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Transparency in Hierarchies

CHRISTIAN HOFMANN* AND RAFFI J. INDJEJIKIAN†

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ABSTRACT

We use an agency model to address the benefits and costs of transparency in a hierarchical organization in which the principal employs a manager entrusted with contracting authority and several workers, all under conditions of moral hazard. We define the principal's transparency choices as a decision to allow workers to observe their coworkers' performances (*observability*) and as an investment in monitoring worker performance (*precision*). We find that whereas precision alleviates agency conflicts as expected, observability can exacerbate agency conflicts, especially if the manager's interests are misaligned sufficiently with those of the principal. Our results suggest several testable hypotheses including predictions that opaque performance measurement practices are well suited for small organizational units at lower hierarchical ranks, and in settings where the sensitivity-precision of the available measures is low, workers' performances are correlated positively, and managerial productivity is modest.

*LMU Munich School of Management; †University of Michigan Ross School of Business

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1. Introduction

Many organizations tout their workplace *transparency* by enabling freer flow of information, widely publicizing employee performance, and by designing interactive work environments. Yet, other organizations continue to employ opaque practices such as establishing employee "privacy zones," using more aggregate and coarser performance measures, and erecting informational boundaries around teams (Bernstein [2014]).[1] We use an agency model to address the benefits and costs of transparent performance measurement practices in a hierarchical organization where the principal (owners or senior managers) employs a midlevel manager and several workers (rank-and-file employees), all under conditions of moral hazard.

We focus on hierarchies to best depict settings where delegation of decision rights to managerial ranks and grouping of workers by rank feature prominently. As a motivating example, consider a consulting firm comprised of a managing partner (principal), a senior consultant (manager), and several junior consultants (workers). In this three-tier hierarchy, we assume the managing partner contracts with the senior consultant but delegates to the senior consultant the authority to hire and compensate some (or all) of the junior consultants.[2]

We define the principal's transparency choices in two ways: (1) as a decision to allow rank-and-file employees to observe their coworkers' performances, labeled performance *observability*, and (2) as an investment in monitoring rank-and-file employee performance, labeled performance *precision*. In our motivating example, the consulting firm's accounting system monitors the junior consultants' performances, where a larger monitoring investment by the managing partner yields more precise (transparent) performance information. The managing partner also decides whether the junior consultants' performances are transparently observed by all (e.g., shared via public performance rankings), selectively observed among a subset of consultants, or privately observed (e.g., via individual performance reviews). This "observability" definition of transparency creates informational boundaries around subsets of consultants

[1] Descriptively, transparency practices vary widely. For instance, whereas some firms use and publicize employee performance rankings (e.g., Amazon, Google, and PwC), others such as Microsoft, GE, and Accenture have mostly abandoned such ranking practices (Kantor and Streitfeld [2015], Cappelli and Tavis [2016]). Similarly, although some firms employ open-book accounting, others erect "Chinese walls" to limit access to information.

[2] We focus on a manager's contracting authority (rather than other decision rights such as providing operational direction and support) to underscore the importance of hiring and evaluating employees as the quintessential managerial task (Fama and Jensen [1983]).

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where individual accomplishments are well known within each subset (or team) of consultants but opaque to others.[3]

We illustrate how transparent practices resolve (or exacerbate) a common agency problem in hierarchical organizations that feature delegated decision rights. We refer to this problem as a "control loss" in the sense that an organization bears a cost (loses control) if midlevel managers' interests are not aligned with the organization's interests.[4] In our model, the control loss manifests as lower output by the manager's workers because divergent risk preferences of the manager and the principal imply that the principal bears an additional risk premium to motivate the manager and his team(s), henceforth referred to as a *team risk premium*.

We characterize a team's risk premium as the product of (i) a team's aggregate risk aversion and (ii) the magnitude of a team's risk. Transparency, as *observability*, affects a team's aggregate risk aversion and the magnitude of a team's risk differently. Because observability among teammates improves the manager's ability to share risk with his workers, it decreases a team's aggregate risk aversion and consequently reduces a team's risk premium. However, observability increases the magnitude of a team's risk, which increases a team's risk premium. The latter effect is most evident in circumstances where risk sharing is most salient; for instance, if the manager is sufficiently risk averse, if he oversees a small group of workers whose performances are difficult to measure, or if the available measures of worker performance are not very sensitive to worker effort (i.e., the sensitivity-times-precision is low). In these settings, we find that the principal prefers opaque performance measurement practices to reduce the magnitude of a team's risk, reduce the associated control loss, and boost worker effort.

Transparency, as *precision*, reduces a team's risk but does not affect a team's aggregate risk aversion. Hence, measures that are more precise always reduce the control loss in a hierarchy and increase worker effort. Importantly though this benefit is in addition to the conventional agency benefit of more precise measures. This means that the marginal benefit of precision is higher in delegated (hierarchical) settings than in centralized ones. Thus, we find that the principal typically invests more in monitoring the manager's workers than she would if she were to contract with the workers herself.

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[3] In our setting, a decision about performance observability is akin to a decision about employee team size where *full* transparency means all employees are on one team and observe everyone's performance, selective transparency means multiple teams with more than one employee each, and complete opaqueness means individualized performance evaluation with one employee per team.

[4] In principal-agent settings, a principal's control loss is the profit foregone by delegating decision rights to an agent (Calvo and Wellisz [1978], Melumad et al. [1995], Mookherjee (2013]). Of course, delegating decision rights can also be beneficial if it generates a positive externality (Aghion and Tirole [1997], Brickley et al. [2021]). We address this issue in section 5.2 where we consider the principal's decision to delegate contracting authority.

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Our findings that transparency practices resolve (or exacerbate) control losses generalize to more realistic settings where synergies among workers' activities or commonalities in their work environment imply that workers' performance measures are correlated. A standard prescription in these settings is to employ relative performance evaluation (RPE). Of course, RPE requires observability, that is, workers observing their coworkers' performances. However, in settings where observability increases a team's risk premium and exacerbates the control loss, the principal may prefer opaque performance measurement practices and thus forego the benefits of RPE. In particular, we find that the principal largely foregoes RPE in settings where workers' performances are correlated *positively* because a team's risk premium is higher with positive correlation than negative correlation.

Our analysis of transparency practices presupposes that delegated contracting authority features prominently in hierarchical organizations. However, if delegating authority triggers a control loss, a more fundamental question is why delegate authority to a midlevel manager in the first place. Although organizations delegate decision rights for many reasons, in our model the principal delegates contracting authority because delegation generates a positive externality; it motivates the manager to provide more effort. We find that the principal chooses to centralize, partially delegate, or fully delegate contracting authority for all workers depending on the tradeoff between the benefit of more managerial effort and the aforementioned control loss associated with delegation. In particular, we find that managerial productivity complements transparency in the sense that managers that are more productive evaluate their employees with more transparent practices than less productive managers.

The economics and management literatures have addressed the meaning, merits, and consequences of transparency from a variety of perspectives. For instance, Schnackenberg and Tomlinson [2016] define transparency as the information quality in a sender-receiver relationship in terms of accuracy, disclosure, and clarity. The standard intuition is that transparency reduces information asymmetries and improves accountability. Winter [2010] shows that observability of coworkers' actions generates implicit incentives if workers' actions are complementary (see also Piccolo et al. [2015]). There is also evidence that performance transparency motivates effort, mitigates misreporting, reduces biases in subjective performance evaluations, and fosters group identity (e.g., Hannan et al. [2013], Tafkov [2013], Maas and Van Rinsum [2013], Bol et al. [2016], Shang et al. [2020]). Finally, some argue that observing information may not suffice to achieve transparency if economic agents have limited resources to extract useful information from publicly observable signals (e.g., Geraats [2002]).

Transparency also has negative consequences. For example, in some agency relationships a principal may benefit from less transparency; for example, by limiting agents' access to information (e.g., Christensen [1981], Sobel [1993], Indjejikian and Nanda [1999], Christensen et al. [2002], Jehiel [2015], Ederer et al. [2018]). Research also suggests that transparency

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misdirects effort, promotes collusive behavior, or triggers feelings of envy, disappointment, or anger among workers (e.g., Prat [2005], Hannan et al. [2008], Evans et al. [2016], Maas and Yin [2022]).

We contribute to the transparency literature in several ways. First, we illustrate how different dimensions of transparency, observability versus precision, have distinct effects on hierarchical organizations. Whereas precision helps alleviate agency conflicts as expected, observability can exacerbate agency conflicts. We suggest several predictions about performance measurement practices, testable either at different hierarchical ranks (within an organization or among organizations in flat versus more decentralized organizations) or at the same hierarchical rank in different organizational units. In particular, we predict that employees at lower hierarchical ranks (below senior management) are monitored more than employees closer to senior management in rank, but their performance evaluations are likely more private and less observable by coworkers.[5] For employees at lower ranks, we also predict that opaque measurement practices are more prevalent in small organizational units with few employees and in units led by modestly productive managers than in larger units or divisions led by managers that are more productive.

Second, we contribute to the RPE literature. Evidence suggests that the use of RPE at the CEO level is common (e.g., Antle and Smith [1986], Albuquerque [2009], Gong et al. [2011]) but the evidence at lower hierarchical ranks is mixed. For example, Matsumura and Shin [2006] find firms employ RPE at lower hierarchical ranks but Bandiera et al. [2005] find that firms forego RPE in favor of individualized piece rates. More recently, Holzhacker et al. [2019] find that RPE discourages cooperation among peers. Consistent with this literature, we predict that RPE is less prevalent for employees at lower ranks than at higher ranks, and particularly less prevalent if employees' performances are correlated positively (e.g., if they work in similar environments).

Third, we contribute to the pay-transparency literature. Evidence suggests pay transparency creates positive career incentives for higher level employees (Gibbons and Murphy [1992]), precludes inefficient executive compensation (Bebchuk and Fried [2003, 2004]), and may reduce an organization's power in collective bargaining and unionization efforts of rank-and-file employees (Corbett [2002], Bierman and Gely [2004]).[6] In contrast to this literature, we provide an agency-based rationale for why

[5] Empirical evidence suggests that performance measurement practices vary by hierarchical rank (e.g., Bushman et al. [1995], Aggarwal and Samwick [2003]). Anecdotally, our predictions comport well with organizations using less precise but broadly observable performance measures to evaluate senior managers (e.g., noisy stock price-based measures) but more individualized measures for employees at lower hierarchical ranks.

[6] Pay transparency may also be detrimental to an organization as it can reduce employee motivation (Greiner et al. [2011], Cullen and Perez-Truglia [2022]); job satisfaction and employee retention (Card et al. [2012], Mas [2017]); and social cohesion and cooperation (Breza et al. [2018]).

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hierarchical organizations may not publicize employee performance and compensation information.

The rest of the paper is organized as follows. In section 2, we present the model. In section 3, we solve for the optimal compensation arrangements, taking the transparency arrangements and delegation of contracting authority as given. In section 4, we solve for the optimal transparency arrangements, taking the delegation of contracting authority as given. In section 5, we extend our analysis to incorporate correlated performance measures and characterize the optimal delegation of contracting authority. In section 6 we conclude. The proofs of the propositions and corollaries are in the appendix.

2. Model

We consider a single-period model of an organization with three actors, a risk-neutral principal acting on behalf of owners or senior management, a midlevel manager, and $N \geq 2$ (ex ante identical) workers lower in the hierarchy. We assume the manager and the workers are risk averse with negative exponential preferences characterized by risk-aversion coefficients r_m and r_w, respectively.

The organization's expected output is given by

$$\mathrm{E}(x) = b_m a_m + b_w \sum_{i=1}^{N} a_{wi}, \tag{1}$$

where a_m and a_{wi} represent the manager's and workers' efforts, respectively, provided at costs $a_m^2/2$ and $a_{wi}^2/2$, with marginal productivities b_m and b_w. We assume output x is completed in sequence so that the manager's effort, a_m, precedes the workers' efforts, a_{wi}. Descriptively, this captures contexts where managers set priorities, establish plans, and procure necessary inputs before starting production.[7]

We assume the accounting system can generate $N+1$ performance measures, one for the manager and one for each worker, characterized by

$$x_m = b_m a_m + \varepsilon_m, \tag{2a}$$

$$x_{wi} = b_w a_{wi} + \varepsilon_{wi}, \quad i = 1, \ldots, N, \tag{2b}$$

where ε_m and the ε_{wi}s are independent with $N(0, \sigma_m^2)$ and $N(0, \sigma_w^2/W_i)$, respectively, and W_i is (scaled) precision as specified below. Because workers' performance measures in practice often are correlated, we address the impact of correlated ε_{wi}s in section 5.1 including the potential for team-based RPE.[8]

[7] The manager can also provide effort both before and concurrently with the workers without qualitatively affecting our results.

[8] The performance measures described in (2) abstract away from other descriptive measurement features in addition to correlation. For instance, in practice, a manager's performance

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2.1 SEQUENCE OF EVENTS

First, the principal decides whether to delegate the authority to hire and compensate some or all N workers to the manager or retain that responsibility for herself. To ensure a meaningful portrayal of a hierarchical organization where managers have contracting authority, we assume the principal cannot bypass the manager and contract directly with the manager's workers.

Second, the principal decides the extent to which the workers' performance measures will be *transparent* within the organization. We consider two dimensions of transparency, which we refer to as (i) performance *observability* and (ii) performance measure *precision.*

To characterize observability, we assume the principal can limit the personnel that are privy to a worker's performance by assigning each worker to a team, where "transparency" is prevalent within teams but not among teams. In particular, we assume a focal worker's performance is observed by the principal, the manager, the focal worker, and (symmetrically) by all coworkers on a focal worker's team, but it is not observed by workers on other teams. We let S_i represent the set of all coworkers on worker i's team and let $t_i = |S_i| + 1$ represent team size (excluding the manager), with larger teams deemed more transparent than smaller ones.

