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Is no news bad news? Information transmission and the role of "early warning" in the principal-agent model

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The standard principal-agent model neglects the potentially important role of information transmission from agent to principal. We study optimal incentive contracts when the agent has a private signal of the likelihood of the project's success. We show that the principal can costlessly extract this signal if and only if this does not lead her to intervene in the project in any way that will influence its outcome. Intervention undermines incentives by weakening the link between the agent's initial effort and the project's outcome. If possible, the principal commits not to cancel some projects with negative expected payoffs. To elicit early warning, contracts must reward agents for coming forward with bad news.

I want you to tell me exactly what's wrong with me and M.G.M., even if it means losing your job.

—Samuel Goldwyn to his staff
after a string of box-office flops
(Bennis, 1993).

1. Introduction

■ Early access to information is critical to managerial decision making within the firm. For example, timely access to accurate information about new product development and product sales is necessary for devising corporate strategy and allocating resources. Early warning about potential crises is also valuable to managers, who often have access to the means, authority, or skills to avoid mishaps that cannot be handled effectively by people lower in the company.

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Often, however, information that resides within an organization is unavailable to key decision makers in a timely fashion. For instance, the project manager on an R&D project is likely to have far better information than the CEO about realistic timelines and the technical feasibility of new product development. The project manager's incentives may not be well aligned with the CEO's, however, leading the project manager to provide incomplete, inaccurate, or delayed information about the project. Not surprisingly, anecdotal evidence suggests that effective information transmission upward through the firm is especially unlikely when the news is bad—precisely the situation where early warning is likely to be most valuable. For example, many of the large trading losses at investment banks (such as those at Barings, which led to its eventual demise) could have been avoided had there been early warning signals. For another example, early warning of transgressions by government employees (such as the apparent excessive use of force against Rodney King by police officers, which eventually precipitated rioting in Los Angeles) could allow officials to assuage public anger.

In this article we examine the design of optimal incentive schemes when the agent not only has private information about his own effort, but also has a private signal about the eventual state of the world. Early access to that information is assumed to be valuable to the principal. The timing of our basic model is as follows. The principal first announces an incentive scheme. The agent then chooses a publicly unobservable effort level, and subsequently receives a publicly unobservable signal about the eventual state of the world. The agent then makes an announcement about the signal to the principal, who takes an action (in our leading case, deciding whether to terminate the project or let it run to completion). After the principal's action, the true state of the world is revealed and contracts are settled.

A number of results emerge from the model. The optimal incentive scheme is structured so that agents who provide early warning to the principal about likely bad outcomes receive a wage intermediate between agents who obtain good outcomes and agents who obtain bad outcomes but provide no early warning to the principal. While intuition might suggest that rewarding agents for acknowledging that the expected outcome is bad would have a deleterious impact on the effort choice of the agent, that intuition is in fact only partially correct. Section 3 demonstrates that if the provision of early warning concerning the agent's signal does not lead the principal to take any action that obscures the state of the world that would have resulted had there been no early warning (we call this a noninterventionist action), then it is costless for the principal to entice truthful early warning from the agent.[1] The provision of early warning has no impact on the principal's ability to determine the level of effort exerted by the agent and therefore does not affect the effort decision. Information is costless to extract because the wage is not conditioned on the signal announcement in the optimal incentive scheme. The fact that a principal may benefit from early warning without reducing the power of the incentive scheme is similar in spirit to the findings of Kaplow and Shavell (1994), who demonstrate that firms can be enticed into self-reporting harmful acts through the proper mix of punishments for self-reported violations and violations detected through monitoring.

In practice, however, the conditions of the preceding paragraph are unlikely to hold, since the agent's provision of early warning will typically lead the principal to take actions that obscure the state of the world; we call these interventionist actions. For instance, it may be optimal for the principal simply to terminate a project in response to an agent's revealing a signal below a given threshold. *Ex post*, there is no way of knowing what would have occurred had the project not been cancelled. Less

[1] An example of a noninterventionist action is the principal's making an investment, after receiving early warning of a bad outcome, providing a positive return in the bad state of the world.

dramatic interventions by the principal (e.g., adding more resources to a project, or even a well-timed phone call) nonetheless may influence the eventual state of the world that is reached. It is precisely this weakening of the link between agent effort and outcomes that induces the tradeoff between early warning and effort. Ironically, by using information about the agent's signal, the principal effectively destroys some of the information about the agent's effort level, making it more difficult for the principal to elicit high effort from the agent. Consequently, eliciting early warning from the agent is costly for the principal, i.e., the expected wage bill required to obtain anything above the minimum level of effort with project cancellation is strictly greater than the expected wage bill without project cancellation.[2] Therefore, the second-best level of effort when project cancellation is feasible is below the second-best effort level when projects cannot be cancelled, which is itself below the first-best level of effort when projects cannot be cancelled.

Because of this tradeoff between information extracted from the agent's signal and the agent's effort, the principal can benefit from designing contracts that extract the optimal level of early warning from the agent. More specifically, the principal will want to commit to limiting her degree of intervention in the project in response to a bad signal. In the particular formulation of the problem we examine, where the principal's only action is a decision about whether to terminate the project prematurely, the principal benefits from committing not to cancel some projects with a negative expected payoff to the principal. The *ex ante* benefit of inducing high effort more than outweighs the expected *ex post* loss on the project.

In an extension of the basic analysis, we consider how the principal's inability to commit to a cancellation policy affects equilibrium. Analogous to the literature on the "ratchet effect" in a regulatory context (see Laffont and Tirole (1993)), we find that the inability to commit substantially reduces the principal's surplus. The inability to commit further hampers the principal's goal of simultaneously eliciting early warning and high effort. Indeed, eliciting early warning may have such a detrimental effect on effort incentives that the principal entirely abandons the attempt to seek early warning.

Our analysis adds to a growing literature addressing the flow of information within organizations (Holmström and Ricart i Costa, 1986; Milgrom and Roberts, 1986; Sah and Stiglitz, 1986; Milgrom, 1988; Milgrom and Roberts, 1990; Bolton and Dewatripont, 1992; Radner, 1992; Prendergast, 1993; Segal and Tadelis, 1995; and Aghion, Bolton, and Fries, 1996). There are also parallels between our analysis and the literature on costly audits (Townsend, 1979; Baron and Besanko, 1984; Reinganum and Wilde, 1985; Border and Sobel, 1987; and Mookerjee and Png, 1989), especially the subliterature on self-reporting (Kaplow, 1992; Malik, 1993; and Kaplow and Shavell, 1994). None of these articles, however, considers either the potential value of early warning or the possibility that interventions by the principal obscure the relationship between the agent's effort and the eventual state of the world. The two works most similar in spirit to this article are Aghion and Tirole (1997), which analyzes managerial intervention in the context of real versus formal authority in organizations, and Povel (1996), which examines the role of early warning in the design of bankruptcy rules.

The article is organized as follows. Section 2 introduces the basic principal-agent model, adding an intermediate signal of the project's eventual outcome that is observed by the agent but not by the principal. Section 3 examines the case where the principal is limited to noninterventionist actions, i.e., actions that have no effect on the eventual

[2] Note, however, that it is costless to extract truthful revelation of the agent's signal if his wage is independent of his announcement, since then the agent is indifferent between hiding and disclosing any private information. Thus, the value of timely access to bad news provides a partial explanation for the use of low-powered incentives within the firm.

