Confidence Management in Contests*

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Abstract

An incumbent employee competes against a new hire for bonuses or promotions. The incumbent's perception of the new hire's ability distribution is biased. This bias can result in overconfidence or underconfidence. We show that debiasing may be counterproductive in incentivizing efforts. We then explore whether a firm that values employees' efforts should disclose an informative signal about the new hire's type and we characterize the conditions under which transparency or opacity is optimal for the firm. We further consider four extensions to the model. Our results contribute to the extensive discussion of confidence management and organizational transparency in firms.

Keywords: Confidence Management; Information Asymmetry; Contests; Effort Incentives; Information Disclosure.

JEL Classification Codes: D21, D23, D82, D91.

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“*Attempt easy tasks as if they were difficult, and difficult as if they were easy; in the one case that confidence may not fall asleep, in the other that it may not be dismayed.*”

—Baltasar Gracián

“*Perhaps a successful life, like a successful company, needs both optimism and at least occasional pessimism, and for the same reason a corporation does.*”

—Martin Seligman

1 Introduction

The internal labor markets inside firms are widely viewed to resemble contests (Lazear and Rosen, 1981; Rosen, 1986). Workers strive for bonuses or to climb the hierarchical ladder (Brown and Minor, 2014). They are rewarded or punished based on their performance relative to competitors or benchmarks instead of absolute output metrics (Chen and Lim, 2013; Chen, 2016). A plethora of anecdotal and empirical observations have documented the prevalence of contest-like competitions and relative performance evaluation (RPE) schemes (see, e.g., Eriksson, 1999; Henderson and Fredrickson, 2001; Belzil and Bognanno, 2008; Connelly, Tihanyi, Crook, and Gangloff, 2014; and Lazear, 2018). Consider, for instance, the popular practice of *vitality curve*—or stack ranking—that was pioneered by Jack Welch and has proliferated in the modern corporate landscape (see, e.g., McGregor, 2006).[1] As argued by DeVaro (2006), promotion contests are an integral component of firms' human resource practices to advance their strategic interests.

The conventional wisdom holds that the incentive of the agents involved in contest situations crucially depends on their relative competitiveness and their perception of each other's competency (Brown, 2011). However, one's knowledge about his opponent is often limited,

[1] In performance management, a vitality curve ranks (or rates) individuals against their coworkers. It is also called “stack ranking,” “forced ranking,” and “rank and yank.” The concept of a vitality curve has been used to justify the “rank-and-yank” system of management at GE, whereby 10% of workers are fired after each evaluation.

and his perception can be systematically biased. Consider the usual scenario in which a new hire joins an organization and competes—under an RPE scheme—against incumbent employees for bonuses or promotion. The competency of the incumbents can be inferred from their established track record, while that of the new hire often remains to be ascertained, which gives rise to the typical problem of information asymmetry (see, e.g., Hurley and Shogren, 1998; Wärneryd, 2003; Zhang and Zhou, 2016; and Denter, Morgan, and Sisak, 2022). Furthermore, incumbent employees may misestimate the new hire. A large body of economics and psychology literature has identified the prevalence of perceptional biases by which people "misplace" themselves in comparison with others or with the population mean, being either overconfident or underconfident (see, e.g., Larwood and Whittaker, 1977; Cooper, Woo, and Dunkelberg, 1988; Malmendier and Tate, 2005, 2015; Moore and Cain, 2007; Moore and Healy, 2008; and Muthukrishna, Henrich, Toyokawa, Hamamura, Kameda, and Heine, 2018)[2]. Such phenomena are pervasive in workplaces. Consider the following examples.

(i) A startup recruits a high-profile executive poached from an industry leader; incumbent employees may presumably overestimate the external hire.

(ii) Optimism typically arises in a rapidly growing firm; incumbent employees would arguably underestimate newbies, as they attribute the firm's success to their own superior competence.

(iii) A corporate culture that champions workplace Darwinism—e.g., that at Enron—typically boosts employees' egos and breeds overconfidence, which also leads them to look down on newcomers.[3]

In this paper, we aim to explore two main questions. Suppose that a firm cares about the aggregate effort supply in the workplace. First, does the firm benefit or suffer from its

[2]Santos-Pinto and Sobel (2005) outline a mechanism under which self-overestimation arises in subjective assessment of relative abilities.