For precision, we let W_i in σ_w^2/W_i represent the principal's monitoring investment for worker i, acquired at a cost of $z_w W_i$.[9] To ensure that some investment is always optimal, $W_i > 0$, and all workers are profitable to employ, we assume $z_w \leq z_w^{\max} = \frac{1}{4}\frac{b_w^4}{r_w \sigma_w^2}$ and $r_w \geq r_w^{\min} = \frac{r_m}{\sqrt{2}}$ where $z_w^{\max}$ and $r_w^{\min}$ are derived in the proof of Proposition 2.

Descriptively, we envision $z_w W_i$ to include the installation costs of new performance measurement systems as well as the expenses associated with improvements in existing systems. In turn, the assumption that $r_w \geq \frac{r_m}{\sqrt{2}}$ matches descriptive evidence that more risk-tolerant individuals often occupy higher level positions or work in environments that are more demanding and volatile, positions more characteristic of managerial ranks than rank-and-file employees (e.g., Bonin et al. [2007], Dohmen et al. [2010]).

Third, the principal selects the manager's compensation contract, c_m, reflecting the manager's contracting authority and her own transparency decisions and set in a manner to ensure the manager receives his reservation wage (we scale the manager's reservation wage so that his reservation

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measure often combines the contributions of the manager and his workers. Such combined or aggregate signals retain the economic effects of our simplified setting with some additional effects due to aggregation (e.g., Feltham et al. [2016], Proposition 3).

[9] Ziv [2000], Drymiotes [2007], and Friedman [2014], among others, provide a similar characterization of performance measure precision. As modeled, W_i is the precision of an individual worker's performance measure but we can extend the model to settings where monitoring investments are directed at team-level, group-level, or organization-wide performance.

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certainty equivalent is zero). We assume c_m is a linear function of potentially all performance measures described in (2),

$$c_m = f_m + v_m x_m + \sum_{i=1}^{N} \delta_{mi} x_{wi}, \tag{3}$$

where f_m is the manager's fixed compensation, v_m is the incentive rate tied to his own performance, and the δ_{mi}s are the manager's incentive rates tied to his workers' performances. We exclude the possibility that the manager's contract depends on the contract signed between the manager and his workers. If such a "contract of contracts" were possible, the principal would have full contracting authority, which would a priori preclude the idea of delegation of authority in a hierarchy (Macho-Stadler and Pérez-Castrillo [1998]).

Fourth, given sequential production, the manager provides a_m and chooses his workers' contracts, whereas the principal chooses the contracts for all workers for whom she retains contracting authority (if any). Sequential production means that workers are aware of the manager's effort and adjust their subsequent behaviors accordingly (see also Baliga and Sjöström [1998], Strausz [1999], Jelovac and Macho-Stadler [2002], Winter [2006]). In particular, we assume the principal and workers observe a soft unverifiable signal of the manager's effort, say $\psi = a_m$, before the workers accept their contracts and provide effort a_{wi} (see also Hortala-Vallve and Sanchez Villalba [2010]).[10]

A key feature of our model is that the principal cannot use ψ in the manager's contract because ψ is unverifiable. Of course, a mechanism where the principal truthfully extracts the workers' soft information about a_m can render ψ verifiable and contractible (Ma [1988], Ma et al. [1988]). However, because such mechanisms are neither technically robust nor descriptively realistic, we preclude such revelation mechanisms (Hermalin and Katz [1991], Aghion et al. [1994]). Technically, this means that delegating contracting authority to a manager-agent is potentially optimal, an issue we address more directly in section 5.2.

The workers' compensation contracts are set to ensure that they receive their reservation wages (scaled so that their reservation certainty equivalents are zero). In line with our assumption for the manager, we assume

[10] We can extend the model to a setting where the principal and the workers observe a noisy soft signal ψ rather than a perfect signal of the manager's effort. Assuming that workers accept their contracts after observing ψ is descriptive of settings where employees accept employment after "doing their homework" about their future employer. For example, in large organizations where employees transfer among divisions, hiring interviews and conversations with future colleagues provide employees with ample soft information about their future bosses.

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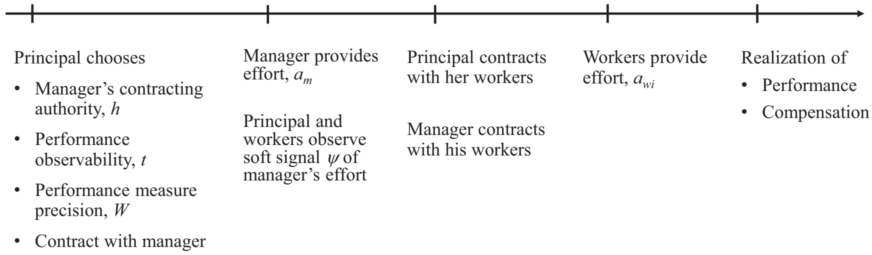

FIG. 1.—Timeline of events.

that the workers' contracts are also linear functions of potentially all observed performance measures described in (2),

$$c_{wi} = f_{wi} + v_{wi}x_{wi} + \sum_{j \in S_i} \delta_{wij}x_{wj} + \delta_{wmi}x_m, \quad \text{for } i = 1, \ldots, N, \tag{4}$$

where the f_{wi} are the workers' fixed compensation, the v_{wi} are the incentive rates tied to their own performance, the δ_{wij} are the incentive rates tied to their coworkers' performances, and the δ_{wmi} are the incentive rates tied to the manager's performance.

Fifth, after accepting their contracts, the workers provide effort, the manager's and the workers' performances are observed, and the manager and the workers are compensated.

Figure 1 summarizes the timeline of events.

3. Incentives in Hierarchies

In this section, we describe the manager's and the workers' effort choices and compensation contracts, assuming the principal's transparency choices (i.e., observability and precision) are already set. We also assume that all workers are assigned either to the principal (centralized contracting, labeled as $h = 0$) or the manager (delegated contracting, labeled as $h = 1$). We defer deriving the principal's transparency choices (observability and precision) to section 4 and her decision to delegate contracting authority to the manager to section 5.2.

We begin by rewriting the manager's and workers' compensation contracts described in (3) and (4). Given ex-ante identical workers and symmetric observability, without loss of generality, we rewrite the contracts as

$$c_m = f_m + v_m x_m + \delta_m A_m \tag{5a}$$

and

$$c_{wi} = f_w + v_w x_{wi} + \delta_{ww} A_{wi} + \delta_{wm} x_m, \text{ for } i = 1, \ldots, N, \tag{5b}$$

where f_m and f_w are the fixed compensation components, v_m and v_w are the incentive rates tied to agents' own performance, the δs are the incentive

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rates tied to other agents' performances, $A_m = \sum_{i=1}^{N} x_{wi}$ is the combined performance of the N workers, and $A_{wi} = \sum_{j \in S_i} x_{wj}$ is the combined performance of worker i's teammates. Also, given identical workers and symmetry, $W_1 = \cdots = W_N = W$ and $t_1 = \cdots = t_N = t$, where $t \in [1, \ldots, N]$.[11]

With centralized contracting, the principal contracts with the manager and with all N workers. That is, the principal sets v_m, v_w, δ_m, δ_{ww}, and δ_{wm}. In contrast, with delegated contracting, the principal contracts with the manager as always but delegates to the manager the authority to set v_w, δ_{ww}, and δ_{wm} for the N workers. Delegation implies that the manager is responsible for hiring and compensating his workers, which in turn requires that the principal compensate the manager for the workers' compensation as well as any risk the manager bears associated with compensating his workers.[12]

In the appendix, we derive the manager's and the workers' optimal effort choices and compensation contracts under both centralized and delegated contracting settings. The following lemma characterizes the key highlights.

Lemma 1.

(i) The manager's and workers' efforts are characterized by:

$$a_m = b_m v_m \quad \textit{and} \quad a_{wi} = b_w v_w \quad \textit{for } i = 1, \ldots N; \tag{6a}$$

(ii) The manager's compensation contract is characterized by:

$$v_m = \frac{b_m^2}{b_m^2 + r_m \sigma_m^2 \left(\frac{r_m^{-1}}{r_m^{-1} + hN r_w^{-1}} \right)} \quad \textit{and} \ \delta_m = h \left(1 - \frac{T_t \sigma_w^2 \left(\frac{1-\gamma_w}{\gamma_w} \right)}{b_w^2 W + T_t \sigma_w^2 \left(\frac{1-\gamma_w}{\gamma_w} \right)} \right); \tag{6b}$$

(iii) The workers' compensation contracts are characterized by:

$$\delta_{wm} = h \left(\frac{N r_w^{-1}}{r_m^{-1} + N r_w^{-1}} \right) \frac{v_m}{N}, \ v_w = \frac{b_w^2 W (1-h)}{b_w^2 W + r_w \sigma_w^2} + \gamma_w \delta_m \ \textit{and}$$

$$\delta_{ww} = \frac{T_t}{r_w} (1 - \gamma_w) \delta_m \ \textit{for} \ t \geq 2, \tag{6c}$$

where $h = 0, 1$ denotes centralized and delegated contracting, respectively, $\gamma_w = \frac{b_w^2 W + r_w \sigma_w^2 \left(\frac{T_t \sigma_w^2}{b_w^2 W + r_w \sigma_w^2 + T_t \sigma_w^2} \right)}{b_w^2 W + r_w \sigma_w^2}$ represents a worker's fraction of the manager's incentive tied to the worker's performance, and $T_t = (r_m^{-1} + (t-1) r_w^{-1})^{-1}$ represents a team's aggregate risk aversion.[13]

[11] Because team size, t, is an integer, for analytical convenience we assume the number of teams that can be formed from N workers, N/t, is also an integer. Importantly, because the optimal t derived in section 4 is either 1 or N, assuming N/t is an integer is inconsequential.

[12] This is not unlike bonus plans in practice where head office determines the size of divisional bonus pools but delegates to divisional management the authority to distribute the pool within the division.

[13] Technically, T_t represents the aggregate risk aversion of a worker's $t - 1$ teammates plus the manager. For ease of exposition, we refer to T_t as a team's aggregate risk aversion.

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To serve as a benchmark for our findings, we begin with a brief characterization of centralized contracting ($h = 0$), where the principal contracts with the manager and all N workers. For $h = 0$, the manager's incentive rates are $v_m = \frac{b_m^2}{b_m^2 + r_m \sigma_m^2}$ and $\delta_m = 0$, and the workers' incentive rates are $v_w = \frac{b_w^2 W}{b_w^2 W + r_w \sigma_w^2}$ and $\delta_{ww} = \delta_{wm} = 0$. v_m and v_w reflect the usual cost-benefit tradeoff in standard agency settings, and the principal does not use other agents' performance measures in any focal agent's contract ($\delta_m = \delta_{ww} = \delta_{wm} = 0$), as expected. With centralized contracting, transparency as precision W alleviates the workers' agency conflicts and boosts their incentives, but transparency as observability t is irrelevant because the workers' efforts are unrelated, and their performance measures are uncorrelated.[14]

For $h = 1$, Lemma 1 highlights several implications of delegated contracting. First, we find that the manager chooses his effort a_m independent of his decision to link workers' compensation in (5b) to his own performance x_m via δ_{wm}. To illustrate, in the proof of Lemma 1 we show that the manager's effort equals $a_m = b_m v_m - b_m N \delta_{wm} - N \frac{df_w}{da_m}$, where the first term reflects his expected performance-based pay, the second term reflects the workers' expected pay based on the manager's performance x_m, and the third term reflects how the manager's effort affects the workers' fixed compensation. Because the workers observe a soft signal of the manager's actual effort prior to contracting, the manager adjusts (reduces) his workers' fixed compensation to substitute for their expected variable compensation based on x_m. That is, $\frac{df_w}{da_m} = -b_m \delta_{wm}$ and hence $a_m = b_m v_m$.[15]

Second, we find that the manager sets $\delta_{wm} > 0$ and links his workers' compensation to his own performance in order to share his compensation risk with his workers. Because efficient risk sharing requires risk-averse parties to bear risk in proportion to their risk tolerance (e.g., Wilson [1968]), the manager retains the fraction $\frac{r_m^{-1}}{r_m^{-1} + N r_w^{-1}}$ of the x_m-related compensation risk and assigns the remaining portion, $\frac{N r_w^{-1}}{r_m^{-1} + N r_w^{-1}}$, equally to each worker via $\delta_{wm} = (\frac{N r_w^{-1}}{r_m^{-1} + N r_w^{-1}}) \frac{v_m}{N}$. Of course, the manager's ability to share risk reduces the risk premium required to motivate the manager. Thus, the principal boosts the manager's effort incentive by setting $v_m = \frac{b_m^2}{b_m^2 + r_m \sigma_m^2 (\frac{r_m^{-1}}{r_m^{-1} + N r_w^{-1}})}$. Hence, an important highlight of Lemma 1 is that the manager provides more effort with delegated contracting than he would with centralized

[14] In section 5.1 where we consider correlated performance measures, transparency as observability t is relevant for the centralized contracting setting as well.

[15] In contrast, if the workers do not observe a signal of the manager's effort (but merely conjecture his effort), then $df_w/da_m = 0$. This means that the manager cannot adjust (reduce) the workers' fixed compensation. In this case, the manager's effort a_m and his contracting choice δ_{wm} are negatively related because $a_m = b_m(v_m - N\delta_{wm})$.

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contracting.[16] This positive externality of more managerial effort provides a rationale for the principal to delegate contracting authority to the manager (see section 5.2).