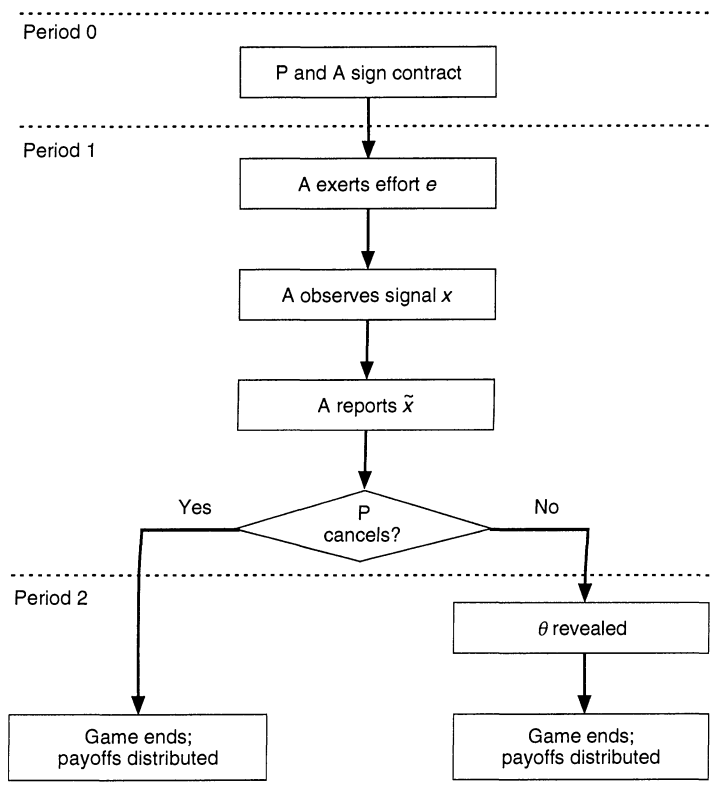
state of the world. We demonstrate that truthful revelation of the agent's signal is costless to the principal in this setting. In other words, there is no tradeoff between information and incentives. Section 4 extends the model by allowing the principal, in response to the agent's announced signal, to take an action that potentially changes the resulting state of the world, i.e., an interventionist action. Although our model focuses on the most extreme form of intervention, namely premature termination of the project, the intuition carries over to less-extreme interventions. Intervention by the principal destroys information about the agent's effort. Consequently, revelation of the agent's signal is now costly to the principal. Section 5 considers the empirical predictions of the model and the extent to which existing incentive and information structures within firms and households appear consistent with the model, and it examines the normative implications of our results for organizational design. Section 6 offers a brief conclusion. All proofs are found in the Appendix.

2. Model

■ The model has two players, a principal and an agent, and three periods, 0, 1, and 2. The timing of the model is depicted in Figure 1. In period 0, the principal offers the agent an employment contract. Among other provisions, the contract specifies a wage w to be paid to the agent as a function of contractible variables listed below. If the agent accepts the contract, he begins work on a project for the principal. In period 1, the agent invests in the project. For concreteness, this investment is called "effort" and is denoted by e, though more generally it can represent any form of nonpecuniary

FIGURE 1

TIMING OF THE GAME



investment. The agent can choose one of two possible effort levels: low effort, e_L, or high effort, e_H. The agent's nonpecuniary cost of exerting low effort is k_L and of exerting high effort is k_H, where $\Delta k \equiv k_H - k_L > 0$. Effort is unobservable to the principal and noncontractible. In period 2, the state of the world θ is realized, determining the project's return. If $\theta = \theta_g$, the state of the world is "good" for the principal: the principal earns gross return $G > 0$ from the project. If $\theta = \theta_b$, the state of the world is "bad" for the principal: the principal earns $-B$ from the project, a loss, since we follow the accounting convention of constraining $B > 0$. The state θ is observable and contractible. After θ is realized, wages are paid to the agent in accordance with the contract, and the principal receives the residual of the project's return.

The state of the world is stochastic, depending in part on the level of effort exerted by the agent. Specifically, we will model effort as affecting the distribution of an intermediate signal, observed by the agent in period 1, of the project's outcome. This intermediate signal in turn determines the probability of a good state. The intermediate signal is represented by the continuously distributed random variable X, with x representing a realization of X. If $e = e_L$, then the distribution function associated with X is $F_L(x)$ and the density, assumed to be continuous, is $f_L(x)$. If $e = e_H$, then the distribution function is $F_H(x)$ and the (continuous) density is $f_H(x)$. Assume that higher effort leads to higher realizations of X in the sense of first-order stochastic dominance: i.e., $F_L(x) > F_H(x)$ for all $x \in (0, 1)$. The intermediate signal is related to the final outcome in a straightforward way: X is the probability that $\theta = \theta_g$, and $1 - X$ is the complementary probability that $\theta = \theta_b$. Given this formulation, the probability of a good state is higher the more effort the agent exerts.

Both players are assumed to be risk neutral. The agent is assumed to have limited liability, formalized by constraining the net payment from the principal to the agent, w, to exceed some minimum, $\bar{w}$, in any contingency. This limited liability assumption can be justified by the existence of minimum-wage laws or limited wealth on the part of the agent. It can also be shown that this limited liability assumption is equivalent (in the sense that the equilibrium outcomes are the same under both) to the assumption that the agent has the freedom to quit the principal's employment in period 2 and earn his outside-opportunity wage, $\bar{w}$. Throughout most of the discussion we shall ignore any capital constraints for the principal, assuming she has unlimited liability.

Another relevant constraint that must be satisfied by a wage contract is the agent's participation or individual-rationality constraint: the expected surplus from signing the contract must exceed the surplus from the agent's best alternative (i.e., the agent's opportunity wage). We suppose throughout that the agent's cost of exerting effort is low enough that the participation constraint is never binding.[3] For example, supposing that $\bar{w}$ measures the agent's opportunity wage (as in the previous paragraph), a sufficient condition for the participation constraint not to bind is $k_L = 0$. If the contract satisfies limited liability and if $k_L = 0$, the agent can earn at least $\bar{w}$ by signing the contract and exerting low effort; so the agent at least weakly prefers to sign the contract.

Turn now to a specification of the form of optimal contracts. By the revelation principle (see Myerson, 1983), we may restrict attention to direct-revelation mechanisms. Referring to Figure 1, after the agent observes x, the realization of the intermediate signal, he makes a report $\tilde{x}$ of this signal to the principal. A direct-revelation mechanism is structured such that the report is truthful: i.e., $\tilde{x} = x$. Depending on the variant of the model under consideration, the principal may be allowed to take an action

[3] If the participation constraint did bind, there would be a multiplicity of optimal contracts. One solution would come from solving for the optimal contract in the absence of the participation constraint (as is done in the subsequent discussion) and then scaling up the resulting wage contract by a constant such that the participation constraint holds with equality.

contingent on $\tilde{x}$. In the variant of the model considered in Section 4, this contingent action takes the form of project cancellation: if the project is cancelled, θ is not realized and the project provides no return (positive or negative) to the principal.

A general direct-revelation mechanism specifies the following: $c(\tilde{x})$, the probability that the project is cancelled; $w_c(\tilde{x})$, the wage paid to the agent if the project is cancelled; $w_g(\tilde{x})$, the wage paid if the project is not cancelled and the state turns out "good" (i.e., $\theta = \theta_g$); and $w_b(\tilde{x})$, the wage paid if the project is not cancelled and the state turns out "bad" (i.e., $\theta = \theta_b$). All provisions of the contract can be contingent on the agent's announcement $\tilde{x}$. The cancellation probability is a function from the set of possible signals to the unit interval: i.e., $c:[0, 1] \to [0, 1]$. The wages—as an accounting convention reflecting transfers from the principal to the agent—are functions from the set of possible signals to the real line $w:[0, 1] \to \mathbf{R}$ (a transfer from the agent to the principal can thus be represented by a negative wage). The wage cannot be contingent on θ if the project is cancelled but can be contingent on θ if the project is continued.

By announcing a value for $\tilde{x}$, the agent effectively chooses a payment scheme that depends on both his announced signal and the true signal:

$$\begin{aligned} t(\tilde{x}, x) &= c(\tilde{x})w_c(\tilde{x}) + [1 - c(\tilde{x})][xw_g(\tilde{x}) + (1 - x)w_b(\tilde{x})] \\ &= a(\tilde{x}) + xb(\tilde{x}), \end{aligned}$$

where $a(\tilde{x}) \equiv w_b(\tilde{x}) + c(\tilde{x})[w_c(\tilde{x}) - w_b(\tilde{x})]$ and $b(\tilde{x}) \equiv [1 - c(\tilde{x})][w_g(\tilde{x}) - w_b(\tilde{x})]$. For any announcement $\tilde{x}$, it is evident that $t(\tilde{x}, x)$ is a linear function of x, with intercept $a(\tilde{x})$ and slope $b(\tilde{x})$. For concreteness, we will call $t(\tilde{x}, x)$ a linear payment schedule.

Four constraints govern the construction of the principal's optimal contract: individual rationality, limited liability, truth telling, and incentive compatibility. As mentioned above, we suppose the parameters of the model are such that individual rationality is never binding. Limited liability as specified above requires

$$\min[w_c(\tilde{x}), w_g(\tilde{x}), w_b(\tilde{x})] \geq \bar{w} \quad \forall \tilde{x} \in [0, 1]; \tag{1}$$

i.e., limited liability requires the wage always to exceed the agent's opportunity wage. Truth telling requires the agent to announce the true value of the signal:

$$t(x, x) \geq t(\tilde{x}, x) \quad \forall x, \tilde{x} \in [0, 1]. \tag{2}$$

To simplify the notation, define $T(x) \equiv t(x, x)$, the expected wage payment in equilibrium conditional on the true signal. Further, define the expectations operator $E_H[\cdot]$ by $E_H[g(x)] \equiv \int_0^1 g(x)f_H(x)\,dx$ and define $E_L[\cdot]$ analogously. Incentive compatibility requires that for the agent to exert high effort, the agent's marginal benefit of high effort must exceed his marginal cost:

$$e = e_H \quad \text{if and only if} \quad E_H[T(x)] - E_L[T(x)] \geq \Delta k. \tag{3}$$

Contracts satisfying constraints (1), (2), and (3) will be called feasible.