[3]See Netessine and Yakubovich (2012).

employee's perceptional bias? Second, suppose that the firm is able to conduct an evaluation to acquire an informative signal about the new hire's true ability. For instance, the firm is able to observe a new hire's performance, which allows for more precise estimate of his ability and/or match to the position. Is the firm willing to disclose it to employees, which manipulates their beliefs and, in turn, influences the performance of the competition?

To answer these questions, we adopt a standard lottery contest setting—as in Denter, Morgan, and Sisak (2022) and Zhang and Zhou (2016)—to model a promotion contest in a firm. Two employees—an incumbent (he) and a new hire (he)—are involved in the competition. They differ in their abilities. The incumbent's ability is common knowledge, while that of the new hire is privately known. The new hire's ability can take either a high or a low value. We allow the incumbent employee to possess a different prior about the new hire than the true underlying distribution. The uncommon priors thus depict the incumbent employee's misperception of his relative competitiveness in the contest. A manager (she)—e.g., HR director—acts in the firm's interest and can secure an informative signal about the new hire's true ability through an evaluation exercise. She decides on the firm's information disclosure policy and commits to either disclosing the signal to both employees or concealing it, with the latter being equivalent to foregoing the evaluation exercise.

The questions posed in this paper are not only theoretically interesting, but also practically relevant. First, successful confidence management is broadly viewed in practice as a key to boosting productivity. The economics literature has espoused the motivation effect of (over)confidence, as a positive self-image could incentivize efforts and catalyze success (see, e.g., Bénabou and Tirole, 2002; Compte and Postlewaite, 2004; Gervais and Goldstein (2007); Chen and Schildberg-Hörisch, 2019). However, overconfidence has typically been examined in settings of stand-alone decision making or a principal-agent relationship. We nevertheless demonstrate the more subtle impact of overconfidence on effort supply in a contest setting. We show that both overconfidence and underconfidence can benefit or harm effort provision. Imagine that the incumbent is the ex ante favorite to win the contest. Overconfidence would stifle the competition, as the complacency entices him to further slack off; in contrast, underconfidence on the part of the incumbent can prevent shirking. Conversely, when the incumbent is the ex ante underdog, his overconfidence would help avoid discouragement, and thus debiasing would weaken the competition. The ramifications result from (i) the relative-performance based reward structure in contests, and (ii) players' nonmonotone best response correspondence in the strategic interactions that occur in such competitive events (Lazear and Rosen, 1981; and Dixit, 1987). To the best of our knowledge, such effects have yet to be formally delineated in the literature.

Second, firms' internal information management—i.e., the information accessible to their employees—has spawned extensive discussion in both academic studies and practice. A large portion of leading firms in Europe and the United States have established internal knowledge system or built competency models that identify best practices and publicize feedback on employees' performance relative to their peers (Nafziger and Schumacher, 2013; O'Connell, 2008; Vanek Smith, 2015; Song, Tucker, Murrell, and Vinson, 2018). Eli Lilly & Co., for instance, allows its employees to access their rankings in the succession planning system. In the National University of Singapore (NUS) Business School, faculty members are allowed to access colleagues' student feedback reports.[4] The informative signal, if disclosed, allows the uninformed incumbent to make inferences about his opponent: It not only ameliorates information asymmetry, but also changes his perception of their relative competitiveness. This update, by the same logic laid out above, would indeterminately affect his incentive in the competition and trigger an ambiguous strategic response from the new hire.

We fully characterize in Section 2 the necessary and sufficient conditions under which the incumbent's misperception benefits/harms the firm in terms of aggregate effort (Proposition 1). We then explore the optimal information disclosure policy in Section 3. Two effects—the information effect and the morale effect—loom large when the incumbent observes the signal with misperception in place. We demonstrate that the optimal disclosure policy is shaped by the tension between these effects; we then identify the conditions under which either disclosing the signal or concealing it is optimal (Proposition 2); illustrate how

[4]NUS conducts annual performance reviews for faculty members. Each department sets aside a bonus pool to reward teaching excellence, and only top-ranked performers receive the monetary reward.

the optimal disclosure policy varies with respect to the degree of the incumbent's misperception (Proposition 3); and interpret the underlying logic in Section 3.2. Our theoretical results yield novel and useful managerial implications for firms' confidence and internal information management, which we elaborate on in Sections 2.4 and 3.3. More details will be provided when the analysis unfolds.