Third, we find that the principal sets $\delta_m > 0$ and links the manager's compensation to his workers' performances in order to motivate the manager to motivate worker effort. Given δ_m, the manager sets $v_w = \gamma_w \delta_m$ in (6c) so that a fraction γ_w of the manager's x_{wi}-related compensation risk is assigned to worker i, with the remaining risk assigned efficiently to the worker's teammates via $\delta_{ww} = \frac{T_t}{r_w}(1-\gamma_w)\delta_m$ for $t \geq 2$.[17]

Using Lemma 1, we write a worker's effort incentive as

$$v_w = \frac{b_w^2}{b_w^2 + \frac{r_w \sigma_w^2}{W} + \underbrace{T_t\ R_t}_{\substack{\text{team risk}\\ \text{premium}}}}. \tag{7}$$

Expression (7) characterizes a worker's incentive rate as the benchmark incentive rate, $v_w = \frac{b_w^2}{b_w^2 + \frac{r_w \sigma_w^2}{W}}$, discounted by a team's risk premium that reflects the repercussions of delegating contracting authority. The team's risk premium is a product of two elements; (i) a team's *aggregate risk aversion*, that is, $T_t = (r_m^{-1} + (t-1)r_w^{-1})^{-1}$, and (ii) the *magnitude* of the team's risk, $R_t = \frac{\sigma_w^2}{W}\left(\frac{r_w \sigma_w^2}{b_w^2 W + T_t \sigma_w^2}\right)^2$, where $\frac{r_w \sigma_w^2}{b_w^2 W + T_t \sigma_w^2} = \frac{1-\gamma_w}{\gamma_w}$ is the share of worker i's x_{wi}-related risk borne by the manager and the worker's teammates, relative to the worker's share of that risk.[18]

Transparency affects workers' effort, $a_{wi} = b_w v_w$ in (6a), in different ways. Transparency as observability t affects a team's risk premium but does not affect the benchmark incentive rate (except with correlated measures in section 5.1). Because a larger team is more risk tolerant (i.e., a larger team is less risk averse), the team's risk premium is lower and a worker's effort is higher, ceteris paribus. However, a larger team also increases the magnitude of the team's risk, which increases the team's risk premium and mutes a worker's effort. These two effects of t are countervailing. Hence, how observability affects a worker's effort depends on whether the impact of a less risk averse team exceeds (or is exceeded by) the impact of a larger team's risk.

Transparency as precision W affects both the benchmark incentive rate and a team's risk premium. More precise measures alleviate the workers' agency conflicts and boost the benchmark rate and second-best effort, as

[16] The manager provides more effort with delegated contracting only if the workers' soft signal ψ about a_m is sufficiently informative (e.g., Feltham et al. [2016], Hofmann and Indjejikian [2021]).

[17] In the proof of Lemma 1, we provide a detailed discussion of the manager's choice of v_w and the principal's choice of δ_m.

[18] Technically, R_t represents the magnitude of risk borne by the worker's $t-1$ teammates plus the manager.

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expected. Precision W also reduces a team's risk premium because more precise measures reduce the magnitude of the additional risk borne (and shared) by team members. Hence, more precise measures always increase worker effort.

We summarize the effect of transparency on worker effort in the following proposition.

Proposition 1. *With delegated contracting ($h = 1$), observability increases worker effort if, and only if, the percentage decrease in a team's risk aversion exceeds the percentage increase in the magnitude of shared risks; precision increases worker effort. We have:*

(i) $a_{wi}(t) > a_{wi}(t')$ *if, and only if* $\frac{T_{t'}-T_t}{(T_{t'}+T_t)/2} > \frac{R_t-R_{t'}}{(R_t+R_{t'})/2}$ *for all* $t > t'$,

where $T_t = (r_m^{-1} + (t-1)r_w^{-1})^{-1}$ *and* $R_j = \frac{\sigma_w^2}{W}\left(\frac{r_w\sigma_w^2}{b_w^2 W + T_j\sigma_w^2}\right)^2$, $j = t, t'$;

(ii) $\dfrac{da_{wi}}{dW} > 0$.

We find that the benefit of a less risk-averse team exceeds the shared burden of a larger team's risk in settings with numerous workers and in contexts where the agency problem between the principal and her agents are relatively modest. In settings with numerous workers, adding one more worker increases a team's risk but only marginally. Moreover, this increase is especially marginal if the agency problem is modest (i.e., if $\frac{\sigma_w^2}{b_w^2 W}$ is low for the workers, r_m is low for the manager, or both). Conversely, contexts where the shared burden of a larger team's risk exceeds the benefit of a less risk-averse team are settings where the agency problem between the principal and her agents are relatively severe. Given Proposition 1, and substituting for R_t and $R_{t'}$, we have the following:

Corollary 1. $a_{wi}(t) > a_{wi}(t')$ *if, and only if,* $b_w^2 > \sqrt{T_t T_{t'}}\frac{\sigma_w^2}{W}$ *for all* $t > t'$.

Proposition 1 and Corollary 1 illustrate how different dimensions of transparency have distinct consequences for worker performance in hierarchical organizations. Whereas, precision always boosts worker effort, observability depresses worker effort if $b_w^2 < \sqrt{T_t T_{t'}}\frac{\sigma_w^2}{W}$ and boosts worker effort otherwise. This has implications for the principals' transparency choices, which we address in the next section.

4. *Optimal Observability and Precision in Hierarchies*

In this section, we describe the principal's transparency choices (i.e., observability t and precision W) taking into account the optimal compensation arrangements from section 3. In section 4.1, we consider the principal's observability choice t, assuming W is given. In section 4.2, we consider the principal's precision choice W taking into account the optimal t. Throughout this section, we assume all workers are assigned

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either to the principal ($h = 0$) or the manager ($h = 1$) and defer deriving the principal's optimal delegation decision to section 5.2.

Given Lemma 1 in section 3, the principal's expect net profit is given by

$$\pi = \frac{1}{2}\frac{b_m^4}{b_m^2 + r_m\sigma_m^2\left(\frac{r_m^{-1}}{r_m^{-1}+hNr_w^{-1}}\right)} + \frac{N}{2}\left\{\frac{b_w^4}{b_w^2 + \frac{r_w\sigma_w^2}{W}} - hL_t - 2z_wW\right\}, \tag{8}$$

where $h = 0, 1$ denotes centralized and delegated contracting, and L_t represents the (per worker) profit foregone by delegating contracting authority to the manager, that is, a *control loss* from the workers' efforts equal to

$$L_t = \left(\frac{b_w^4 W}{b_w^2 W + r_w\sigma_w^2}\right)\frac{T_t R_t}{b_w^2 + \frac{r_w\sigma_w^2}{W} + T_t R_t}. \tag{9}$$

Expressions (8) and (9) highlight the benefits and costs of delegated contracting vis-à-vis centralized contracting. The upside is more managerial effort because the first term in (8) is increasing in N as explained in section 3. The downside is less worker effort because of the team risk premium, T_tR_t, described in (7) as the product of $T_t = (r_m^{-1} + (t-1)r_w^{-1})^{-1}$ (a team's aggregate risk aversion) and $R_t = \frac{\sigma_w^2}{W}\left(\frac{r_w\sigma_w^2}{b_w^2W+T_t\sigma_w^2}\right)^2$ (the magnitude of a team's risk). Expression (9) suggests that the principal's transparency (or, opacity) choices are means to reduce the control loss in hierarchical organizations.

4.1 TRANSPARENCY AS OBSERVABILITY t

The principal's observability choice, t, maximizes her expected net profit in (8), or equivalently minimizes the control loss in (9). For centralized contracting ($h = 0$), observability is moot as noted earlier in section 3. For delegated contracting ($h = 1$), expressions (8) and (9) imply that $\pi(t) > \pi(t')$ for all $t > t'$ if, and only if, the control loss is lower, namely, if $T_tR_t < T_{t'}R_{t'}$. Note that this is equivalent to Proposition 1. That is, observability increases (or decreases) profit depending on whether the percentage decrease in a team's risk aversion exceeds (or is exceeded by) the percentage increase in the magnitude of the team's risks.

Importantly, the comparison of T_tR_t and $T_{t'}R_{t'}$ implies that the optimal t^* is not interior. If the percentage decrease in T_t exceeds the percentage increase in R_t, the principal chooses $t^* = N$. The principal opts for as much observability as possible because broader observability maximizes a worker's contribution to profit. Conversely, if the percentage increase in R_t exceeds the percentage decrease in T_t, the principal prefers as much opaqueness as possible, that is, $t^* = 1$, because in this case opaqueness maximizes a worker's contribution.

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More formally, following Corollary 1, the principal prefers $t^* = 1$ if, and only if,

$$b_w^2 W < \sigma_w^2 \sqrt{T_1 T_N} \quad \text{or} \quad r_m \frac{\left(\frac{\sigma_w^2}{b_w^2 W}\right)}{\sqrt{1 + (N-1)\frac{r_m}{r_w}}} > 1. \tag{10}$$

That is, the principal's preference for $t^* = 1$ or $t^* = N$ depends on the severity of the manager's and workers' agency problems as well as the size of the workforce.[19] We summarize the preceding discussion in the following corollary.

Corollary 2.

(i) *With delegated contracting ($h = 1$), the principal prefers either completely opaque or fully transparent measurement practices (i.e., $t^* = 1$ or $t^* = N$).*

(ii) *The principal prefers opaque measurement practices ($t^* = 1$) if the manager is sufficiently risk averse (high r_m), the workers' agency problem is sufficiently severe (high $\frac{\sigma_w^2}{b_w^2 W}$), or if workers are few in number (low N).*

(iii) *The principal prefers transparent measurement practices ($t^* = N$) if the manager is sufficiently risk tolerant (low r_m), the workers' agency problem is sufficiently modest (low $\frac{\sigma_w^2}{b_w^2 W}$), or if workers are numerous (high N).*

4.2 TRANSPARENCY AS PRECISION *W*

The principal's precision choice, *W*, maximizes her expected net profit in (8) taking into account her optimal choice of $t^* = 1$ or $t^* = N$. We have the following:

Proposition 2. *The principal's precision choice, W^*, is characterized by:*

$$W_{t^*}^* = \sqrt{\frac{r_w \sigma_w^2}{2z_w + h\frac{dL_t(W_{t^*}^*)}{dW}}} - \frac{r_w \sigma_w^2}{b_w^2}, \tag{11}$$

where $h = 0, 1$ denotes centralized and delegated contracting, $t^* = 1$ or N, and $\frac{dL_t(W_{t^*}^*)}{dW}$ (derived in the appendix) is the precision's marginal impact on the principal's control loss, L_t.

Proposition 2 shows that the principal's precision choice depends on her delegation choice ($h = 0$ or 1), that is, centralized versus delegated contracting, and on her observability choice ($t^* = 1$ or *N*) via the $h\frac{dL_t(W_{t^*}^*)}{dW}$ term in (11). Accordingly, we compare the principal's precision choices, W_1^*, W_N^*, $W_{h=0}^*$, where the first two are her choices with delegated contracting ($t^* = 1$ or *N*) and $W_{h=0}^*$ is her choice with centralized contracting.

[19] In a setting where the manager rather than the principal chooses performance observability, we can show that the manager always sets $t = N$. Intuitively, the manager chooses maximum observability to fully exploit risk sharing with his workers. Thus, in contexts where the principal's preference is also $t = N$ (Corollary 2 (iii)), the principal can also delegate the observability choice to the manager without any repercussions.

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Corollary 3.

(i) With delegated contracting ($h = 1$), the optimal performance precision with $t^* = N$ exceeds the optimal performance precision with $t^* = 1$. That is, $W_N^* > W_1^*$.

(ii) For $t^* = N$, the optimal performance precision under delegated contracting ($h = 1$) exceeds the optimal performance precision under centralized contracting ($h = 0$), $W_N^* > W_{h=0}^*$.

(iii) For $t^* = 1$, the optimal performance precision under delegated contracting ($h = 1$) exceeds the optimal performance precision under centralized contracting ($h = 0$), $W_1^* > W_{h=0}^*$ if $z_w < 0.8989 z_w^{\max}$.

Part (i) of Corollary 3 suggests that the principal's transparency choices, t^* and W^*, are complements rather than substitutes. That is, the principal optimally invests more in monitoring the manager's workers if their performances are also broadly observable than if they are opaque. Intuitively, $W_N^* > W_1^*$ because precision is more effective in reducing the control loss in larger teams (with a higher magnitude of shared risk) than in smaller ones. The intuition for parts (ii) and (iii) are somewhat similar. Because more precise performance measures reduce the control loss with some caveats, the marginal benefit of precision is higher in delegated settings than in centralized ones. Hence, the principal invests more in monitoring the manager's workers than she would invest in a centralized setting where the workers are her responsibility.[20]

Taken together, Corollaries 2 and 3 offer a number of testable predictions about measurement practices in hierarchical organizations. *First*, we predict that opaque measurement practices are more prevalent in small organizational units with few employees than in larger units or divisions. For instance, if we assume that subjective employee evaluations are less precise and less public than objective financially oriented performance measures, then we predict greater reliance on subjective evaluations in smaller units than larger ones, ceteris paribus. *Second*, if we assume that employees at higher organizational ranks are more risk-tolerant and/or more productive than employees at lower ranks, then we expect to observe more transparent measurement practices at higher ranks and more opaque practices at lower ranks. And *third*, if we assume that measuring employee performance in some organizational units (e.g., R&D departments) is more difficult and

[20] The control loss in (9) can be thought of as a fraction, $T_t R_t / (b_w^2 + \frac{r_w \sigma_w^2}{W} + T_t R_t)$, of the benchmark profit of $b_w^4 W / (b_w^2 W + r_w \sigma_w^2)$, where more precise measures increase the benchmark but decrease the fraction. Typically, a decreasing fraction of an increasing benchmark decreases the control loss. The sufficient condition in Corollary 3 Part (iii) precludes settings that are more atypical where measures that are more precise increase the control loss. This occurs if the percentage increase in the profit benchmark (e.g., z_w is high and thus W^* is low) exceeds the percentage decrease in the fraction ($t^* = 1$ and r_m is high). For instance, if $t^* = 1$ and $r_w = r_w^{\min} = r_m/\sqrt{2}$ then $z_w \in [0.8989 z_w^{\max}, z_w^{\max})$ is necessary and sufficient for the control loss to increase in W. Hence, $W_1^* \leq W_{h=0}^*$.