3. No cancellation possible

■ As a benchmark, we derive the optimal contract in the case in which the principal does not have the option to cancel the project, so that $c(\tilde{x}) = 0$ for all $\tilde{x} \in [0, 1]$. The only two contractual instruments left for the principal are $w_g(\tilde{x})$ and $w_b(\tilde{x})$ (since the principal never cancels the project, there is no scope for a cancellation wage $w_c(\tilde{x})$).

The main result of the section is that the wage is contingent on θ, the state of the world, but not on $\tilde{x}$, the announcement of the signal.

Following Grossman and Hart (1983), the problem of constructing the optimal contract can be divided into two stages. For each effort level, the feasible contract minimizing the principal's expected wage costs is computed in the first stage. In the second stage, the effort level giving the principal the highest surplus is selected for implementation. Suppose the principal wishes to elicit effort e_L from the agent. It is straightforward to verify that the optimal contract sets $w_g = w_b = \bar{w}$, and so the optimal contract is independent of $\tilde{x}$.

Next, suppose the principal wishes to elicit effort e_H from the agent. It can be shown that the contract minimizing the principal's expected wage costs is independent of $\tilde{x}$ in this case as well. Figure 2 provides intuition for the result. The figure presents a contract (indicated with a superscript o for "original") in which the wage levels $w_g^o(\tilde{x})$ and $w_b^o(\tilde{x})$ vary with $\tilde{x}$. Since the wage levels vary, the values of $a^o(\tilde{x})$ and $b^o(\tilde{x})$ will also vary, implying that there will be several linear payment schedules $t^o(\tilde{x}, x)$ having different slopes and different intercepts with the vertical axis. The figure is drawn with three different linear payment schedules. To ensure truth telling, $T^o(x)$, the equilibrium expected wage payment, must be the upper envelope of the linear payment schedules and therefore must be convex. The principal could earn more by offering a different contract (indicated with superscript n for "new") that sets fixed wages w_g^n and w_g^n so that only the steepest linear payment schedule is implemented. For the particular example in Figure 2, $w_b^n = w_b^o(x^3)$ and $w_g^n = w_g^o(x^3)$, implying $T^n(x) = t^o(x^3, x)$ for all $x \in [0, 1]$. Since $T^n(x)$ is below $T^o(x)$, the new contract reduces the principal's wage costs. Graphically, the difference between $E_H[T^o(x)]$ and $E_H[T^n(x)]$ is the area, weighted by $f_H(x)$, of the shaded region. Since $T^n(x)$ is steeper than $T^o(x)$, the new contract improves the agent's incentives to exert high effort, relaxing constraint (3).[4] Formally, we have

Proposition 1. Suppose the principal cannot cancel the project. The optimal contract sets $w_g(\tilde{x}) = w_g$ and $w_b(\tilde{x}) = w_b$, constants independent of $\tilde{x}$.

Proposition 1 stands in seeming contrast to the standard result that incentive schemes should be conditioned on all available information (Holmström, 1979; Shavell, 1979). The present setup differs from the standard one in that the additional information embodied in x is private information for the agent. Even though x is private information, it might be possible to insure a risk-averse agent against variation in θ by conditioning the contract on $\tilde{x}$ (see Segal and Tadelis, 1995). A crucial assumption for Proposition 1 to hold, therefore, is agent risk neutrality.

Given the results of Proposition 1, it is a straightforward exercise to derive the exact form of the optimal contract:

Proposition 2. Suppose the principal cannot cancel the project. The optimal contract sets $w_b^* = \bar{w}$. If the optimal contract elicits effort e_L, then $w_g^* = \bar{w}$. If the optimal contract elicits effort e_H, then $w_g^* = \bar{w} + \Delta k/(E_H[x] - E_L[x])$.

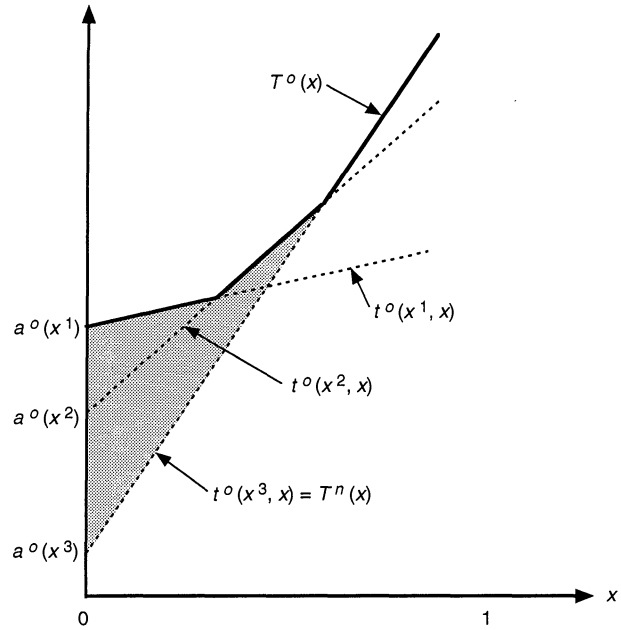
The wage in the bad state is set to preserve limited liability. If the optimal contract elicits high effort, the wage in the good state is constrained by incentive compatibility, so w_g is set such that (3) holds with equality.

Note that the contract in Proposition 2 is also the optimal contract in the case in which the signal X cannot be observed by the agent. Thus, as long as the principal

[4] The Appendix completes the proof that the optimal wage scheme when the principal cannot cancel the project is independent of $\tilde{x}$ by showing that the new wage scheme satisfies the remaining constraints, (1) and (2).

FIGURE 2

OPTIMAL CONTRACT WHEN CANCELLATION IS NOT POSSIBLE



cannot cancel the project, it is costless for the principal to extract the agent's information about the intermediate signal: the expected wage costs for a given effort level are the same whether the agent announces X or not.

There is no benefit to the agent's announcement of X in the present variant of the model, there are extensions in which the costless extraction of the agent's signal is beneficial to the principal. For example, consider the case in which the principal can make an investment that is negatively correlated with θ.[5] To be concrete, suppose the cost of investment is I; suppose the investment returns $R > I$ if $\theta = \theta_b$ and nothing if $\theta = \theta_g$. In this extension, the principal can benefit by conditioning her investment decision on the agent's report of x. Her optimal decision rule is to invest if and only if its expected return conditional on x, $(1 - x)\,R$, exceeds the cost, I. Equivalently, she invests if and only if the reported signal is low enough: $x < (R - I)/R$. Compared to the unconditional decision rule "never invest," for example, the conditional rule would provide the principal with additional surplus $\int_0^{(R-I)/R} [(1 - x)R - I]f_H(x)\,dx > 0$.[6]

We show in the next section (Proposition 4) that the principal cannot costlessly learn X if this information is used to cancel the project. Cancellation must therefore be fundamentally different from such actions as (from the preceding paragraph) the principal's investing I, actions we shall label noninterventionist. The difference between interventionist actions such as cancellation and noninterventionist actions is that the latter class of action does not reduce the amount of information the principal has about the performance of the agent. In the preceding paragraph, whether or not the principal

[5] The investment can be thought of as a real asset, such as an alternative technology licensed if it appears in-house development will be unsuccessful. It can also be thought of as the short sale of the firm's stock by shareholders based on the manager's inside information (we are grateful to Klaus Schmidt for this interpretation).

[6] Compared to the unconditional decision rule "always invest," the conditional rule gives the principal additional surplus $-\int_{(R-I)/R}^{1} [(1 - x)\,R - I]f_H(x)\,dx > 0$. (This surplus calculation and the one in the text preceding the footnote implicitly assume $e = e_H$. The calculations for effort e_L are analogous.)

invests I, θ is realized. On the other hand, cancellation prevents the realization of θ, destroying the one signal of the agent's effort.

4. Cancellation possible

■ In this section we allow the principal to cancel the project; i.e., we return to the assumption that the cancellation probability $c(\tilde{x})$ can take on positive values. For clarity, the analysis is limited to the case of deterministic cancellation, constraining $c(\tilde{x})$ to be zero or one.[7] We first present results maintaining the assumption that the principal can commit to a cancellation policy; the section concludes with an exploration of the no-commitment case.