Related Literature Our paper contributes to the literature on information transmission in contests/contests. One stream of this literature assumes that a designer possesses superior information about the contenders and explores her optimal disclosure policy, e.g., Fu, Jiao, and Lu (2014), Zhang and Zhou (2016), Serena (2022), Lu, Ma, and Wang (2018), Chen (2021), and Boosey, Brookins, and Ryvkin (2020). The other stream of work studies contenders' strategic action to reveal private information. Denter, Morgan, and Sisak (2022) and Fu, Gürtler, and Münster (2013) let the informed party take a costly action to signal his private type prior to the competition. Kovenock, Morath, and Münster (2015) and Wu and Zheng (2017) study contenders' voluntary information disclosure. These studies mainly assume common priors and rational beliefs.[5] Our paper belongs to the former class of studies, as it allows the firm to conduct an evaluation and decide whether or not to disclose an informative signal. However, this strand of literature does not allow for perceptionally biased players; as a result, the morale effect due to the perceptional bias in our setting—which plays a subtle and important role in determining the optimum—is absent. Our study thus complements these studies.

Our paper is naturally linked to the literature on the incentive effect of over(under)-confidence, such as Bénabou and Tirole (2002, 2003), Compte and Postlewaite (2004), Fang and Moscarini (2005), and Chen and Schildberg-Hörisch (2019).[6] However, these studies

[5]In an extension (Proposition 5 and Appendix K), Denter, Morgan, and Sisak (2022) consider a case of overconfident players. Their model sharply differs from ours: They allow the player of private type to misperceive himself and assume that both players possess the same biased belief, while in ours, one knows precisely his private type, while the other systematically misestimate his opponent.

[6]Santos-Pinto and de la Rosa (2020) provide a thorough survey of the literature on the incentive effect of self-perceptional bias. Also see Kőszegi (2014), Grubb (2015a,b), and Heidhues and Kőszegi (2018) for surveys on behavioral industrial organization and overconfident consumers in the marketplace.

focus on the decision making of a single agent or in a principal-agent setting. Santos-Pinto (2008) examine both single-agent and multi-agent scenarios. Fang (2001) explores the role of perceptional bias in a team-production setting. Gervais and Goldstein (2007) show that overconfidence reduces free-riding and benefits teamwork, as an overconfident agent works harder. Kyle and Wang (1997) demonstrate in a Cournot duopoly setting the commitment value of overconfidence. However, Kyle and Wang (1997) interpret overconfidence as overoptimism, i.e., excessively optimistic perception of the precision of his own signal; in contrast, we focus on over(under)-placement (Moore and Healy, 2008), by which a player over(under)-estimates his relative competitiveness. Grubb (2009) analyzes a model of optimal contracting between firms and overconfident consumers in the cellular phone services market. Fang and Wu (2020) study the welfare effects of secondary markets when consumers are overconfident in the context of life settlement market.

In particular, our study is closely related to those of Bénabou and Tirole (2003) and Fang and Moscarini (2005), since both examine how a principal can manipulate workers' beliefs in her favor. Bénabou and Tirole (2003) examine how performance incentives awarded by a principal would affect a worker's perception of his own abilities. Fang and Moscarini (2005) assume that a firm hires a continuum of workers with the same initial belief and investigate how the prevailing wage policy affects workers' morale—i.e., their confidence in their abilities. However, the two studies do not study consider competition between workers. In our setting, the signal disclosed by the firm varies employees' beliefs and therefore manipulates the competition, which differentiates our study from those of Bénabou and Tirole (2003) and Fang and Moscarini (2005).

We join the small but growing literature that explores the role played by the perceptional bias in a contest in which the reward is based on relative performance. Santos-Pinto (2010) considers a contest inside a firm in which both workers overestimate their own productivity; he finds that under plausible conditions, workers' positive self-image accrues to the benefit of the firm. Santos-Pinto and Sekeris (2023) examine tournaments/contests in which one worker overestimates his ability and winning odds and link the setting to the context of gender gaps.