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costly than in other units (e.g., sales departments), then we expect to observe more opaque measurement practices in units in which performance is difficult and costly to measure.

5. *Extensions*

In this section, we extend the model in two ways. In section 5.1, we examine the principal's transparency choice(s) in a setting where workers' performance measures are correlated. In section 5.2, we consider the principal's delegation choice: whether (and to what extent) to delegate contracting authority to a manager. For brevity and to simplify the model, we focus only on t as the principal's transparency choice and assume precision W is preset to 1.

5.1 CORRELATED PERFORMANCE MEASURES

In this subsection, we examine the principal's observability choice, t, with correlated worker performance measures. This is important because, in most organizations, workers' performances are correlated and team-based relative performance evaluation is possible.

To begin, we let the N error terms in the workers' performance measures be correlated rather than independent. That is, for $x_{wi} = b_w a_{wi} + \varepsilon_{wi}$, we assume $\mathrm{Cov}[\varepsilon_{wi}, \varepsilon_{wj}] = \rho\sigma_w^2$, where $\mathrm{Var}[\varepsilon_{wi}] = \sigma_w^2$ as before, and $\rho \in (-\frac{1}{N-1}, 1)$ ensures that the variance-covariance matrix of the N error terms is positive definite. With correlated performance measures, the workers' profit contribution in (8) (ignoring the cost acquiring W) is:

$$\pi_w = \frac{N}{2} \frac{b_w^4}{b_w^2 + r_w\sigma_w^2\left(1 - \frac{(t-1)\rho^2}{1+(t-2)\rho}\right) + hT_t R_t}, \tag{12}$$

where $h = 0, 1$ denotes centralized and delegated contracting, $T_t = \left(\frac{r_m^{-1}}{1+(N-1)\rho} + \frac{(t-1)r_w^{-1}}{1+(t-2)\rho}\right)^{-1}$ is a team's aggregate risk aversion (where the manager's and the workers' weights reflect the shared per capita variance), and $R_t = \sigma_w^2\left(\frac{\frac{b_w^2(t-1)\rho}{1+(t-2)\rho} + r_w\sigma_w^2\left(1-\frac{(t-1)\rho^2}{1+(t-2)\rho}\right)}{b_w^2 + T_t\sigma_w^2(1-\rho)}\right)^2$ is the magnitude of the team's risk.

Given (12), the principal's choice reflects the same fundamental tradeoff between T_t and R_t identified in section 4.1, but with the added element that workers' contracts can also feature "relative performance evaluation" (RPE) if $t^* \neq 1$. The benefit of RPE is captured by $\frac{(t-1)\rho^2}{1+(t-2)\rho}$ in the denominator of (12), which is increasing in t. Hence, if contracting is centralized, the principal always prefers full observability ($t^* = N$) because she could design her workers' compensation to maximize the benefits of RPE. Of course, if $\rho = 0$, observability is moot with centralized contracting because the principal treats her workers independently, as noted in section 3. If contracting is delegated, as in section 4.1, we find that the principal prefers either transparent ($t = N$) or opaque ($t = 1$) measurement practices. We have:

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Proposition 4. *With delegated contracting ($h = 1$) and correlated performance measures, the principal prefers opaque measurement practices ($t^* = 1$) if, and only if, $\rho_l \leq \rho \leq \rho_u$ and transparent measurement practices ($t^* = N$) otherwise, where $\rho_l \leq \rho_u$ are functions of model parameters.*

Proposition 4's key insight is that the principal prefers opaque measurement practices for a wide range of correlation values. To illustrate via an example, consider the benchmark condition that makes the principal indifferent between transparent and opaque practices if workers' performance measures are uncorrelated; that is, $\frac{b_w^2}{\sigma_w^2} = \sqrt{T_1 T_N} = r_m(1 + (N-1)\frac{r_m}{r_w})^{-1/2}$ from section 4.1 (equation (10)) and $\bar{W}$ preset to 1. At this benchmark, and assuming (say) that $\frac{r_w}{r_m} = 1$ and $N = 9$, we find that the principal prefers opaque practices for all $0 \leq \rho \leq 0.963$. Conversely, the principal prefers transparent practices for all $-\frac{1}{8} < \rho < 0$ and $0.963 < \rho < 1$.

The intuition rests on how performance measure correlation affects the control loss, namely, the tradeoff between T_t and R_t illustrated earlier for $\rho = 0$ in section 4.1. We find that settings where performance measures are *negatively* correlated typically favor transparent practices and employ RPE. Conversely, settings where performance measures are *positively* correlated typically call for opaque practices despite foregoing RPE. Positive correlation favors opaque practices because, in comparing $t = 1$ to $t = N$, low levels of risk (low R_t) more than offset more risk-averse teams (high T_t). For instance, although transparency makes teams less risk averse, its impact is much more pronounced if $\rho > 0$ than if $\rho < 0$, that is, $\frac{d\left(\frac{T_1 - T_N}{(T_1+T_N)/2}\right)}{d\rho} > 0$.[21]

The range of correlation values that favor opaque versus transparent practices largely parallel our results in Corollary 2. In particular, $\rho_u - \rho_l$ is wider if the manager is sufficiently risk averse (high r_m), or if the workers' agency problem is sufficiently severe (high $\frac{\sigma_w^2}{b_w^2}$).

Corollary 4. *The opaque region defined as $\rho_u - \rho_l$ is wider if the manager is more risk averse (high r_m), or if the workers' agency problem is more severe (high $\frac{\sigma_w^2}{b_w^2}$).*

Proposition 4 and Corollary 4 offer novel predictions about the use of RPE that complement those suggested by Corollaries 2 and 3. Because observability is a prerequisite for RPE, our earlier predictions that measurement practices are more transparent at higher ranks than in lower ranks or in organizational units where performance is easier to measure also imply that RPE is more prevalent in those settings. Moreover, we expect RPE to be less prevalent in settings where workers' performance measures are positively correlated (e.g., the workers operate in similar markets) rather than negatively correlated (e.g., the workers' performance measures comprise allocated joint revenues or costs) because positive (negative) correlation promotes opaque (transparent) measurement practices.

[21] An individual worker's share of the "correlated risk" of a team of size k is $(k-1)\rho$. Hence, positive (negative) correlation increases (decreases) the worker's share and increases (decreases) a team's aggregate risk aversion.

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5.2 MANAGER'S CONTRACTING AUTHORITY IN THE HIERARCHY

In this subsection, we examine the principal's choice to delegate contracting authority to a manager, taking into account the optimal compensation and observability arrangements from sections 3 and 4.1, respectively. To simplify the model, we assume uncorrelated performance measures, $\rho = 0$.

To allow the principal to choose centralization, partial delegation, or full delegation, we assume the manager has contracting authority for $h = \{0, \dots, N\}$ workers and the principal has contracting authority for $N - h$ workers. Accordingly, we characterize the principal's delegation decision as her choice of h that maximizes expected profit, with $h = 0$ and $h = N$ representing centralization and full delegation, respectively, and $h \in [1, N)$ representing partial delegation.

The principal's expect net profit (ignoring the cost acquiring W) is

$$\pi = \frac{1}{2}\frac{b_m^4}{b_m^2 + r_m\sigma_m^2\left(\frac{r_m^{-1}}{r_m^{-1}+hr_w^{-1}}\right)} + \frac{N-h}{2}\left\{\frac{b_w^4}{b_w^2 + r_w\sigma_w^2}\right\} + \frac{h}{2}\left\{\frac{b_w^4}{b_w^2 + r_w\sigma_w^2 + T_{t^*}R_{t^*}}\right\}, \quad (13)$$

where $T_{t^*} = (r_m^{-1} + (t^* - 1)r_w^{-1})^{-1}$, $R_{t^*} = \sigma_w^2(\frac{r_w\sigma_w^2}{b_w^2+T_{t^*}\sigma_w^2})^2$, and $t^* = \{1, h\}$ is the optimal performance observability from section 4.1 (Corollary 2). The first term in (13) is the profit contribution of the manager. The second and third terms represent the profit contributions of workers assigned to the principal and manager, respectively. Proposition 5 characterizes the principal's delegation choice, h.

Proposition 5. *Given the optimal compensation and observability arrangements; the principal prefers delegation ($h^* \in [1, N]$) if the manager is sufficiently productive (high b_m) and centralization ($h^* = 0$) otherwise.*

As noted earlier in section 4, the principal benefits from delegation because the manager provides more effort (the first term in (13) is increasing in the number of workers assigned to the manager, h) but also bears a cost because delegation implies a control loss from the workers' efforts.[22] From (13), the marginal benefit of h increases in the manager's marginal productivity, b_m, which generates the positive externality. However, the marginal cost of h is independent of b_m. Thus, if b_m is sufficiently high, the principal assigns all N workers to the manager ($h^* = N$), but if b_m is sufficiently low, the principal centralizes all contracting authority ($h^* = 0$). For intermediate values of b_m, the principal assigns some workers to the manager but retains contracting authority over the rest ($1 \leq h^* < N$).

Proposition 5 offers predictions about an organization's transparency practices that complement those suggested by Corollary 2. For instance, Proposition 5 suggests that more productive managers manage larger orga-

[22] We note that the benefit of delegation relies on the assumption that workers observe soft information of sufficient quality about the manager's effort prior to contracting. Otherwise, the manager provides less effort under delegated contracting relative to centralized contracting and delegating contracting authority is not optimal for the principal.

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nizational units. Corollary 2 suggests that larger organizational units have more transparent measurement practices. Ceteris paribus, this means that managerial productivity complements transparency in the sense that more productive managers evaluate their employees with more transparent practices than less productive managers.

6. Summary and Conclusion

Workplace transparency is a much-ballyhooed concept as a set of practices that minimize organizational conflict, promote employee productivity and retention, and offer myriad other benefits. Yet, when it comes to performance evaluation, many organizations are circumspect and do not routinely publicize employee performance within the organization, or even among an employee's coworkers.

Our analysis suggests that transparency is not a panacea, particularly in hierarchical organizations where performance evaluation and compensation of rank-and-file employees is the purview of midlevel managers. In these organizations, making employee performance more transparent also affects an organization's ability to motivate its middle managers. In particular, because middle managers' interests rarely align perfectly with owners' or senior executives' interests, middle managers are unlikely to use their employees' transparent performance information to faithfully implement an organization's interest. Thus, an organization's decision to be (or not to be) transparent is dictated, in part, by a desire to adequately motivate its middle managers.

We model transparency as two dimensions: observability and precision of rank-and-file employee performance. Whereas precision is a conventional metric of monitoring quality (e.g., an organization's decision to invest in performance measurement systems), observability refers to structures and practices that allow employees to observe their coworkers' performances. We find that organizations always prefer measures that are more precise (as expected), but may also opt for less transparency by limiting employee observations of their coworkers' performances. We identify organizational, performance measure, and manager-specific characteristics that favor the use of transparent (conversely opaque) measurement practices and suggest several testable hypotheses. For instance, for employees of comparable hierarchical rank, we predict that opaque measurement practices work well in small organizational units or departments and for employees whose performance is more difficult or costly to measure. Similarly, for employees of different hierarchical rank, we predict less transparency in the form of less use of RPE at lower hierarchical ranks below managerial levels.

Although we frame our model in a corporate setting with an owner-manager-worker hierarchy, conceptually the model applies equally well in other economic settings. For instance, we suggest that transparency (or lack of transparency) can serve to alleviate agency conflicts in industries organized around an owner-general contractor-subcontractor relationship, or in capital market contexts where, for example, large investors authorize

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private equity fund managers to select and motivate investee-firms on their behalf (e.g., Baliga and Sjöström [1998], Gryglewicz and Mayer [2023]).

Our analysis also contributes to the pay transparency literature. Pay transparency refers to organizations broadly reporting compensation formulas and amounts to all employees, and perhaps even to outsiders. Although pay transparency is touted often as a step toward pay equity, in practice compensation arrangements are usually opaque (Cullen and Perez-Truglia [2022]). Our analysis suggests that hierarchical organizations' preferences for less transparent performance measures may be one explanation for opaque compensation arrangements observed in practice.

APPENDIX

Proof of Lemma 1:

Given $x_m = b_m a_m + \varepsilon_m$ and $x_{wi} = b_w a_{wi} + \varepsilon_{wi}$ in (2) and the fact that the workers are ex ante identical, we write the manager's and workers' compensation as

$$c_m = f_m + v_m x_m + \delta_m A_m \tag{A.1a}$$

and

$$c_{wi} = f_w + v_w x_{wi} + \delta_{ww} A_{wi} + \delta_{wm} x_m \quad \text{for } i = 1, \dots, N, \tag{A.1b}$$

where f_m and f_w are the fixed compensation components, v_m and v_w are the incentive rates tied to agents' own performance, the δs are the incentive rates tied to other agents' performance, $A_m = \sum_{i=1}^{N} x_{wi}$ is the aggregate performance of the N workers, and $A_{wi} = \sum_{j \in S_i} x_{wj}$ is worker i's team performance (except for worker i). Also, given identical workers and symmetry, $W_1 = \cdots = W_N = W$ and $t_1 = \cdots = t_N = t$, where $t \in [1, \dots, N]$.

For ease of exposition, we present the proofs separately for centralized and delegated contracting settings. With centralized contracting ($h = 0$), the manager's certainty equivalent is

$$CE_m = \mathrm{E}\left[f_m + v_m x_m + \delta_m \sum_{i=1}^{N} x_{wi} \right] - \frac{1}{2} a_m^2 - \frac{r_m}{2} \left(v_m^2 \sigma_m^2 + N \delta_m^2 \frac{\sigma_w^2}{W} \right). \tag{A.2a}$$

From (A.2a), the manager's effort is $a_m = b_m v_m$. The manager's binding individual rationality constraint is $CE_m = 0$.