To fix ideas, it is instructive to compute the cancellation policy that the principal would choose in the first-best case (i.e., the case in which the principal can verify effort and the intermediate signal). The principal would cancel the project if and only if, conditional on the intermediate signal x, the expected return from the project is non-negative: $xG - (1 - x)\, B \geq 0$. Defining $\hat{x} \equiv B/(B + G)$, the first-best policy is to cancel the project if and only if $x < \hat{x}$.

As in the previous section, we characterize the optimal contract using a two-stage procedure, first determining the optimal contracts that elicit effort levels e_L and e_H, respectively, and then determining which effort level gives the principal the higher surplus. It is a straightforward exercise to compute the optimal contract eliciting effort e_L. The contract sets $\bar{w}$ as the wage level in all contingencies, and the principal implements the first-best cancellation policy.

The first important result is that the added flexibility of being able to cancel the project is useful to the principal: i.e., the optimal contract with no cancellation is dominated by a contract with some cancellation. As argued in the previous paragraph, this result obviously holds if the optimal contract in the no-cancellation case elicits effort e_L. The proof for the case in which the contract elicits effort e_H involves an envelope-theorem-style argument. Take the optimal contract with no cancellation (indicated by superscript o for "original") and consider modifying it (the new contract indicated by superscript n) in the following way: for fixed cutoff z set $c^n(\tilde{x}) = 1$ for $\tilde{x} < z$ and $c^n(\tilde{x}) = 0$ for $\tilde{x} \geq z$, and set the wages to the lowest levels maintaining truth telling and incentive compatibility. Under this formulation, the original contract can be thought of as a special case of the new contract with $z = 0$. It can be shown that in a neighborhood of zero, increasing z by dz produces a first-order benefit $Bf_H(z)\, dz$. Intuitively, for $x \in (z, z + dz)$ (a realization of X occuring with probability $f_H(z)\, dz$), cancelling the project prevents the almost-certain loss of B. Increasing z may reduce the agent's incentives to exert effort by reducing the dependence of the wage on the project's outcome, but in a neighborhood of zero this is only a second-order loss. Intuitively, considering the set of x near zero, the project's return is almost certainly bad and thus does not depend on the agent's effort. Formally, we have

Proposition 3. Any contract with no cancellation is dominated by a contract with some cancellation (i.e., with the set $\{\tilde{x} \mid c(\tilde{x}) > 0\}$ having positive measure).

The next important result is that, compared to the benchmark case in which the principal can take no action after the initial contract offer, effort is lower if the principal can cancel the project. To make the discussion concrete, denote the principal's gross surplus (the principal's surplus ignoring wage payments to the agent) from the optimal contract eliciting effort e_L in the cancellation case by Π_L^C. Denote the principal's gross surplus from the optimal contract eliciting effort e_H by Π_H^C. Denote the expected wage

[7] In a previous version of the article available from the authors, random cancellation was considered. Propositions 3 through 6 generalize to this case.

payments to the agent by W_L^C and W_H^C, respectively. There are two effects leading the principal to elicit lower effort in the cancellation case. The first of these effects lowers the marginal benefit of high effort, $\Pi_H^C - \Pi_L^C$; the second increases the marginal cost of eliciting high effort, $W_H^C - W_L^C$. The marginal benefit is reduced because some projects are eventually cancelled. High effort on cancelled projects provides no benefit to the principal because the extra effort has no impact on the eventual state of the world. If, in contrast, there were no cancellation, that extra effort would have been valuable to the principal because it would have affected the likelihood of the good state of the world. The marginal cost of eliciting effort rises with project cancellation because the relationship between effort and the state of the world is weakened. When projects are cancelled, the state of the world that would have been realized in the absence of cancellation is never observed. Thus, the linkage between effort and outcomes is obscured, requiring a steep, costly incentive scheme to induce high effort from the agent.[8] We have thus sketched a proof that effort is lower when cancellation is possible than when cancellation is not possible. Stated formally,

Proposition 4. Suppose that the optimal contract in the no-cancellation benchmark (i.e., the case in which the principal can take no action after offering the contract to the agent) elicits effort e_L. Then the optimal contract in the cancellation case elicits effort e_L.

The following result, concerning the structure of wages, also emerges from the model:

Proposition 5. Suppose cancellation is possible. Then any contract is at least weakly dominated by a contract with $w_g(\tilde{x}) \geq w_c(\tilde{x}) \geq w_b(\tilde{x})\ \forall \tilde{x} \in [0, 1]$.

Proposition 5 implies that, conditional on the announcement $\tilde{x}$, the wage levels can be ranked without loss of generality. The agent is punished with the lowest wage level if the project is continued based on his announcement yet the bad state of the world results. The agent is rewarded with the highest of the three wage levels if the project is continued based on his announcement and the good state of the world results. He earns an intermediate wage if the project is cancelled based on his announcement. In effect, the agent receives a bonus for being honest about the future of the project, even if that means admitting that its prospects are not good.

The next proposition characterizes the principal's cancellation decision:

Proposition 6. Suppose cancellation is possible. First, any contract that cancels positive net present value projects (i.e., sets $c(\tilde{x}) > 0$ for $\tilde{x}$ in a subset of $(\hat{x}, 1]$ of positive measure) is at least weakly dominated by a contract that never cancels positive net present value projects (i.e., sets $c(\tilde{x}) = 0\ \forall \tilde{x} \in (\hat{x}, 1]$). Second, any contract that both elicits effort e_H and cancels all negative net present value projects (i.e., sets $c(\tilde{x}) = 1\ \forall \tilde{x} < \hat{x}$) is dominated by a contract that continues at least some negative net present value projects (i.e., sets $c(\tilde{x}) < 1$ for $\tilde{x}$ in a subset of $[0, \hat{x})$ of positive measure).

The second statement of the proposition implies that the first best can never be attained by feasible contracts if cancellation is possible.

Proposition 6 accords with intuition. Cancellation has two effects: (1) it changes the return on a project from either B or G to zero, and (2) it dulls the agent's incentives. For positive net present value projects, both effects hurt the principal. Consequently, such projects will never be cancelled, the first statement of Proposition 6. The second

[8] Though the second effect is not present in the first-best case since incentives are not an issue, the effect relating to the marginal benefit of effort is present in the first-best case. Consequently, the first-best level of effort is lower if cancellation is possible than in the no-cancellation benchmark.

statement of the proposition uses envelope-theorem-style arguments to show that it is optimal to allow some negative net present value projects to go to completion. For projects just below the break-even point $\hat{x}$, the benefit of cancellation in terms of increasing the project's expected return is second order, whereas the cost in terms of reducing incentives is first order. Thus, the principal would gain from continuing the project for $\tilde{x}$ in an interval below $\hat{x}$.[9]

Given that we have limited attention to contracts with deterministic cancellation, it is possible to characterize the optimal contract explicitly:[10]

Proposition 7. The optimal contract given deterministic cancellation specifies a cutoff $z^* \in (0, \hat{x})$ such that $c^*(\tilde{x}) = 0$ for $\tilde{x} \geq z^*$ and $c^*(\tilde{x}) = 1$ for $\tilde{x} < z^*$. It specifies three wage levels: $w_b^* = \bar{w}$,

$$w_g^* = \bar{w} + \frac{\Delta k}{E_H[\max(x, z^*)] - E_L[\max(x, z^*)]},$$

and

$$w_c^* = \bar{w} + \frac{z^* \Delta k}{E_H[\max(x, z^*)] - E_L[\max(x, z^*)]}.$$

It is possible to demonstrate graphically the costs associated with intervention using the results from the previous proposition. Figure 3 presents the expected wage scheme with no cancellation (line $\bar{w}$DE, also labelled $T^{NC}(x)$) and the expected wage scheme with deterministic cancellation for all $x < z^*$ (line BCF, also labelled $T^C(x)$) assuming that effort e_H is elicited at an optimum in both cases. Line $\bar{w}$DE would not be a feasible expected wage scheme if the principal cancelled the project for all $\tilde{x} < z^*$. In particular, the agent would gain by announcing a higher value for $\tilde{x}$ than the actual value x for all $x < z^*$, violating the truth-telling constraint. To preserve truth telling in the presence of cancellation, the expected wage scheme needs to be flat for $x < z^*$, e.g., line ADE. Line ADE is still not a feasible expected wage scheme in the presence of cancellation, however: the incentive-compatibility constraint just binds with scheme $\bar{w}$DE; the flatter scheme ADE would thus violate incentive compatibility. To preserve incentive compatibility while compensating for the flat region for $x < z^*$, the slope of the expected wage scheme for $x > z^*$ needs to be increased (shown in the figure as a movement from DE to CF). In sum, to counteract the detrimental effect of cancellation on the agent's incentives, the expected wage scheme must be raised from $\bar{w}$DE to BCF. The expected wage bill increases by the area of the shaded region (suitably weighted by $f_H(\cdot)$). Hence, the shaded region is a measure of the cost of "early warning" when it informs the principal's decision to intervene in the project (here, cancel the project for $x < z^*$).

