$\nu = \frac{\left(h - h_0(x)\right)\left(T\left(1-\lambda\right) - t\lambda\right)^2}{\lambda\left(sT\left(1-\lambda\right)^2 + \left(h - h_0\left(x\right)\right)\left(T - \left(T+t\right)\lambda\right)\right)}\,. \tag{A.6}$$

Pick any δ such that

$$0 < \delta < \min\left\{\nu,\, \frac{T - \lambda\left(T+t\right)}{\lambda},\, \frac{ht}{2h - S\lambda}\right\}\,; \tag{A.7}$$

we can do that because all three upper bounds in A.7 are always positive.
Now, we can pick any k such that

$$k_d\left(x\right) \equiv \lambda t\left(3 - \frac{S\lambda}{h}\right) < k < \lambda\left(t+\delta\right)\left(3 - \frac{S\lambda}{h}\right) \equiv k_d\left(y\right)\,. \tag{A.8}$$

By construction, $h > h_0\left(x\right)$ and $k > k_d\left(x\right)$, hence by Proposition 1 the unique equilibrium of the game at x is (*Delegation*, *Inquiry*). Now, (A.6) and (A.7) together imply that

$$h > \frac{sT(1-\lambda)^2}{T(1-\lambda)-(t+\delta)\lambda} \equiv h_0(y) \ ,$$

which, together with (A.8) imply that the unique equilibrium of the game at y is (*Centralization*, *No Inquiry*).

It remains to show that the conditions of Proposition 2 are satisfied at x and y. The first inequality in (A.8) implies that

$$k > \lambda t\left(3-\frac{S\lambda}{h}\right) > \lambda t\left(2-\frac{S\lambda}{h}\right) \equiv k_R(x) \ .$$

Condition $\delta < \frac{ht}{2h-S\lambda}$ in (A.7) implies that

$$k > \lambda(t+\delta)\left(2-\frac{S\lambda}{h}\right) \equiv k_R(y) \ .$$

This establishes the claim. □