The certainty equivalent of worker i is

$$CE_{wi} = \mathrm{E}\left[f_w + v_w x_{wi} + \delta_{ww} \sum_{j \in S_i} x_{wj} + \delta_{wm} x_m | \psi \right] - \frac{1}{2} a_{wi}^2 - \frac{r_w}{2} \left[\left(v_w^2 + (t-1) \delta_{ww}^2 \right) \frac{\sigma_w^2}{W} + \delta_{wm}^2 \sigma_m^2 \right]. \tag{A.2b}$$

From (A.2b), the worker's effort is $a_{wi} = b_w v_w$. The worker's binding individual rationality constraint is $CE_{wi} = 0$. Substituting the man-

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ager's and the workers' effort choices and the binding individual rationality constraints into the principal's objective function, $\mathrm{E}[(x_m - c_m) + \sum_{i=1}^{N}(x_{wi} - c_{wi} - z_w W)]$, yields the principal's unconstrained objective function,

$$\pi = b_m^2 v_m - \frac{1}{2} b_m^2 v_m^2 - \frac{r_m}{2}\left(v_m^2 \sigma_m^2 + N\delta_m^2 \frac{\sigma_w^2}{W}\right) + N\left\{b_w^2 v_w - \frac{1}{2} b_w^2 v_w^2 - \frac{r_w}{2}\left[\left(v_w^2 + (t-1)\delta_{ww}^2\right)\frac{\sigma_w^2}{W} + \delta_{wm}^2 \sigma_m^2\right] - z_w W\right\}. \quad \text{(A.3)}$$

Differentiating (A.3) with respect to v_m, δ_m, v_w, δ_{ww}, and δ_{wm} and solving the first-order conditions yields (6b) and (6c) for $h = 0$. It is straightforward to show that the second-order conditions are satisfied.

With delegated contracting $(h = 1)$, worker i's certainty equivalent, his effort choice, and binding individual rationality constraint is as before. Using worker i's individual rationality constraint, $CE_{wi} = 0$, worker i's fixed compensation is

$$f_w = \frac{1}{2} a_{wi}^2 + \frac{r_w}{2}\left[\left(v_w^2 + (t-1)\delta_{ww}^2\right)\frac{\sigma_w^2}{W} + \delta_{wm}^2 \sigma_m^2\right] - \left[v_w b_w a_{wi} + \delta_{ww} b_w \sum_{j \in S_i} \hat{a}_{wj} + \delta_{wm} b_m a_m\right], \quad \text{(A.4)}$$

where the $\hat{a}_{wj}$s are the conjectured teammates' efforts and a_m is the observed manager's effort.

Given the manager's net compensation, $c_m^{net} = c_m - \sum_{i=1}^{N} c_{wi}$, the manager maximizes

$$CE_m = \mathrm{E}\left[f_m + v_m x_m + \sum_{i=1}^{N}(\delta_m x_{wi} - c_{wi})\right] - \frac{1}{2} a_m^2 - \frac{r_m}{2}\mathrm{Var}\left[v_m x_m + \sum_{i=1}^{N}(\delta_m x_{wi} - c_{wi})\right].$$

Substituting c_{wi}, the manager's certainty equivalent is given by

$$CE_m = f_m - N f_w + (v_m - N\delta_{wm})\, b_m a_m + (\delta_m - v_w - (t-1)\delta_{ww})\sum_{i=1}^{N}\mathrm{E}[x_{wi}] - \frac{1}{2} a_m^2 - \frac{r_m}{2}\mathrm{Var}\left[(v_m - N\delta_{wm})\, x_m + (\delta_m - v_w - (t-1)\delta_{ww})\sum_{i=1}^{N} x_{wi}\right]. \quad \text{(A.5a)}$$

Differentiating (A.5a) with respect to a_m and solving the first-order condition yields $a_m = b_m v_m - b_m N\delta_{wm} - N\frac{df_w}{da_m}$, where $\frac{df_w}{da_m} = -b_m\delta_{wm}$ from (A.4). Hence, $a_m = b_m v_m$.

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Substituting $CE_{wi} = 0$, $a_m = b_m v_m$, and $a_{wi} = b_w v_w$, the manager's certainty equivalent is given by

$$CE_m = f_m + \frac{1}{2} b_m^2 v_m^2 - \frac{r_m}{2}\left[(v_m - N\delta_{wm})^2\sigma_m^2 + N(\delta_m - v_w - (t-1)\delta_{ww})^2\frac{\sigma_w^2}{W}\right]$$
$$+ N\left\{\delta_m b_w^2 v_w - \frac{1}{2} b_w^2 v_w^2 - \frac{r_w}{2}\left[\left(v_w^2 + (t-1)\delta_{ww}^2\right)\frac{\sigma_w^2}{W} + \delta_{wm}^2\sigma_m^2\right]\right\}. \quad \text{(A.5b)}$$

Differentiating (A.5b) with respect to v_w, δ_{ww}, and δ_{wm}, and solving the first-order conditions yields (6c) for $h = 1$, where $T_t = (r_m^{-1} + (t-1)r_w^{-1})^{-1}$. It is straightforward to show that the second-order conditions are satisfied. We note that the manager sets v_w as a fraction of δ_m. That is, if we let $v_w = \gamma_w \delta_m$, then γ_w is given by

$$\gamma_w = \frac{b_w^2 W + r_w\sigma_w^2\left(\frac{T_t\sigma_w^2}{b_w^2 W + r_w\sigma_w^2 + T_t\sigma_w^2}\right)}{b_w^2 W + r_w\sigma_w^2} = \frac{b_w^2 W}{b_w^2 W + r_w\sigma_w^2}$$
$$+ \frac{r_w\sigma_w^2}{b_w^2 W + r_w\sigma_w^2}\left(\frac{T_t\sigma_w^2}{b_w^2 W + r_w\sigma_w^2 + T_t\sigma_w^2}\right). \quad \text{(A.6)}$$

For a given δ_m, the manager's choice of γ_w is comprised of two components; a component equal to $\frac{b_w^2 W}{b_w^2 W + r_w\sigma_w^2}$ that motivates the benchmark effort in centralized settings and a "risk-sharing" component. Because the manager allocates risk efficiently among his team, the risk-sharing component boosts the incentive rate in (A.6) by an amount equal to each worker's remaining fraction of their output risk (i.e., $\frac{r_w\sigma_w^2}{b_w^2 W + r_w\sigma_w^2}$) that cannot be shouldered efficiently by the worker's teammates and the manager.[23]

Substituting the agents' efforts, the manager's binding individual rationality constraint, $CE_m = 0$, and the manager's choice of the workers' incentive rates into the principal's objective function, $\mathrm{E}[(x_m - c_m) + \sum_{i=1}^{N}(x_{wi} - z_w W)]$, yields the principal's unconstrained objective function,

$$\pi = b_m^2 v_m - \frac{1}{2} b_m^2 v_m^2 - \frac{r_m}{2}\left[\frac{r_m^{-1}}{r_m^{-1} + N r_w^{-1}}\right]\sigma_m^2 v_m^2$$
$$+ N\left\{b_w^2\gamma_w\delta_m - \frac{1}{2} b_w^2\gamma_w^2\delta_m^2 - \frac{r_w}{2}\gamma_w^2\frac{\sigma_w^2}{W}\delta_m^2 - \frac{1}{2}T_t(1-\gamma_w)^2\frac{\sigma_w^2}{W}\delta_m^2 - z_w W\right\}. \quad \text{(A.7a)}$$

Differentiating (A.7a) with respect to v_m and δ_m and solving the first-order conditions yields (6b) for $h = 1$. It is straightforward to show that the

[23] As risk sharing becomes moot ($r_m \to 0$, implying $T_t \to 0$), workers' remaining risk is shouldered by the manager, and hence motivating worker effort implies $\gamma_w \to \frac{b_w^2 W}{b_w^2 W + r_w\sigma_w^2}$. In contrast, as motivating effort becomes moot ($b_w \to 0$), efficient risk sharing implies $\gamma_w \to \frac{T_t}{r_w + T_t} = \frac{r_w^{-1}}{r_m^{-1} + t r_w^{-1}}$, where $T_t = (r_m^{-1} + (t-1)r_w^{-1})^{-1}$.

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second-order conditions are satisfied. Specifically, the principal's choice of the manager's incentives for worker effort is given by

$$\delta_m = \left(1 - \frac{T_t \sigma_w^2 \left(\frac{1-\gamma_w}{\gamma_w}\right)}{b_w^2 W + T_t \sigma_w^2 \left(\frac{1-\gamma_w}{\gamma_w}\right)}\right) = \frac{b_w^2/\gamma_w}{b_w^2 + r_w \frac{\sigma_w^2}{W} + T_t \frac{\sigma_w^2}{W}\left(\frac{1-\gamma_w}{\gamma_w}\right)^2}. \quad \text{(A.7b)}$$

The principal's choice of δ_m reflects that δ_m motivates, per-capita, an expected worker output of $b_w^2 \gamma_w \delta_m$ and involves an effort cost of $\frac{1}{2} b_w^2 \gamma_w^2 \delta_m^2$ and a risk premium of $\frac{r_w}{2} \gamma_w^2 \frac{\sigma_w^2}{W} \delta_m^2$ for the focal worker and a risk premium of $\frac{1}{2} T_t (1-\gamma_w)^2 \frac{\sigma_w^2}{W} \delta_m^2$ for the manager and the worker's teammates.[24]

Proof of Proposition 1:

The countervailing effects of transparency as observability t manifest in how t affects the manager's choice of v_w for a given δ_m and the principal's choice of δ_m, respectively, where $v_w = \gamma_w \delta_m$, γ_w is given by (A.6), and δ_m is given by (A.7b). For all $t > t'$, we have

$$\gamma_w(t) - \gamma_w(t') = \frac{(T_t - T_{t'}) r_w \sigma_w^4}{\left(b_w^2 W + (r_w + T_t)\sigma_w^2\right)\left(b_w^2 W + (r_w + T_{t'})\sigma_w^2\right)} < 0 \text{ and}$$

$$\delta_m(t) - \delta_m(t') = \frac{(T_{t'} - T_t) r_w \sigma_w^4}{\left(b_w^2 W + T_t \sigma_w^2\right)\left(b_w^2 W + T_{t'} \sigma_w^2\right)} \delta_m(t) \delta_m(t') > 0.$$

Transparency as observability t mutes γ_w because a larger team (an increase in t) is a less risk-averse team (reduces T_t), and thus the manager allocates less risk to each worker. In contrast, observability t boosts δ_m because a larger team is a less risk-averse team, which reduces the risk premium the principal owes the manager.

Considering the total effect of observability t on a worker's effort, using $a_{wi} = b_w v_w$ and v_w from (7), we obtain $a_{wi}(t) - a_{wi}(t') \propto T_{t'} R_{t'} - T_t R_t$, where $R_j = \frac{\sigma_w^2}{W} \left(\frac{r_w \sigma_w^2}{b_w^2 W + T_j \sigma_w^2}\right)^2$, $j = t, t'$. As

$$T_{t'} R_{t'} - T_t R_t = T_t \left(1 - \frac{T_t - T_{t'}}{T_t}\right)\left(R_t + (R_{t'} - R_t)\right) - T_t R_t$$
$$= \frac{(T_{t'} - T_t)(R_t + R_{t'})}{2} - \frac{(R_t - R_{t'})(T_t + T_{t'})}{2},$$

$a_{wi}(t) - a_{wi}(t') > 0$ for all $t > t'$ if, and only if, $\frac{T_{t'} - T_t}{(T_t + T_{t'})/2} > \frac{R_t - R_{t'}}{(R_t + R_{t'})/2}$.

[24] As expected, if workers' efforts are observable (i.e., $W \to \infty$), the principal's and the manager's interests are perfectly aligned, $\delta_m \to 1$, and workers provide first-best effort. Similarly, if risk sharing becomes moot ($r_m \to 0$, implying $T_t \to 0$), the principal's and the manager's interests converge, $\delta_m \to 1$, but now the workers provide the benchmark (second-best) effort.

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We also obtain

$$\frac{da_{wi}}{dW} = \frac{r_w \sigma_w^2}{b_w W^2}\left(1 + \frac{2b_w^2 W T_t r_w \sigma_w^4}{(b_w^2 W + T_t \sigma_w^2)^3} + \frac{T_t r_w \sigma_w^4}{(b_w^2 W + T_t \sigma_w^2)^2}\right) a_{wi}^2 > 0.$$

Proof of Corollary 1:

Substituting for $R_t = \frac{\sigma_w^2}{W}(\frac{r_w \sigma_w^2}{b_w^2 W + T_t \sigma_w^2})^2$ and $R_{t'} = \frac{\sigma_w^2}{W}(\frac{r_w \sigma_w^2}{b_w^2 W + T_{t'} \sigma_w^2})^2$, we have $\frac{T_{t'} - T_t}{(T_t + T_{t'})/2} > \frac{R_t - R_{t'}}{(R_t + R_{t'})/2}$ if, and only if, $b_w^2 > \sqrt{T_t T_{t'}} \frac{\sigma_w^2}{W}$ for all $t > t'$.

Proof of Corollary 2:

Substituting (6b) and (6c) into (A.3) and (A.7a) yields the principal's expected profit in (8) for $h = 0$ and $h = 1$, respectively.

Part (i): Given the profit expression in (8) and the control loss L_t in (9), $\pi(t) = \pi(t')$ for all $t > t'$ if, and only if $\frac{T_{t'} - T_t}{(T_t + T_{t'})/2} = \frac{R_t - R_{t'}}{(R_t + R_{t'})/2}$, where $T_t = (r_m^{-1} + (t-1) r_w^{-1})^{-1}$ and $R_t = \frac{\sigma_w^2}{W}(\frac{r_w \sigma_w^2}{b_w^2 W + T_t \sigma_w^2})^2$. Hence, if $\frac{T_{t'} - T_t}{(T_t + T_{t'})/2} > \frac{R_t - R_{t'}}{(R_t + R_{t'})/2}$, the principal maximizes profit by setting $t^* = N$ so that $T_N = (r_m^{-1} + (N-1) r_w^{-1})^{-1}$. Conversely, if $\frac{T_{t'} - T_t}{(T_t + T_{t'})/2} < \frac{R_t - R_{t'}}{(R_t + R_{t'})/2}$, the principal maximizes profit by setting $t^* = 1$ so that $T_1 = r_m$.