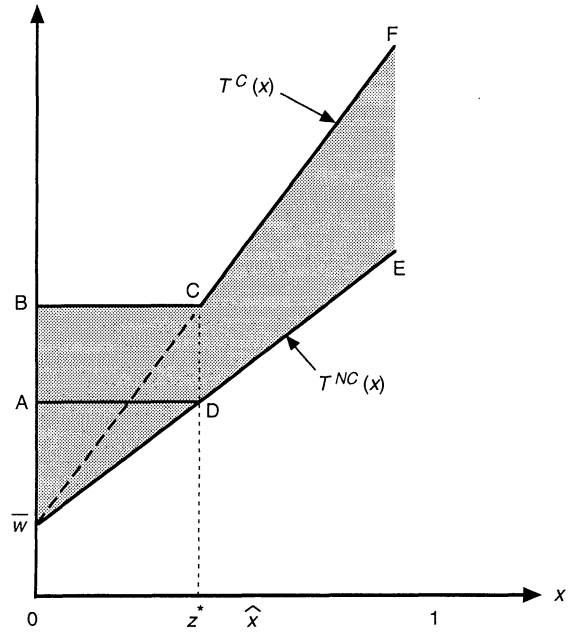
□ **No-commitment case.** The contractual assumptions under which the optimum in Proposition 7 can be attained are weaker than might first be thought. Suppose, for

[9] Bai and Wang (1995), in the context of soft-budget constraints, obtain similar conclusions about the continuance of *ex post* suboptimal projects.

[10] If random cancellation is possible, the first best can be approached arbitrarily closely by allowing the continuation probability for $\hat{x} < \tilde{x}$ to become arbitrarily small while allowing $w_g(\tilde{x})$ to grow without bound. Intuitively, for $\tilde{x} < \hat{x}$, the principal "audits" the project (by letting it continue and observing its outcome) with increasingly small probability but rewards the agent for successful performance with an increasingly large payment.

FIGURE 3

IDENTIFYING THE COSTS OF INTERVENTION



example, that the announcement $\tilde{x}$ is "soft" information, perhaps merely the agent's vague impressions of the progress of the project, and thus not contractible. It is still possible for the principal to obtain the same surplus as in Proposition 7. Consider a contract that specifies the same wage levels as in the proposition (w_g^*, w_b^*, w_c^*) but that delegates the decision to cancel to the agent. Given a realization x of the intermediate signal X, the agent cancels the project if $w_c^* \geq xw_g^* + (1 - x)w_b^*$ and continues it if $w_c^* < xw_g^* + (1 - x)w_b^*$. Substituting for the wage levels, it can be seen that the agent's equilibrium cancellation decision is identical to the principal's in Proposition 7; i.e., the agent cancels the project if and only if $x < z^*$ for the same cutoff z^* as in the proposition.[11]

In practice, it may be impossible for the principal to commit to delegate the cancellation decision to the agent; that is, cancellation authority may be inalienable. To explore this case formally, we shall assume that contracts cannot specify cancellation, maintaining the assumption from the previous paragraph that $\tilde{x}$ is observable but not contractible. Though the cancellation decision cannot be specified in the contract, we assume that once the cancellation decision has been made, the decision is verifiable and the wage can be conditioned on it. We shall refer to this set of assumptions as the no-commitment case. In the no-commitment case, general contracts can specify only three constant wages: w_c if the project is cancelled, w_g if the project is continued and θ_g is realized, and w_b if the project is continued and θ_b is realized.

One possibility is for the principal to design a contract that does not elicit early warning; i.e., in equilibrium the agent makes no announcement $\tilde{x}$.[12] A second possibility

[11] There exist contracts specifying random cancellation that strictly dominate the contract in Proposition 7. Thus, the inability to contract on $\tilde{x}$ does impair the performance of contracts if random cancellation is possible.

[12] Equivalently, if the agent makes an announcement, it is "babble." Intuitively, if w_c is set below $\max(w_g, w_b)$, the agent would never truthfully announce a value of $\tilde{x}$ that induces the principal to cancel the project.

is for the principal to design a contract eliciting early warning; i.e., in equilibrium the agent makes truthful announcements, $\tilde{x}$, of x. Interestingly, there is only one cancellation policy consistent with Bayesian-Nash equilibrium given that the contract elicits early warning. Only the first-best cancellation policy (recall this involves cancellation if and only if $x \leq \hat{x} \equiv B/(B + G)$) is consistent with the requirements that (a) the agent's report $\tilde{x}$ is truthful given the wage scheme and (b) the principal's cancellation decision is optimal conditional on the belief that $\tilde{x} = x$. Once the equilibrium cancellation policy is determined, it is straightforward to compute the remaining provisions of the optimal contract:

Proposition 8. The optimal contract eliciting early warning in the no-commitment case specifies wages $w_b^{**} = \bar{w}$,

$$w_g^{**} = \bar{w} + \frac{\Delta k}{E_H[\max(x, \hat{x})] - E_L[\max(x, \hat{x})]},$$

and

$$w_c^{**} = \bar{w} + \frac{\hat{x}\Delta k}{E_H[\max(x, \hat{x})] - E_L[\max(x, \hat{x})]}.$$

In equilibrium, the principal cancels the project if and only if $\tilde{x} \leq \hat{x}$.

Comparing this proposition with Proposition 7, it is evident that the optimal contracts eliciting early warning in the commitment and no-commitment cases share a similar structure. The only difference is that the cutoff value of $\tilde{x}$ below which the principal cancels the project is chosen optimally in the commitment case (z^*) but is exogenously given by $\hat{x}$ in the no-commitment case. Proposition 6 implies that in the commitment case, a contract with cutoff $\hat{x}$ is strictly dominated by one with a lower cutoff. Thus, we have the familiar result that an inability to commit reduces the principal's surplus.[13]

Indeed, it can be shown that the performance of contracts eliciting early warning in the no-commitment case may be so impaired that the principal prefers not to elicit early warning.[14] Intuitively, the principal is constrained to an exogenously given cutoff $\hat{x}$ for project cancellation rather than being able to fine tune the cutoff to preserve effort incentives. Consequently, the cost of early warning (loss of effort incentives) may outweight the benefit (early information about the project's outcome). In the commitment case, by contrast, the principal *is* able to fine tune the cancellation cutoff, leading to the result that the principal always prefers to elicit early warning (Proposition 3).

5. Discussion and applications

■ While the stylized nature of the model and lack of systematic data on the subject prevent direct testing of the model's predictions, it is nonetheless possible to relate its insights at an anecdotal level to real-world behavior. One observation that emerges from the model is that there is nothing intrinsic to bad news that makes it difficult to communicate. As long as the revelation of bad news does not lead to actions by the

[13] See, for example, the literature on the "ratchet effect" in a regulatory context (Laffont and Tirole (1993)) and the literature on the Coase conjecture regarding a durable-good monopolist (Tirole (1988)).

[14] Consider an example with $k_L = 0$, $\bar{w} = 0$, $G = B = 30$, $F_L(x) = x$, and $F_H(x) = x^\gamma$ for $\gamma > 1$. Fixing $\gamma = 1.35$ and allowing Δk to vary, it can be shown that the principal prefers not to elicit early warning if and only if $\Delta k < .04$ or $\Delta k > .18$. Fixing $\Delta k = 1$ and allowing γ to vary, the principal prefers not to elicit early warning if and only if $\gamma < 1.55$.

principal that destroy information about the agent's effort (actions we denote noninterventionist), early warning is costlessly obtained by the principal. A good example of this phenomenon is the reliance on information transmission from agents who are not responsible for the status quo and therefore will not be punished for revealing bad outcomes. Independent auditors are valuable precisely because they have no incentive to hide bad news.[15] One potential benefit of hiring outside consultants is that they may offer their clients an unbiased appraisal of situations, possible because the consultants had no hand in reaching the current state.[16] This may explain why relationships between consulting firms and clients tend to be short-lived: once the consultant is involved in changing an organization, he can no longer be trusted to convey bad news costlessly.[17]

Organizations also use a number of means to elicit early warning of bad outcomes from those whose incentives may naturally lead them not to reveal such information.[18] Honor codes, for instance, often note that those who come forward willingly will be punished less severely than those who are exposed through other means. Similarly, a guilty plea will typically result in a more lenient sentence in the criminal justice system. The Japanese business concept of *kaizen* or "continuous improvement" indirectly accomplishes the goal of early information revelation. Workers at all levels of the organization are expected to identify areas of improvement, analyze the problem, and develop their own solutions. Allowing workers to solve their own problems (thus avoiding intervention on the part of the principal that obscures the link between agent effort and outcomes) and rewarding workers for solving a problem rather than punishing them for its presence leads to a dramatic increase in the amount of information flowing upward through the hierarchy (Imai, 1986).