Both papers assume complete-information settings, while we allow for one-sided asymmetric information and examine the optimal information disclosure.[7]

Crutzen, Swank, and Visser (2013) demonstrate that manager may refrain from differentiation among employees, as differentiation may lead them to downgrade their self-ratings and dampen incentives. Nafziger and Schumacher (2013) show that revealing peer performance can be counterproductive as an employee can infer the impact of his effort on the probability of success. However, these settings do not involve competition or perceptional biases.

In our model, the manager conducts an evaluation of the new hire's ability after he starts the job and decides whether to disclose the signal she obtains. Our paper can thus be connected to the literature on interim feedback and information disclosure in dynamic contests (Yildirim, 2005; Gershkov and Perry, 2009; Aoyagi, 2010; Ederer, 2010; Gürtler and Harbring, 2010; Goltsman and Mukherjee, 2011). These studies typically assume a two-player two-period setting: The organizer decides whether to disclose contestants' intermediate performance and the winner is to be determined by contestants' overall performance summed up over the two periods. Our paper, in contrast, assumes a one-shot competition and abstracts away any interactions prior to the contest.

The rest of our paper is organized as follows. In Section 2, we set up an asymmetric-information contest model with uncommon priors, characterize the equilibrium, and elaborate on the impact of perceptional bias. In Section 3, we explore the optimal information disclosure policy in the contest and interpret the results. In Section 4, we consider an alternative context in which the firm is concerned about the expected winner's effort instead of the aggregate effort. In Section 5, we briefly discuss three variations to the baseline setting—which demonstrate the robustness of our results—and conclude.

[7]Park and Santos-Pinto (2010) document empirical evidence of overestimation bias in field.

2 Asymmetric-Information contest with Uncommon Priors

We model the competition between two employees inside a firm as a contest. In this part, we spell out the fundamentals of the contest model and solve for the equilibrium, which lays a foundation for the analysis of optimal information policy.

2.1 Model

We consider a firm with a manager and two risk-neutral employees, indexed by $i \in \{A, B\}$. The two employees compete for a prize—e.g., a promotion—by exerting irreversible efforts $x_i \geq 0$ simultaneously. The common value of the prize is normalized to unity.

We assume a lottery *contest success function* (CSF) to model the contest competition in the firm's internal labor market: For an effort profile $(x_A, x_B) \geq (0, 0)$, employee i wins with a probability[8]

$$p_i(x_A, x_B) = \begin{cases} x_i/(x_A + x_B) & \text{if } x_A + x_B > 0, \\ 1/2 & \text{if } x_A + x_B = 0. \end{cases} \tag{1}$$

This winning probability specification, conventionally called a lottery contest, is uniquely underpinned by a noisy rank-order tournament. Imagine that contestants are evaluated through the noisy signals of their performance y_is. Following the discrete choice framework of McFadden (1973, 1974), the noisy signal y_i is assumed to be described by

$$\log y_i = \log x_i + \varepsilon_i, \quad \forall\, i \in \{A, B\}, \tag{2}$$

where the noise term ε_i reflects the randomness in the production process or the imperfection of the measurement and evaluation process. Idiosyncratic noises $\boldsymbol{\varepsilon} \triangleq \{\varepsilon_A, \varepsilon_B\}$ are indepen-

[8] A closed-form equilibrium solution to the model is not available if we assume a CSF in the form of $(x_i)^\gamma/[(x_A)^\gamma + (x_B)^\gamma]$, with $\gamma \in (0, 1]$. Simulation shows that our results remain qualitatively unchanged if $0 < \gamma < 1$.

dently and identically distributed, being drawn from a type I extreme-value (maximum) distribution.[9]

An employee i's effort x_i entails a constant marginal effort cost $1/a_i$, where $a_i > 0$ measures his ability. That is, a higher ability allows for less costly effort. Employee i chooses his effort to maximize his expected payoff

$$\pi_i(x_i, x_j) = p_i(x_A, x_B) - x_i/a_i,\ i, j \in \{A, B\}, i \neq j.$$

Importantly, we assume that the incumbent worker's ability a_A is commonly known, but the new hire's ability a_B is B's private information.[10] Specifically, a_B is a random variable on the set $\left\{a_B^L, a_B^H\right\}$ with $0 < a_B^L < a_B^H$ and $\Pr(a_B = a_B^H) = \mu \in (0,1)$. We impose the following assumption throughout the paper:

Assumption 1 $a_B^L \geq a_A/4$.