Parts (ii) and (iii): To characterize the settings under which the principal prefers $t^* = 1$ or $t^* = N$, we note that $\pi(t^* = N) \geq \pi(t^* = 1)$ if, and only if $\frac{T_1 - T_N}{(T_1 + T_N)/2} \geq \frac{R_N - R_1}{(R_N + R_1)/2}$ where $T_1 = r_m$, $T_N = (r_m^{-1} + (N-1) r_w^{-1})^{-1}$, $R_1 = \frac{\sigma_w^2}{W}(\frac{r_w \sigma_w^2}{b_w^2 W + T_1 \sigma_w^2})^2$, and $R_N = \frac{\sigma_w^2}{W}(\frac{r_w \sigma_w^2}{b_w^2 W + T_N \sigma_w^2})^2$. Hence, $\pi(t^* = N) \geq \pi(t^* = 1)$ if, and only if $b_w^2 \geq \sqrt{T_1 T_N} \frac{\sigma_w^2}{W}$ or $N \geq 1 + r_w(r_m(\frac{\sigma_w^2}{b_w^2 W})^2 - r_m^{-1})$. It follows that the principal prefers $t^* = N$ in settings where r_m is low, N is high, or $\frac{\sigma_w^2}{b_w^2 W}$ is low. Conversely, the principal prefers $t^* = 1$ in settings where r_m is high, N is low, or $\frac{\sigma_w^2}{b_w^2 W}$ is high.

Proof of Proposition 2:

Using (8) and the principal's optimal choice of t^*, the profit component from the workers' efforts only is

$$\pi_w = \frac{N}{2}\left\{\frac{b_w^4}{b_w^2 + \frac{r_w \sigma_w^2}{W}} - h L_{t^*} - 2 z_w W\right\}, \tag{A.8}$$

where $L_{t^*} = (\frac{b_w^4 W}{b_w^2 W + r_w \sigma_w^2}) \frac{T_{t^*} R_{t^*}}{b_w^2 + \frac{r_w \sigma_w^2}{W} + T_{t^*} R_{t^*}}$, $T_{t^*} = (r_m^{-1} + (t^* - 1) r_w^{-1})^{-1}$, $R_{t^*} = \frac{\sigma_w^2}{W}(\frac{r_w \sigma_w^2}{b_w^2 W + T_{t^*} \sigma_w^2})^2$, $t^* = 1$, or $t^* = N$ (Corollary 2), and $h = 0, 1$. Differentiating (A.8) with respect to W yields

$$H = \frac{N}{2}\left\{\frac{b_w^4 r_w \sigma_w^2}{(b_w^2 W + r_w \sigma_w^2)^2} - h \frac{dL_{t^*}}{dW} - 2 z_w\right\} \quad \text{forall } t^*, \tag{A.9}$$

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where the optimal $W_{t^*}^*$ solves $H = 0$ and

$$\frac{dL_{t^*}(W,t^*)}{dW} = -\frac{L_{t^*}}{W}\frac{b_w^2\left(1+\frac{2b_w^2W+r_w\sigma_w^2}{b_w^2W+T_{t^*}\sigma_w^2}\right)-\frac{r_w\sigma_w^2}{W}T_{t^*}\left(\frac{\sigma_w^2}{b_w^2W+T_{t^*}\sigma_w^2}+\frac{WR_{t^*}}{b_w^2W+r_w\sigma_w^2}\right)}{\left(b_w^2+\frac{r_w\sigma_w^2}{W}+T_{t^*}R_{t^*}\right)} \text{ forall } t^*. \quad (A.10)$$

For $h=0$, $H=0$ implies $W_{h=0}^* = \sqrt{\frac{r_w\sigma_w^2}{2z_w}} - \frac{r_w\sigma_w^2}{b_w^2}$. We also have $\pi_w(W_{h=0}^*) > 0$ for all $W_{h=0}^* > 0$, which is satisfied for all $z_w < z_w^{\max} = \frac{b_w^4}{4r_w\sigma_w^2}$. The second-order condition, $\frac{dH}{dW} = -\frac{Nb_w^6r_w\sigma_w^2}{(b_w^2W+r_w\sigma_w^2)^3} < 0$, ensures that $W_{h=0}^* = \sqrt{\frac{r_w\sigma_w^2}{2z_w}} - \frac{r_w\sigma_w^2}{b_w^2}$ is a global maximum.

For $h=1$, $H=0$ yields the implicit solution $W_{t^*}^* = \sqrt{\frac{r_w\sigma_w^2}{2z_w+\frac{dL_{t^*}(W_{t^*}^*,t^*)}{dW}}} - \frac{r_w\sigma_w^2}{b_w^2}$. Substituting $W_{t^*}^* = \sqrt{\frac{r_w\sigma_w^2}{2z_w+\frac{dL_{t^*}(W_{t^*}^*,t^*)}{dW}}} - \frac{r_w\sigma_w^2}{b_w^2}$ in (A.8) yields $\pi_w = \frac{N}{2}\frac{b_w^6}{(b_w^2+\frac{r_w\sigma_w^2}{W_{t^*}^*}+T_{t^*}R_{t^*}^*)^2}(1-\frac{2T_{t^*}\sigma_w^2(r_w\sigma_w^2)^2}{(b_w^2W_{t^*}^*+T_{t^*}\sigma_w^2)^3})$, where $R_{t^*}^* = \frac{\sigma_w^2}{W_{t^*}^*}(\frac{r_w\sigma_w^2}{b_w^2W_{t^*}^*+T_{t^*}\sigma_w^2})^2$ and $t^* = 1$ or $t^* = N$. It follows $\pi_w \geq 0$ if, and only if, $b_w^2W_{t^*}^* > \sigma_w^2[(2T_{t^*})^{1/3}r_w^{2/3} - T_{t^*}]$ for all t^*.

To ensure that $b_w^2W_{t^*}^* > \sigma_w^2[(2T_{t^*})^{1/3}r_w^{2/3} - T_{t^*}] > 0$ for all t^*, first we note that $2^{1/3}(\frac{r_w}{T_{t^*}})^{2/3} - 1 > 0$ for all $r_w \geq r_w^{\min} = \frac{r_m}{\sqrt{2}}$. Next, we substitute $b_w^2W_{t^*}^* = \sigma_w^2[(2T_{t^*})^{1/3}r_w^{2/3} - T_{t^*}]$ into H to yield $H = \frac{N}{2}b_w^2(\frac{b_w^2}{\sigma_w^2[(r_w-T_{t^*})+3T_{t^*}^{1/3}(\frac{r_w}{2})^{2/3}]} - \frac{2z_w}{b_w^2})$. Hence, $b_w^2W_{t^*}^* > T_{t^*}\sigma_w^2[2^{1/3}(\frac{r_w}{T_{t^*}})^{2/3} - 1] > 0$ for all t^* if, and only if, $z_w < \frac{b_w^4}{2\sigma_w^2[(r_w-T_{t^*})+3T_{t^*}^{1/3}(\frac{r_w}{2})^{2/3}]}$. The cutoff for z_w has a minimum at $T_{t^*} = \frac{r_w}{2}$, implying that $z_w < z_w^{\max} = \frac{b_w^2}{4r_w\sigma_w^2}$ ensures $\pi_w \geq 0$ for $t^* = 1$ or $t^* = N$.

The second-order condition is $\frac{dH}{dW} = -\frac{N}{2}\{\frac{2b_w^6r_w\sigma_w^2}{(b_w^2W+r_w\sigma_w^2)^2} - h\frac{d^2L_{t^*}}{dW^2}\}$, which we can easily show to be negative for all $W_{t^*}^* > T_{t^*}\frac{\sigma_w^2}{b_w^2}[2^{1/3}(\frac{r_w}{T_{t^*}})^{2/3} - 1]$ and all t^*. Hence, $W_{t^*}^* = \sqrt{\frac{r_w\sigma_w^2}{2z_w+\frac{dL_{t^*}(W_{t^*}^*,t^*)}{dW}}} - \frac{r_w\sigma_w^2}{b_w^2}$ is a global maximum for $t^* = 1$ or $t^* = N$.

Proof of Corollary 3:

Part (i) $W_N^* > W_1^*$:

From $H = 0$ in (A.9), $W_N^* > W_1^*$ if, and only if, $\frac{dL_{t^*}}{dW}|_{T_1} > \frac{dL_{t^*}}{dW}|_{T_N}$ where $T_1 = r_m$, $T_N = (r_m^{-1} + (N-1)r_w^{-1})^{-1}$, and $\frac{dL_{t^*}}{dW}$ is given in (A.10) for all t^*. From the proof of Corollary 2, the principal is indifferent between $t^* = N$ and $t^* = 1$ if, and only if $b_w^2 = \sqrt{T_1T_N}\frac{\sigma_w^2}{W}$. Hence, comparing (A.10) at T_1 and T_N evaluated at $b_w^2 = \sqrt{T_1T_N}\frac{\sigma_w^2}{W}$, we have

$$\left.\frac{dL_{t^*}}{dW}\right|_{T_1} - \left.\frac{dL_{t^*}}{dW}\right|_{T_N} \propto T_1 - T_N > 0.$$

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Parts (ii) and (iii) $W^*_{t^*} > W^*_{h=0}$ for $t^* = 1$ or $t^* = N$:

From Proposition 2, for $h = 1$, $W^*_{t^*} > \sqrt{\frac{r_w\sigma_w^2}{2z_w}} - \frac{r_w\sigma_w^2}{b_w^2}$ for $t^* = 1$ or $t^* = N$ if, and only if, $\frac{dL_{t^*}(W,t^*)}{dW}$ in (A.10) evaluated at $W = \sqrt{\frac{r_w\sigma_w^2}{2z_w}} - \frac{r_w\sigma_w^2}{b_w^2}$ is negative. Substituting for $W = \sqrt{\frac{r_w\sigma_w^2}{2z_w}} - \frac{r_w\sigma_w^2}{b_w^2}$, $\frac{dL_{t^*}(W,t^*)}{dW} < 0$ is equivalent to the following condition:

$$3\left(\frac{b_w^2}{\sqrt{2z_w r_w \sigma_w^2}} - 1\right)^4 + 4\left(1 + \frac{T_{t^*}}{r_w}\right)\left(\frac{b_w^2}{\sqrt{2z_w r_w \sigma_w^2}} - 1\right)^3 + \left(1 + 4\frac{T_{t^*}}{r_w} + \frac{T_{t^*}^2}{r_w^2}\right)\left(\frac{b_w^2}{\sqrt{2z_w r_w \sigma_w^2}} - 1\right)^2 - \left(\frac{T_{t^*}}{r_w} + \frac{T_{t^*}^2}{r_w^2}\right) > 0 \quad \text{(A.11)}$$

for $t^* = 1$ or $t^* = N$. We note that the left-hand side of (A.11) is decreasing in z_w for all $z_w < z_w^{\max}$. Hence, substituting for $z_w^{\max} = \frac{b_w^4}{4r_w\sigma_w^2}$, (A.11) is satisfied if

$$3\left(\sqrt{2} - 1\right)^4 + 4\left(1 + \frac{T_{t^*}}{r_w}\right)\left(\sqrt{2} - 1\right)^3 + \left(1 + 4\frac{T_{t^*}}{r_w} + \frac{T_{t^*}^2}{r_w^2}\right)\left(\sqrt{2} - 1\right)^2 - \left(\frac{T_{t^*}}{r_w} + \frac{T_{t^*}^2}{r_w^2}\right) > 0,$$

which is satisfied if $\frac{r_w}{T_{t^*}} = t^* - 1 + \frac{r_w}{r_m} > \frac{2(3+\sqrt{2})}{7} = 1.2612$.

For $t^* = N$, $\frac{r_w}{T_N} = N - 1 + \frac{r_w}{r_m} > 1.2612$ by definition, because $N \geq 2$ and $r_w \geq r_w^{\min} = \frac{r_m}{\sqrt{2}}$. Hence, $W_N^* > \sqrt{\frac{r_w\sigma_w^2}{2z_w}} - \frac{r_w\sigma_w^2}{b_w^2}$.

For $t^* = 1$, $\frac{r_w}{T_1} = \frac{r_w}{r_m}$. Hence, $W_1^* > \sqrt{\frac{r_w\sigma_w^2}{2z_w}} - \frac{r_w\sigma_w^2}{b_w^2}$ if $r_w \geq 1.2612 r_m = \frac{2(3\sqrt{2}+2)}{7} r_w^{\min}$. Using (A.11), an alternative condition that satisfies $W_1^* > \sqrt{\frac{r_w\sigma_w^2}{2z_w}} - \frac{r_w\sigma_w^2}{b_w^2}$ for all $r_w \geq r_w^{\min}$ is $z_w < 0.8989 z_w^{\max}$. Conversely, using $r_w = r_w^{\min} = \frac{r_m}{\sqrt{2}}$ means that (A.11) is not satisfied if $\frac{b_w^2}{\sqrt{\sqrt{2} z_w r_m \sigma_w^2}} < 1.4916$, that is, if $z_w > 0.8989 z_w^{\max}$.

Proof of Proposition 4:

The proof of Proposition 4 parallels the proof of Lemma 1 with the added feature that the workers' performance measures are correlated. To ensure that the variance-covariance matrix of the N error terms is positive definite (and thus first-best effort is not attainable), we assume that $-\frac{1}{N-1} < \rho < 1$ for all $N \geq 2$.