Because extracting information about the private signal can be costly to the principal, we would expect that organizations in which the agent's effort is important to outcomes, but in which the principal derives little value from early access, will not be structured to facilitate information transmission. The militaristic organization of most police departments fits this mold (Wilson, 1989; Bayley, 1994). Officers in the field are given tremendous discretion in responding to calls and in their treatment of suspected criminals. Officers are expected to interact only with their direct superiors. A "cover your back" mentality is pervasive. When problems are discovered, punishments are severe. This organizational form almost guarantees that bad news will not travel upward. The benefit to the principal (e.g., the police chief or mayor) from knowing what is going on within the organization, however, may be relatively small in this case.

Finally, our model predicts that the principal would like to commit not to intervene too actively in projects in order not to distort the effort levels of agents too much. The development of "skunk works" (Peters, 1987), in which a group of workers is moved off site and given greater spending and decision-making authority, is one example of such a commitment device. Another way for the principal to commit not to be overly interventionist is for her to be simply too busy, a solution also noted by Aghion and

[15] However, if the auditor later realizes that that he has made an error in his evaluation, e.g., failed to detect fraud, the auditor then has incentives to hide his mistake, just as the agent in our model does. See, for instance, Berton (1995).

[16] Consultants do not always solve the problem of information transmission, however: a consultant may be brought in to support the position of the manager who hired him.

[17] Prendergast and Stole (1996) offer another explanation for why job tenure may lead to excessive conservatism: a manager may be reluctant to change the level of investment in a project because such changes may reflect badly on his ability to identify projects' initial quality.

[18] Sometimes the incentives to report problems truthfully are naturally in place. We need not worry about an airline pilot's incentives to report problems with an aircraft, because the pilot flies along with the passengers. If we were sufficiently worried about an airline mechanic's willingness to provide early warning, sending him along on the flight would be a simple solution.

Tirole (1997). If a principal has many ongoing projects and obligations, the attention given to any one project is constrained.

6. Conclusion

■ This article examines the design of incentive schemes when the agent has not only unobservable effort but also a private signal about the eventual project outcome that is valuable to the principal. An agent who predicts a bad outcome receives a higher wage than an agent who incorrectly predicts a good outcome; in other words, agents are rewarded for early warning of impending problems. As long as the principal does not take any action that obscures the state of the world that would have transpired had the principal not received an agent's announcement of the signal, it is costless for the principal to elicit truthful revelation of the signal. More likely, however, the signal is valuable to the principal precisely because she bases actions on the agent's announcement that influence the outcome of the project. Extracting information about the signal interferes with extracting information about the unobserved effort. Consequently, obtaining early warning of the agent's signal is costly to the principal, i.e., it requires a higher expected wage bill for any given level of effort. Because of this tradeoff, the principal will commit to limit the level of intervention in response to the agent's announcement of the signal. In the model presented here, some negative net present value projects are not cancelled because the direct benefit of doing so is outweighed by the *ex ante* incentive effects of allowing such projects to continue. Although we restrict our analysis to the most extreme case of principal intervention, namely project termination, the intuition continues to hold for less-extreme actions taken by the principal that obscure the relationship between agent effort and project outcome (e.g., adding resources to the project or changing the reporting structure).

The tradeoff between early warning and effort incentives is even more clear if the principal cannot commit to a cancellation policy (or at least cannot commit to delegate the cancellation decision to the agent). In the no-commitment case, the principal may prefer not to elicit early warning from the agent. Playing on the phrase in our article's title, no news may not be bad news after all. This is true if effort incentives are particularly important—for example if high effort causes a substantial increase in the likelihood of project success.

While our model does not include a monitoring technology, it is clear that in the real world, monitoring is a substitute for the design of incentive schemes to elicit early warning of bad news. The choice of whether to use monitoring or incentive schemes that elicit early warning is likely to depend on the particular circumstances. Where monitoring is both cheap and easy, such as with a bank teller, it is likely to be the method of choice. When monitoring is less feasible, such as in research and development or in evaluating CEO performance, early-warning incentive schemes may be more prevalent.

An interesting extension to the model developed here is to allow for renegotiation. Segal and Tadelis (1995) demonstrate that access to an informative signal about the eventual state of the world can be costly to the principal when renegotiation is possible.[19] Similarly, we are able to show in our model that renegotiation may lead the principal to abandon any attempt to elicit early warning.

[19] The central tradeoff in Segal and Tadelis (1995) between *ex post* allocative efficiency and *ex ante* productive efficiency has appeared in a number of other contexts as well. See, among others, Schmidt (1991), Hansmann and Kraakman (1992), Aghion and Tirole (1997), Rotemberg and Saloner (1994), and Crémer (1995).

Appendix

■ Proofs of Propositions 1 through 8 follow.

Proof of Proposition 1. The proposition is obviously true if the optimal contract elicits effort e_L. Consider therefore a feasible contract eliciting effort e_H (the provisions of which are indicated by superscript o). Since $c^o(\tilde{x}) = 0\ \forall \tilde{x} \in [0, 1]$, $a^o(\tilde{x}) = w_b^o(\tilde{x})$ and $b^o(\tilde{x}) = w_g^o(\tilde{x}) - w_b^o(\tilde{x})$. We show that the principal can gain by offering a new contract (indicated by superscript n) specifying wage levels $w_b^n(\tilde{x}) = w_b^o(1)$ and $w_g^n(\tilde{x}) = w_g^o(1)$.

We need to show that the new contract is feasible. It satisfies limited liability, since the original contract satisfies (1). It satisfies truth telling, since the wage is not conditioned on $\tilde{x}$. To verify incentive compatibility, since the original contract satisfies (3), it is sufficient to prove $E_H[T^n(x)] - E_L[T^n(x)] \geq E_H[T^o(x)] - E_L[T^o(x)]$ or, defining $\Theta(x) \equiv T^o(x) - T^n(x)$, $E_L[\Theta(x)] \geq E_H[\Theta(x)]$.

First we show $\Theta(\cdot)$ is nonincreasing. Choose $x', x'' \in [0, 1]$ with $x' < x''$. Now

$$T^o(x'') - T^o(x') \leq (x'' - x')b(x'') \leq (x'' - x')b(1) = T^n(x'') - T^n(x').$$

The first inequality holds because (2) implies $T^o(x') \geq a^o(x'') + x'b^o(x'')$. The second inequality holds because $b^o(\tilde{x})$ is nondecreasing, a fact that can be established using standard revealed-preference arguments. Rearranging, $\Theta(x') \geq \Theta(x'')$. Second, $\Theta(x)$ is absolutely continuous on [0, 1] (see below); so the usual formula for integration by parts holds (Jones (1993)). Since $\Theta(x)$ is nonincreasing, integrating by parts implies $E_L[\Theta(x)] \geq E_H[\Theta(x)]$.

The proof is completed by verifying that the total wage bill falls with the new contract. Integrating by parts and noting that $\Theta(x)$ is nonincreasing shows that $E_H[\Theta(x)] \geq 0$.

To prove $\Theta(x)$ is absolutely continuous on [0, 1], note first that $\Theta(x)$ has bounded variation since it is monotone. Further, $\Theta(x)$ is convex on (0, 1) since $T^o(x)$ is convex and $T^n(x)$ is linear. (A revealed-preference argument establishes that $T^o(x)$ is convex if (2) holds.) Thus $\Theta(x)$ is locally absolutely continuous on (0, 1) (Royden (1988)). $\Theta(x)$ is continuous on [0, 1], since $T^o(x)$ and $T^n(x)$ are. Therefore, by Jones (1993), $\Theta(x)$ is absolutely continuous on [0, 1]. *Q.E.D.*

Proof of Proposition 2. The proposition is obviously true if the principal wishes to elicit effort e_L. Suppose the principal wishes to elicit effort e_H. By Proposition 1, the optimal contract specifies fixed wages w_b and w_g. It can easily be shown that $w_b^* = \bar{w}$. Consider any contract with $w_b = \bar{w}$ and with w_g such that (3) does not hold with equality. It is easy to verify that the principal's surplus can be improved by reducing w_g slightly. Hence, (3) must bind at an optimum. Treating (3) as an equality, substituting $E_H[T(x)] = \bar{w} + (w_g - \bar{w})E_H[x]$ (similarly for $E_L[T(x)]$), and solving yields the expression for w_g^* given in the statement of the proposition. *Q.E.D*

Proof of Proposition 3. The optimal contract with no cancellation was characterized in Proposition 2. Call this the original contract. Assuming cancellation is possible, we shall show that the original contract is strictly dominated by a new contract with cancellation on a set of positive measure. In the text it was argued that this result holds given that the original contract elicits effort e_L. Turn then to the case in which the original contract elicits effort e_H. Consider a class of contracts, indexed by z, that set $c(\tilde{x}) = 1$ if $\tilde{x} < z$ and $c(\tilde{x}) = 0$ if $\tilde{x} \geq z$. We label this class of contracts z-cutoff contracts. Within the class of z-cutoff contracts, we consider the subclass with the following wage structure: $\forall \tilde{x} \in [0, 1]$, $w_b(\tilde{x}) = \bar{w}$,

$$w_g(\tilde{x}) = \bar{w} + \frac{\Delta k}{E_H[\max(x, z)] - E_L[\max(x, z)]}$$

and

$$w_c(\tilde{x}) = \bar{w} + \frac{z\Delta k}{E_H[\max(x, z)] - E_L[\max(x, z)]}.$$

It is shown in the proof of Proposition 7 that this subclass of z-cutoff contracts is feasible. Denote the principal's surplus under a z-cutoff contract by $\Pi^n(z)$. We have

$$\begin{aligned}\Pi^n(z) &= \int_z^1 [xG - (1 - x)B]f_H(x)\,dx - E_H[T(x)] \\ &= \int_z^1 [xG - (1 - x)B]f_H(x)\,dx - \bar{w} - \frac{\Delta k E_H[\max(x, z)]}{E_H[\max(x, z)] - E_L[\max(x, z)]},\end{aligned}$$

where the second line holds by substituting for $E_H[T(x)]$ from (7) and then substituting for w_g from above. Differentiating,

$$\left.\frac{\partial \Pi^n(z)}{\partial z}\right|_{z=0} = Bf_H(z) > 0.$$

Note that setting $z = 0$ gives the original contract. Hence, there exists a z-cutoff contract that strictly improves on the original contract (namely, for some $z > 0$ in a neighborhood of zero). *Q.E.D.*

Proof of Proposition 4. We show first that the marginal benefit of high effort is lower in the cancellation case than in the no-cancellation benchmark; i.e., $\Pi_H^C - \Pi_L^C < \Pi_H^{NC} - \Pi_L^{NC}$. We then show that the marginal cost of high effort is greater in the cancellation case than in the no-cancellation benchmark; i.e., $W_H^C - W_L^C \geq W_H^{NC} - W_L^{NC}$. (Variables with NC superscripts are the analogs in the no-commitment case of those with the C superscripts defined in the text).

To compute the marginal benefit of effort in the cancellation case, note that

$$\begin{aligned}\Pi_L^C &= \int_{\hat{x}}^1 [xG - (1 - x)B]f_L(x)\,dx \\ &= (G + B)E_L[\max(x, \hat{x})] - B,\end{aligned} \tag{A1}$$

where the second line holds since $B = \hat{x}(B + G)$ by definition of $\hat{x}$ and since

$$\int_{\hat{x}}^1 xf_L(x)\,dx + \hat{x}F_L(\hat{x}) = E_L[\max(x, \hat{x})].$$

Further,

$$\begin{aligned}\Pi_H^C &= \int_0^1 [1 - c(x)][xG - (1 - x)B]f_H(x)\,dx \\ &\leq \int_{\hat{x}}^1 [xG - (1 - x)B]f_H(x)\,dx \\ &= (G + B)E_H[\max(x, \hat{x})] - B,\end{aligned}$$

where the second line holds since the first-best cancellation policy maximizes gross surplus and the third line holds by calculations similar to those for Π_L^C. Therefore,

$$\begin{aligned}\Pi_H^C - \Pi_L^C &\leq (G + B)\{E_H[\max(x, \hat{x})] - E_L[\max(x, \hat{x})]\} \\ &< (G + B)\{E_H[\max(x, 0)] - E_L[\max(x, 0)]\} \\ &= \Pi_H^{NC} - \Pi_L^{NC}.\end{aligned}$$

To see the second line, define $Q(z) \equiv E_H[\max(x, z)] - E_L[\max(x, z)]$. But $Q'(z) = F_H(z) - F_L(z) < 0$, implying $Q(0) > Q(\hat{x})$ since $\hat{x} > 0$. The last line can be seen by substituting $\Pi_H^{NC} = (G + B)E_H[x] - B$ and noting $E_H[x] = E_H[\max(x, 0)]$ (similarly for Π_L^{NC}).

Turn to the calculations of the marginal cost of effort. Now $W_L^{NC} = W_L^C = \bar{w}$. Thus the marginal cost of effort is higher in the cancellation case than in the no-cancellation benchmark if and only if $W_H^C \geq W_H^{NC}$. Denote by MIN1 the problem of minimizing $E_H[T(x)]$ subject to feasibility constraints. An argument paralleling the proof of Proposition 2 can be used to show that MIN1 is solved by the optimal contract in the no-cancellation case. Hence, the expected wage in the cancellation case must at least weakly exceed W_H^{NC}. *Q.E.D.*

Proof of Proposition 5. Take any feasible contract (indicated by superscript o). We show that the original contract is at least weakly dominated by a new contract (indicated by superscript n) with

$$w_g^n(\tilde{x}) \geq w_c^n(\tilde{x}) \geq w_b^n(\tilde{x})\ \forall \tilde{x} \in [0, 1].$$

Consider an arbitrary $\tilde{x} \in [0, 1]$. Suppose, first, that $c^o(\tilde{x}) = 1$. Then we can set $w_c^n(\tilde{x}) = w_c^o(\tilde{x})$. Since the project is always cancelled, we are free to set $w_g^n(\tilde{x}) = w_b^n(\tilde{x}) = w_c^o(\tilde{x})$. Suppose, second, that $c^o(\tilde{x}) = 0$. Then, as long as $w_g^o(\tilde{x}) \geq w_b^o(\tilde{x})$, we can set $w_g^n(\tilde{x}) = w_g^o(\tilde{x})$ and $w_b^n(\tilde{x}) = w_b^o(\tilde{x})$. Since the project is never cancelled, the value of $w_c^n(\tilde{x})$ is immaterial. Thus, we are free to set $w_c^n(\tilde{x}) \in [w_b^o(\tilde{x}), w_g^o(\tilde{x})]$.

It is left to show that a contract with $w_g^o(x') < w_b^o(x')$ for some $x' \in (0,1)$ such that $c^o(x') < 1$ is strictly

dominated by another contract. Consider a new contract with identical provisions to the original except for the wage levels for $\tilde{x} \leq x'$: $w_g^n(\tilde{x}) = \bar{w}$,

$$w_c^n(\tilde{x}) = \begin{cases} \dfrac{1}{c^o(\tilde{x})}\{c^o(x')w_c^o(x') + [1 - c^o(x')]w_g^o(x') - \bar{w}[1 - c^o(\tilde{x})]\} & \text{if } c^o(\tilde{x}) > 0 \\ w_c^o(x') & \text{if } c^o(\tilde{x}) = 0 \end{cases}$$

and

$$w_b^n(\tilde{x}) = \begin{cases} \bar{w} + \left[\dfrac{1 - c^o(x')}{1 - c^o(\tilde{x})}\right][w_b^o(x') - w_g^o(x')] & \text{if } c^o(\tilde{x}) < 1 \\ w_b^o(x') & \text{if } c^o(\tilde{x}) = 1. \end{cases}$$

Effectively, the new contract replaces $T^o(x)$ with the linear payment schedule $t^o(x', x)$ for $x < x'$. Since $T^o(x)$ is convex (see the proof of Proposition 1), the movement from $T^o(x)$ to $t^o(x', x)$ is a downward shift, implying that the new contract involves a lower expected wage bill than the original. The new contract is feasible by construction.