First, we derive the optimal incentive rates with centralized and delegated contracting, along with the principal's expected net profit. Second, we characterize the principal's optimal observability choice, t.

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a) Optimal incentive rates and the principal's expected net profit

Given the separability of the manager's and the workers' efforts, the manager's effort is as reported in Lemma 1. Hence, without loss of generality, we focus on the workers' efforts.

With centralized contracting ($h = 0$), worker i's certainty equivalent is given by

$$CE_{wi} = \mathrm{E}\left[f_w + v_w x_{wi} + \delta_{ww} \sum_{j \in S_i} x_{wj} | \psi \right] - \frac{1}{2} a_{wi}^2 - \frac{r_w}{2} \left[v_w^2 + (t-1)(1+(t-2)\rho)\delta_{ww}^2 + 2(t-1)\rho v_w \delta_{ww} \right] \sigma_w^2. \quad \text{(A.12)}$$

Given the workers' efforts and binding individual rationality constraints, the principal's unconstrained objective function regarding the workers' contribution is given by

$$\pi_w = N \left\{ b_w^2 v_w - \frac{1}{2} b_w^2 v_w^2 - \frac{r_w}{2} \left[v_w^2 + (t-1)(1+(t-2)\rho)\delta_{ww}^2 + 2(t-1)\rho v_w \delta_{ww} \right] \sigma_w^2 \right\}. \quad \text{(A.13)}$$

From (A.13), the optimal incentive rates follow as

$$v_w = \frac{b_w^2}{b_w^2 + r_w \sigma_w^2 \left(1 - \frac{(t-1)\rho^2}{1+(t-2)\rho}\right)} \quad \text{and} \quad \frac{\delta_{ww}}{v_w} = -\frac{\rho}{(1+(t-2)\rho)}. \quad \text{(A.14)}$$

It is straightforward to show that the second-order conditions are satisfied. Substituting (A.14) into (A.13) yields the principal's expected net profit from the workers' efforts in (12) for $h = 0$,

$$\pi_w = \frac{N}{2} \frac{b_w^4}{b_w^2 + r_w \sigma_w^2 \left(1 - \frac{(t-1)\rho^2}{1+(t-2)\rho}\right)}.$$

With delegated contracting ($h = 1$), the certainty equivalent of worker i, the worker's effort choice, and the binding individual rationality constraint are as before. The manager maximizes

$$CE_m = f_m - \frac{r_m}{2} (\delta_m - v_w - (t-1)\delta_{ww})^2 N(1+(N-1)\rho)\sigma_w^2 + N \left\{ \delta_m b_w^2 v_w - \frac{1}{2} b_w^2 v_w^2 - \frac{r_w}{2} \left[v_w^2 + (t-1)(1+(t-2)\rho)\delta_{ww}^2 + 2(t-1)\rho v_w \delta_{ww} \right] \sigma_w^2 \right\}. \quad \text{(A.15)}$$

From (A.15), the optimal incentive rates for the workers follow as

$$v_w = \gamma_w \delta_m = \left[\frac{b_w^2 + \frac{\sigma_w^2(1-\rho)}{1+(t-2)\rho} T_t}{b_w^2 + r_w \sigma_w^2 (1-\rho) + \frac{\sigma_w^2(1-\rho)}{1+(t-2)\rho} T_t \left(1 + \frac{r_w}{T_1}\rho\right)} \right] \delta_m \quad \text{(A.16a)}$$

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and

$$\frac{\delta_{ww}}{v_w} = \frac{T_t}{r_w[1+(t-2)\rho]}\left(\frac{1-\gamma_w}{\gamma_w} - \rho\frac{r_w}{T_1}\right), \tag{A.16b}$$

where $T_t = \left(\frac{(t-1)r_w^{-1}}{1+(t-2)\rho} + \frac{r_m^{-1}}{1+(N-1)\rho}\right)^{-1}$.

It is straightforward to show that the second-order conditions are satisfied.

Given the workers' efforts and incentive rates and the manager's binding individual rationality constraint, the principal's unconstrained objective function is given by

$$\pi_w = N\left\{b_w^2\gamma_w\delta_m - \frac{1}{2}b_w^2\gamma_w^2\delta_m^2 - \frac{r_w}{2}\left(1-\frac{(t-1)\rho^2}{1+(t-2)\rho}\right)\sigma_w^2\gamma_w^2\delta_m^2\right.$$
$$\left. -\frac{1}{2}T_t\sigma_w^2\left(\frac{\frac{b_w^2(t-1)\rho}{1+(t-2)\rho} + r_w\sigma_w^2\left(1-\frac{(t-1)\rho^2}{1+(t-2)\rho}\right)}{b_w^2 + r_w\sigma_w^2(1-\rho) + \frac{\sigma_w^2(1-\rho)}{1+(t-2)\rho}T_t\left(1+\frac{r_w}{T_1}\rho\right)}\right)^2\delta_m^2\right\}, \tag{A.17}$$

where γ_w is defined in (A.16a).

From (A.17), the optimal incentive rate for the manager follows as

$$\delta_m = \frac{b_w^2}{b_w^2 + T_t\sigma_w^2\left(\frac{\frac{b_w^2(t-1)\rho}{1+(t-2)\rho} + r_w\sigma_w^2\left(1-\frac{(t-1)\rho^2}{1+(t-2)\rho}\right)}{b_w^2 + \frac{\sigma_w^2(1-\rho)}{1+(t-2)\rho}T_t}\right)}. \tag{A.18}$$

It is straightforward to show that the second-order conditions are satisfied.

Substituting (A.18) into (A.17) yields the principal's expected profit in (12) for $h=1$,

$$\pi_w = \frac{N}{2}\frac{b_w^4}{b_w^2 + r_w\sigma_w^2\left(1-\frac{(t-1)\rho^2}{1+(t-2)\rho}\right) + T_tR_t}, \tag{A.19}$$

where

$$R_t = \sigma_w^2\left(\frac{\frac{b_w^2(t-1)\rho}{1+(t-2)\rho} + r_w\sigma_w^2\left(1-\frac{(t-1)\rho^2}{1+(t-2)\rho}\right)}{b_w^2 + T_t\sigma_w^2(1-\rho)}\right)^2.$$

b) Optimal performance observability

With centralized contracting ($h=0$), using (12), it is straightforward that $t^* = N$ because $\frac{(t-1)\rho^2}{1+(t-2)\rho} > \frac{(t'-1)\rho^2}{1+(t'-2)\rho}$ for all $t > t'$.

To characterize the principal's choice of t with delegated contracting ($h=1$), we assume that t is a continuous variable (for analytical convenience) and show that the stationary points (if any) are not interior maxima. Hence, the corner solutions of $t=1$ or $t=N$ satisfy the constraint that t is an integer.

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Given (A.19), $\frac{d\pi_w}{dt} \propto \frac{r_w\sigma_w^2\rho^2(1-\rho)}{[1+(t-2)\rho]^2} - \frac{d(T_tR_t)}{dt}$, where $\frac{dT_t}{dt} = -(\frac{T_t}{r_w})\frac{T_t(1-\rho)}{[1+(t-2)\rho]^2}$ and $\frac{dR_t}{dt} = \frac{2R_t(1-\rho)}{[1+(t-2)\rho]^2}\{\frac{\rho(b_w^2-r_w\sigma_w^2\rho)}{\frac{b_w^2(t-1)\rho}{1+(t-2)\rho}+r_w\sigma_w^2(1-\frac{(t-1)\rho^2}{1+(t-2)\rho})} + (\frac{T_t}{r_w})\frac{T_t\sigma_w^2(1-\rho)}{b_w^2+T_t\sigma_w^2(1-\rho)}\}$.

Hence,

$$\frac{d\pi_w}{dt} \propto \frac{(1-\rho)T_tR_t}{[1+(t-2)\rho]^2}\left\{\left(\frac{T_t}{r_w}\right)\frac{b_w^2 - T_t\sigma_w^2(1-\rho)}{b_w^2+T_t\sigma_w^2(1-\rho)} + \frac{r_w\sigma_w^2\rho^2}{T_tR_t}\right.$$
$$\left. - \frac{2\rho\left(b_w^2 - r_w\sigma_w^2\rho\right)}{\frac{(t-1)\rho}{1+(t-2)\rho}\left(b_w^2 - r_w\sigma_w^2\rho\right) + r_w\sigma_w^2}\right\}$$

and stationary points t (if any) satisfy

$$\left(\frac{T_t}{r_w}\right)\frac{b_w^2 - T_t\sigma_w^2(1-\rho)}{b_w^2+T_t\sigma_w^2(1-\rho)} + \frac{r_w\sigma_w^2\rho^2}{T_tR_t} - \frac{2\rho(b_w^2 - r_w\sigma_w^2\rho)}{\frac{(t-1)\rho}{1+(t-2)\rho}(b_w^2 - r_w\sigma_w^2\rho) + r_w\sigma_w^2} = 0.$$

However, we can show that $\frac{d\pi_w^2}{dt^2}$ evaluated at $\frac{d\pi_w}{dt} = 0$ is positive. Hence, the optimal t is not interior, and the principal prefers either $t^* = 1$ or $t^* = N$.

It follows that the principal prefers $t^* = 1$ if, and only if, $\pi_w(t = 1) \geq \pi_w(t = N)$, and prefers $t^* = N$ otherwise. Using (A.19), $\pi_w(t = 1) \geq \pi_w(t = N)$ requires that

$$T_NR_N - T_1R_1 > r_w\sigma_w^2\frac{(N-1)\rho^2}{1+(N-2)\rho}, \tag{A.20}$$

where $T_1 = r_m[1 + (N-1)\rho]$, $R_1 = \sigma_w^2(\frac{r_w\sigma_w^2}{b_w^2+T_1\sigma_w^2(1-\rho)})^2$, $T_N = \frac{T_1}{1+(\frac{T_1}{r_w})\frac{(N-1)}{1+(N-2)\rho}}$, and $R_N = \sigma_w^2(\frac{\frac{(N-1)\rho^2}{[1+(N-2)\rho]}(\frac{b_w^2}{\rho}-r_w\sigma_w^2)+r_w\sigma_w^2}{b_w^2+T_1\sigma_w^2(1-\rho)(1-(\frac{T_1}{r_w})(\frac{(N-1)}{(1+(N-2)\rho)+(N-1)(\frac{T_1}{r_w})}))})^2$. Substituting for T_1, R_1, T_N, and R_N and simplifying, we find that $T_NR_N - T_1R_1 > r_w\sigma_w^2\frac{(N-1)\rho^2}{1+(N-2)\rho}$ for all $\rho_l \leq \rho \leq \rho_u$, where $0 \leq \rho_u < 1$ solves $K_u = \rho_u - \frac{T_{1,u}s}{1+T_{1,u}s} = 0$ and $\rho_l \geq \rho_l^{\min}$ solves $K_l = \rho_l - \frac{T_{1,l}s}{1+T_{1,l}s}Z = 0$, where $s = \frac{\sigma_w^2}{b_w^2}$, $T_{1,u} = r_m[1 + (N-1)\rho_u]$, $T_{1,l} = r_m[1 + (N-1)\rho_l]$, $Z = \frac{1-r_ws\rho_l-r_wT_{1,l}s^2(1-\rho_l)Q}{1+2T_{1,l}s+r_wT_{1,l}s^2(1-\rho_l)(1+Q)}$, and $Q = \frac{(T_{1,l}+\rho_lr_w)}{(N-1)(T_{1,l}+\rho_lr_w)+r_w(1-\rho_l)}$ for notational convenience, and $\rho_l^{\min} = \lim_{s\to\infty}\frac{T_{1,l}s}{1+T_{1,l}s}Z = -\frac{Q}{1+Q}$ where $0 < Q < 1$. Hence, $t^* = 1$ if, and only if, $\rho_l \leq \rho \leq \rho_u$; otherwise, $t^* = N$.

Proof of Corollary 4:

For ρ_u, the following are useful for the proof of Corollary 4.

(i) $\frac{dT_{1,u}}{d\rho_u} = r_m(N-1) \geq 0$; $\frac{dT_{1,u}}{dr_m} = 1 + (N-1)\rho_u > 0$;

(ii) $\frac{\partial K_u}{\partial \rho_u} = 1 - \frac{\rho_u\frac{\partial T_{1,u}}{\partial \rho_u}}{T_{1,u}(1+T_{1,u}s)} = \frac{r_m+T_{1,u}^2s}{T_{1,u}(1+T_{1,u}s)} \geq 0$;

(iii) $\frac{\partial K_u}{\partial r_m} = -\frac{\rho_u\frac{\partial T_{1,u}}{\partial r_m}}{T_{1,u}(1+T_{1,u}s)} \leq 0$; $\frac{\partial K_u}{\partial s} = -\frac{\rho_u}{s(1+T_{1,u}s)} \leq 0$.

For ρ_l, the following are useful for the proof of Corollary 4.