This completes the proof for the case of deterministic cancellation. The proof of the proposition in the random-cancellation case, similar in spirit to the preceding argument, is available upon request from the authors. *Q.E.D.*

Proof of Proposition 6. First statement of the proposition. Take any feasible contract (indicated by superscript o) with $c^o(\tilde{x}) > 0$ for some $\tilde{x} > \hat{x}$. Without loss of generality, we can assume $w_g^o(\tilde{x}) \geq w_c^o(\tilde{x}) \geq w_b^o(\tilde{x})$ by Proposition 5. Consider a new contract (indicated by superscript n) with $c^n(\tilde{x}) = 0$,

$$w_g^n(\tilde{x}) = [1 - c^o(\tilde{x})]w_g^o(\tilde{x}) + c^o(\tilde{x})w_c^o(\tilde{x}),$$

and

$$w_b^n(\tilde{x}) = [1 - c^o(\tilde{x})]w_b^o(\tilde{x}) + c^o(\tilde{x})w_c^o(\tilde{x}).$$

Note that this implies $w_g^n(\tilde{x}) \geq w_b^n(\tilde{x})$, since $w_g^o(\tilde{x}) \geq w_b^o(\tilde{x})$. We are free to set $w_c^n(\tilde{x}) \in [w_b^n(\tilde{x}), w_g^n(\tilde{x})]$, since the project is never cancelled. It can be verified that $a^n(\tilde{x}) = a^o(\tilde{x})$ and $b^n(\tilde{x}) = b^o(\tilde{x})$; so the new contract is feasible if it satisfies the limited-liability constraint. This is immediate since $w_g^o(\tilde{x}), w_c^o(\tilde{x}), w_b^o(\tilde{x}) \geq \bar{w}$.

The principal's expected wage bill is unchanged with the new contract. Conditional on $\tilde{x}$, her expected gross surplus (i.e., her surplus ignoring wage payments) increases by $[\tilde{x}G - (1 - \tilde{x})B]c^o(\tilde{x})$, a positive expression since $\tilde{x} > \hat{x}$.

Second statement of the proposition. Take any contract eliciting effort e_H and setting $c(\tilde{x}) = 1\ \forall \tilde{x} < \hat{x}$. The contract must also set $c(\tilde{x}) = 0\ \forall \tilde{x} > \hat{x}$ or it is dominated as shown in the first statement of the proposition. Hence it is a z-cutoff contract as defined in the proof of Proposition 3. The proof of Proposition 7 constructs the optimal z-cutoff contract for each z. Based on these results we can compute the principal's surplus from the optimal z-cutoff contract, which after some algebraic manipulation can be written

$$\int_z^1 [xG + (1 - x)B]f_H(x)\,dx - \bar{w} - \frac{\Delta k E_H[\max(x, z)]}{E_H[\max(x, z)] - E_L[\max(x, z)]}, \tag{A2}$$

where the first term is the principal's gross benefit from the project and the second and third terms are the expected wage $E_H[T(x)]$. The partial derivative of (A2) with respect to z can be shown to be negative $\forall z \geq \hat{x}$, implying that at an optimum, $z < \hat{x}$. *Q.E.D.*

Proof of Proposition 7. Step 1. We first show that the optimal contract involves a cutoff, z, such that there is cancellation if and only if $\tilde{x} \leq z$. Consider any contract with deterministic cancellation (indicated by superscript o). Take $x'' \in (0, 1)$ such that $c^o(x'') = 1$. (If such x'' does not exist, the claim is trivially true.) Suppose $\exists x' < x''$ such that $c^o(x') = 0$. Then

$$w_c^o(x'') \geq w_b^o(x') + x''[w_g^o(x') - w_b^o(x')] \geq w_b^o(x') + x'[w_g^o(x') - w_b^o(x')] \geq w_c^o(x'').$$

The first inequality follows since, by truth telling, $t^o(x'', x'') \geq t^o(x', x'')$; the second inequality follows since $w_g^o(x') \geq w_b^o(x')$ by Proposition 5; the third inequality follows from $t^o(x', x') \geq t^o(x'', x')$. In view of the second inequality, $w_g^o(x') = w_b^o(x')$. Consider replacing the original contract with a new contract (indicated by superscript n) with $c^n(x') = 1$ and $w_c^n(x') = w_g^o(x')$. The new contract is feasible and maintains the same

expected wage payments as in the original contract. Now by the first statement of Proposition 6, $x'' \leq \hat{x}$, implying $x' < \hat{x}$. Increasing the probability of cancellation increases the principal's gross surplus, since $x' < \hat{x}$.

Step 2. We next show that the optimum in the class of z-cutoff contracts specifies wage levels independent of $\tilde{x}$. Consider a feasible contract (indicated by superscript o) with $c^o(\tilde{x}) = 0\ \forall \tilde{x} \geq z$ and $c^o(\tilde{x}) = 1\ \forall \tilde{x} < z$. If this contract elicits effort e_L from the agent, it is at least weakly dominated by a contract offering wage $\bar{w}$ in all states. (It is strictly dominated if the wage is higher than $\bar{w}$ in any contingency.) Assume, therefore, that the contract under consideration elicits effort e_H from the agent. The principal can offer a new contract (indicated by superscript n) that at least weakly dominates the original contract, the new contract having the following provisions: $w_g^n(\tilde{x}) = w_g^o(1)$, $w_b^n(\tilde{x}) = w_b^o(1)$, and $w_c^n(\tilde{x}) = w_b^o(1) + z[w_g^o(1) - w_b^o(1)]$. Arguments similar to those in the proof of Proposition 2 can be used to show that the new contract is feasible. To show that the principal pays a lower expected wage with the new contract, note first that $\forall x \geq z$,

$$T^o(x) = w_b^o(x) + x[w_g^o(x) - w_b^o(x)] \geq w_b^o(1) + x[w_g^o(1) - w_b^o(1)] = T^n(x).$$

Note second that $\forall x < z$, $T^o(x) = w_c^o$, where w_c^o is a constant independent of x to maintain truth telling. Now $\forall x < z$, $w_c^o \geq w_b^o(1) + x[w_g^o(1) - w_b^o(1)]$, or else truth telling would be violated with the original contract. By continuity, then, $w_c^o \geq w_c^n$. Hence, $\forall x < z$, $T^o(x) \geq T^n(x)$.

Step 3. Last, we explicitly compute the wage levels w_g^*, w_b^*, and w_c^*. To ensure truth telling, $w_c \geq w_b + x(w_g - w_b)\ \forall x < z$; and $w_c \leq w_b + x(w_g - w_b)\ \forall x \geq z$. By continuity,

$$w_c = w_b + z(w_g - w_b). \tag{A3}$$

Therefore,

$$\begin{aligned} E_H[T(x)] &= \int_z^1 [w_b + x(w_g - w_b)]f_H(x)\,dx + w_c F_H(z) \\ &= w_b + (w_g - w_b)]E_H[\max(x, z)], \end{aligned} \tag{A4}$$

where the second line follows by substituting for w_c from (A3) and noting $\int_z^1 xf_H(x)\,dx + zF_H(z) = E_H[\max(x, z)]$.

Consider the problem of minimizing $E_H[T(x)]$ subject to (1) and (3). In view of (A4), this problem is equivalent to minimizing $w_b + (w_g - w_b)E_H[\max(x, z)]$ subject to w_g, $w_b \geq \bar{w}$ and

$$(w_g - w_b)\{E_H[\max(x, z)] - E_L[\max(x, z)]\} \geq \Delta k.$$

It is evident that the solution is $w_b = \overline{w}$ (the lowest w_b subject to the limited-liability constraint) and w_g as given in the statement of the proposition (the lowest w_g subject to the incentive-compatibility constraint); w_c can then be computed from (A3). *Q.E.D.*

Proof of Proposition 8. If $\tilde{x}$ is a truthful announcement, the principal cancels the project if and only if $\tilde{x}$ satisfies $-w_c \geq \tilde{x}(G - w_g) - (1 - \tilde{x})(B + w_b)$ or, equivalently, if and only if $\tilde{x} \geq z$ for

$$z = \frac{B - (w_c - w_b)}{G + B - (w_g - w_b)}. \tag{A5}$$

To induce truth telling, the wages must satisfy $w_c > xw_g + (1 - x)w_b$ for $x < z$ and $w_c < xw_g + (1 - x)\,w_b$ for $x > z$. By continuity,

$$w_c = zw_g + (1 - z)w_b. \tag{A6}$$

Equations (A5) and (A6) together imply $z = \hat{x}$. Thus, the principal's cancellation policy is identical to the first-best one.

Arguments similar to the proof of Proposition 7 show that the optimal wages are w_g^{**}, w_b^{**}, and w_c^{**}. *Q.E.D.*

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