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(i) $-\frac{T_{1,l}s}{1+T_{1,l}s}(\frac{Q}{1+Q}) < \rho_l < (\frac{T_{1,l}s}{1+T_{1,l}s})\frac{1-r_w s\rho_l}{1+2T_{1,l}s}$;

(ii) $\frac{dT_{1,l}}{d\rho_l} = r_m(N-1) \geq 0$; $\frac{dT_{1,l}}{dr_m} = 1 + (N-1)\rho_l > 0$;

(iii) $\frac{dQ}{dT_{1,l}} = \frac{1-Q(N-1)}{(N-1)(T_{1,l}+\rho_l r_w)+r_w(1-\rho_l)} > 0$; $\frac{dQ}{d\rho_l} = \frac{[1-Q(N-1)]\frac{dT_{1,l}}{d\rho_l}+r_w[1-Q(N-2)]}{(N-1)(T_{1,l}+\rho_l r_w)+r_w(1-\rho_l)} > 0$;

(iv) $\frac{\partial K_l}{\partial \rho_l} = 1 - \frac{\rho_l \frac{\partial T_{1,l}}{\partial \rho_l}}{T_{1,l}(1+T_{1,l}s)} - \frac{T_{1,l}s}{1+T_{1,l}s}\frac{dZ}{d\rho_l} = \frac{r_m}{T_{1,l}(1+T_{1,l}s)} + \frac{T_{1,l}s}{1+T_{1,l}s}(1 - \frac{dZ}{d\rho_l})$;

(v) $1 - \frac{dZ}{d\rho_l} = (1 - \frac{\partial Z}{\partial \rho_l}) - \{\frac{\partial Z}{\partial T_{1,l}}\frac{dT_{1,l}}{d\rho_l} + \frac{\partial Z}{\partial Q}\frac{dQ}{d\rho_l}\}$;

(vi) $1 - \frac{\partial Z}{\partial \rho_l} = \frac{(1-r_w s\rho_l)(1+2T_{1,l}s)+r_w s(1-\rho_l Q)+r_w T_{1,l}s^2(1-2\rho_l Q)}{[1+2T_{1,l}s+r_w T_{1,l}s^2(1-\rho_l)(1+Q)]} > 0$ for all ρ_l because $(1 - r_w s\rho_l) > 0$, $0 < Q < 1$, and $\rho_l < \frac{1}{3}$ from (i);

(vii) $\frac{\partial Z}{\partial T_{1,l}} = -\frac{r_w s^2(1-\rho_l)Q+(2s+r_w s^2(1-\rho_l)(1+Q))(1-r_w s\rho_l)}{[1+2T_{1,l}s+r_w T_{1,l}s^2(1-\rho_l)(1+Q)]^2} < 0$ because $(1 - r_w s\rho_l) > 0$;

(viii) $\frac{\partial Z}{\partial Q} = -\frac{r_w s^2(1-\rho_l)T_{1,l}(1+Z)}{1+2T_{1,l}s+r_w T_{1,l}s^2(1-\rho_l)(1+Q)} < 0$ because $Z > -\frac{Q}{1+Q}$;

(ix) $\frac{\partial K_l}{\partial r_m} = -\frac{dT_{1,l}}{dr_m}(\frac{\rho_l}{T_{1,l}(1+T_{1,l}s)} + \frac{T_{1,l}s}{(1+T_{1,l}s)}[\frac{\partial Z}{\partial T_{1,l}} + \frac{\partial Z}{\partial Q}\frac{dQ}{dT_{1,l}}])$;

(x) $\frac{\partial K_l}{\partial s} = -\frac{\rho_l}{s(1+T_{1,l}s)} - \frac{T_{1,l}s}{(1+T_{1,l}s)}\frac{dZ}{ds}$;

(xi) $\frac{dZ}{ds} = -s^{-1}\frac{(1-Z)}{1+2T_{1,l}s+r_w T_{1,l}s^2(1-\rho_l)(1+Q)}$ $- s^{-1}\frac{r_w T_{1,l}s^2(1-\rho_l)(Q(1+2T_{1,l}s)+(1+Q)(1-r_w s\rho_l))}{[1+2T_{1,l}s+r_w T_{1,l}s^2(1-\rho_l)(1+Q)]^2} < 0$ because $(1 - r_w s\rho_l) > 0$.

Proof of $\frac{d(\rho_u-\rho_l)}{dr_m}$:

$$\frac{d\rho_u}{dr_m} = -\frac{\frac{\partial K_u}{\partial r_m}}{\frac{\partial K_u}{\partial \rho_u}} = \frac{\rho_u \frac{\partial T_{1,u}}{\partial r_m}}{r_m + T_{1,u}^2 s} > 0 \text{ and } \frac{d\rho_l}{dr_m} = -\frac{\frac{\partial K_l}{\partial r_m}}{\frac{\partial K_l}{\partial \rho_l}} = \frac{\rho_l \frac{\partial T_{1,l}}{\partial r_m}}{r_m + T_{1,l}^2 s}$$

$$+\frac{T_{1,l}^2 s\left[\frac{\partial Z}{\partial T_{1,l}} + \frac{\partial Z}{\partial Q}\frac{dQ}{dT_{1,l}} + \frac{\rho_l}{r_m+T_{1,l}^2 s}\frac{dZ}{d\rho_l}\right]\frac{dT_{1,l}}{dr_m}}{r_m + T_{1,l}^2 s\left(1 - \frac{dZ}{d\rho_l}\right)}.$$

Hence, $\frac{d(\rho_u-\rho_l)}{dr_m} = (\frac{\rho_u \frac{\partial T_{1,u}}{\partial r_m}}{r_m+T_{1,u}^2 s} - \frac{\rho_l \frac{\partial T_{1,l}}{\partial r_m}}{r_m+T_{1,l}^2 s}) - \frac{T_{1,l}^2 s[\frac{\partial Z}{\partial T_{1,l}} + \frac{\partial Z}{\partial Q}\frac{dQ}{dT_{1,l}} + \frac{\rho_l}{r_m+T_{1,l}^2 s}\frac{dZ}{d\rho_l}]\frac{dT_{1,l}}{dr_m}}{r_m+T_{1,l}^2 s(1-\frac{dZ}{d\rho_l})} > 0$ because $\rho_u \geq \rho_l$, $\frac{\partial T_{1,u}}{\partial r_m} > 0$, $\frac{\partial T_{1,l}}{\partial r_m} > 0$, $[\frac{\partial Z}{\partial T_{1,l}} + \frac{\partial Z}{\partial Q}\frac{dQ}{dT_{1,l}} + \frac{\rho_l}{r_m+T_{1,l}^2 s}\frac{dZ}{d\rho_l}] < 0$, and $(1 - \frac{dZ}{d\rho_l}) > 0$.

Proof of $\frac{d(\rho_u-\rho_l)}{ds}$:

$$\frac{d\rho_u}{ds} = -\frac{\frac{\partial K_u}{\partial s}}{\frac{\partial K_u}{\partial \rho_u}} = \frac{\rho_u T_{1,u}}{s[r_m + T_{1,u}^2 s]} > 0 \text{ and } \frac{d\rho_l}{ds} = -\frac{\frac{\partial K_l}{\partial s}}{\frac{\partial K_l}{\partial \rho_l}}$$

$$= \frac{\rho_l T_{1,l}}{s[r_m + T_{1,l}^2 s]} + \frac{T_{1,l}^2\left[s\frac{dZ}{ds} + \frac{\rho_l T_{1,l}}{(r_m+T_{1,l}^2 s)}\frac{dZ}{d\rho_l}\right]}{r_m + T_{1,l}^2 s\left(1 - \frac{dZ}{d\rho_l}\right)}.$$

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Hence, $\frac{d(\rho_u-\rho_l)}{ds} = (\frac{\rho_u T_{1,u}}{s[r_m+T_{1,u}^2 s]} - \frac{\rho_l T_{1,l}}{s[r_m+T_{1,l}^2 s]}) - \frac{T_{1,l}^2[s\frac{dZ}{ds}+\frac{\rho_l T_{1,l}}{(r_m+T_{1,l}^2 s)}\frac{dZ}{d\rho_l}]}{r_m+T_{1,l}^2 s(1-\frac{dZ}{d\rho_l})} > 0$ because $\rho_u \geq \rho_l$, $[\frac{dZ}{ds} + \frac{\rho_l T_{1,l}}{r_m+T_{1,l}^2 s}\frac{dZ}{d\rho_l}] < 0$, and $(1-\frac{dZ}{d\rho_l}) > 0$.

Proof of Proposition 5:

Given the principal's choice of compensation and observability arrangements (Lemma 1 and Corollary 2), we write the principal's expected net profit (ignoring the cost acquiring W) as

$$\pi_h = \frac{1}{2}\frac{b_m^4}{b_m^2 + r_m\sigma_m^2\left(\frac{r_m^{-1}}{r_m^{-1}+hr_w^{-1}}\right)} + \frac{N}{2}\frac{b_w^4}{b_w^2 + r_w\sigma_w^2} - \frac{h}{2}L_{t^*}, \tag{A.21}$$

where contracting authority for $h = \{0, 1, \ldots, N\}$ workers is delegated to the manager, $L_{t^*} = (\frac{b_w^4}{b_w^2+r_w\sigma_w^2})\frac{T_{t^*}R_{t^*}}{b_w^2+r_w\sigma_w^2+T_{t^*}R_{t^*}}$, $T_{t^*} = (r_m^{-1} + (t^*-1)r_w^{-1})^{-1}$, $R_{t^*} = \sigma_w^2(\frac{r_w\sigma_w^2}{b_w^2+T_{t^*}\sigma_w^2})^2$, $t \leq h$ for all $1 \leq h \leq N$, and from section 4.1$t^*(h) = 1$ if $\frac{b_w^2}{\sigma_w^2} < \sqrt{T_1 T_h}$ and $t^*(h) = h$ otherwise.

Using (A.21), the incremental profit of assigning h versus h' workers to the manager is

$$\pi_h - \pi_{h'} = \frac{(h-h')}{2}\left\{\frac{b_m^4 r_m\sigma_m^2\left(\frac{r_m}{r_w}\right)}{\left(b_m^2 + r_m\sigma_m^2 + b_m^2 h\frac{r_m}{r_w}\right)\left(b_m^2 + r_m\sigma_m^2 + b_m^2 h'\frac{r_m}{r_w}\right)} - \frac{hL_{t^*(h)} - h'L_{t^*(h')}}{h-h'}\right\}. \tag{A.22}$$

For ease of exposition, we present the proofs separately for opaque and transparent measurement practices. With opaque measurement practices $(t^*(h) = 1)$, $L_{t^*(h)} = L_{t^*(h')} = L_1$ for all $h = \{1, \ldots, N\}$. The principal's optimal delegation choice is as follows:

(1) Full delegation $(h^* = N)$ if the curly bracket in (A.22) is positive for all $h > h'$, that is, if
$$\frac{b_m^4 r_m\sigma_m^2(\frac{r_m}{r_w})}{(b_m^2 + r_m\sigma_m^2 + b_m^2 N\frac{r_m}{r_w})(b_m^2 + r_m\sigma_m^2 + b_m^2(N-1)\frac{r_m}{r_w})} > L_1;$$
(2) centralization $(h^* = 0)$ if the curly bracket in (A.22) is negative for all $h > h'$, that is, if
$$\frac{b_m^4 r_m\sigma_m^2(\frac{r_m}{r_w})}{(b_m^2 + r_m\sigma_m^2 + b_m^2\frac{r_m}{r_w})(b_m^2 + r_m\sigma_m^2)} < L_1;$$
(3) partial delegation $(1 \leq h^* < N)$ if the curly bracket in (A.22) is positive for $h = 1$; $h' = 0$ but negative for $h = N$; $h' = N-1$, that is, if
$$(b_m^2 + r_m\sigma_m^2 + b_m^2\frac{r_m}{r_w})(b_m^2 + r_m\sigma_m^2)L_1 < b_m^4 r_m\sigma_m^2(\frac{r_m}{r_w})$$
$$< (b_m^2 + r_m\sigma_m^2 + b_m^2 N\frac{r_m}{r_w})(b_m^2 + r_m\sigma_m^2 + b_m^2(N-1)\frac{r_m}{r_w})L_1.$$

With transparent measurement practices ($t^*(h) = h$ if $\frac{b_w^2}{\sigma_w^2} > \sqrt{T_1 T_h}$), we can write the incremental cost in (A.22) as $\frac{hL_h - h'L_{h'}}{h-h'} = L_{h'} + \frac{h}{h-h'}(L_h - L_{h'})$. We can show that for all $h > h'$, $hL_h - h'L_{h'} > 0$ and $L_h - L_{h'} < 0$ for $\frac{b_w^2}{\sigma_w^2} > \sqrt{T_{h'} T_h}$, which is weaker than $\frac{b_w^2}{\sigma_w^2} > \sqrt{T_1 T_h}$ for $h' > 1$. Hence, the principal's optimal delegation choice is as follows:

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(1) Full delegation ($h^* = N$) if the curly bracket in (A.22) is positive for all $h > h'$, that is, if $\frac{b_m^4 r_m \sigma_m^2 (\frac{r_m}{r_w})}{(b_m^2 + r_m\sigma_m^2 + b_m^2 N \frac{r_m}{r_w})(b_m^2 + r_m\sigma_m^2 + b_m^2 (N-1)\frac{r_m}{r_w})} > L_1$;

(2) centralization ($h^* = 0$) if the curly bracket in (A.22) is negative for all $h > h'$, that is, if $\frac{b_m^4 r_m \sigma_m^2 (\frac{r_m}{r_w})}{(b_m^2 + r_m\sigma_m^2 + b_m^2 \frac{r_m}{r_w})(b_m^2 + r_m\sigma_m^2)} < L_{N-1} + N(L_N - L_{N-1})$;

(3) partial delegation ($1 \leq h^* < N$) if for some h, the curly bracket in (A.22) is positive for smaller but negative for larger adjacent values of h, that is, if

$$(b_m^2 + r_m\sigma_m^2 + b_m^2 (h-1)\frac{r_m}{r_w})(L_{h-1} + h(L_h - L_{h-1})) < \frac{b_m^4 r_m \sigma_m^2 (\frac{r_m}{r_w})}{(b_m^2 + r_m\sigma_m^2 + b_m^2 h \frac{r_m}{r_w})}$$
$$< (b_m^2 + r_m\sigma_m^2 + b_m^2 (h+1)\frac{r_m}{r_w})(L_h + (h+1)(L_{h+1} - L_h)).$$

We can show that there are parameter values such that the prior region is not empty and thus $1 \leq h^* < N$.

We close by noting that the incremental benefit in (A.22) increases in the manager's marginal productivity, b_m, whereas the incremental cost is independent of b_m. Hence, in case of partial delegation, the principal assigns more workers to the manager if the manager is more productive.

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