Assumption 1 is intuitive. It ensures that the competition will not be excessively lopsided even if employee B is of the low(-ability) type, which rules out the possibility of a corner solution in which a low-ability employee B is discouraged from exerting any effort in equilibrium.[11]

The manager possesses the prior μ, while employee A believes that $\Pr(a_B = a_B^H) = \tilde{\mu} \in (0,1)$.[12] When $\tilde{\mu} < \mu$, employee A underestimates his opponent, and we say that employee A exhibits overconfidence; when $\tilde{\mu} > \mu$, he overestimates his opponent, and we say that he

[9] More formally, the cumulative distribution function of ε_i is $G(\varepsilon_i) = e^{-e^{-\varepsilon_i}}, \varepsilon_i \in (-\infty, +\infty)$.

[10] Incumbents' ability can presumably be inferred from their established track records. For instance, a senior faculty member's teaching competence can credibly be revealed by his past student feedback reports. Alternatively, previous portfolio performance provides an informative account of a fund manager's professional standards. This assumption is consistent with the premise of the usual career concerns model (e.g., Holmström, 1999), which assumes that a worker's true type is better known in a later stage of his career.

[11] Our model abstracts away the firm's decision to recruit new employees. However, it is noteworthy that the level of the new hire's ability—either high or low—is presumably defined in relative terms; we implicitly assume that the worker of relatively lower ability qualifies for the job, despite the ability gap when compared with the high type. This implicit assumption is endorsed by Assumption 1, which states that the gap in ability between types is not excessive.

[12] Note that employee B's belief about a_B does not matter in our model because (i) he has private information about a_B; and (ii) he only cares about employee A's effort.

is underconfident. Misplacement may stem from an employee's misperception of himself, or from his misperception of others. Our setting focuses on the latter, e.g., Moore and Schatz (2017). One may arguably have more precise knowledge about himself than about others, while a bias about oneself is less likely to persist.[13] The manager's prior departs from employee A's. The bias may arise from employees' inability (relative to the manager) to make accurate inferences about others from common observations, as in Zabojnik (2004).

Three remarks are in order before we carry out the analysis. First, the setting can be interpreted flexibly. One could view $\tilde{\mu}$ as the common perception held about workers' ability distribution in the labor market or workplace, which can be underpinned by social or corporate culture. Imagine, for instance, a stereotype prevalently held in favor of or against certain types of workers, or the example laid out in the Introduction: A halo effect often arises when a high-profile executive from an industry leader joins a grassroots start-up.

Second, employee A's perception of the newcomer—i.e., his prior $\tilde{\mu}$ about a_B—is common knowledge to both employees, which plays a critical role in shaping the competition. The manager understands that employee A holds a prior $\tilde{\mu}$ and his prior is commonly known to both A and B. However, our analysis does not require that the prior μ held by the manager be known to either employee. As will be shown in the subsequent analysis, only employee A's belief affects the strategic interaction and the equilibrium in the contest.

Third, in line with Fang and Moscarini (2005), we assume that workers and the manager can hold different priors.[14] The economics literature has broadly embraced the notion that uncommon beliefs about underlying states can arise from a Bayesian process, even when individuals hold common priors (see, e.g., Van den Steen, 2011; Benoît and Dubra, 2011). The model thus assumes that parties "agree to disagree," as in Santos-Pinto (2010), Santos-Pinto and Sekeris (2023), and Ba and Gindin (2023).

[13] However, it should be noted that our analysis can seamlessly incorporate a case in which employee A also systematically over(under)estimates his own ability, a_A. We omit this case because the firm monotonically benefits from employee A's biased perception of his *own* ability, which refers to the usual motivational effect.

[14] Fang and Moscarini (2005) assume that the firm's and workers' beliefs are common knowledge and each believes the other party to be wrong when they are are inconsistent.

2.2 Equilibrium in Contest

We derive the equilibrium in the model by standard technique.[15] Employee A exerts effort

$$x_A = \left(\frac{\frac{1-\tilde{\mu}}{\sqrt{a_B^L}} + \frac{\tilde{\mu}}{\sqrt{a_B^H}}}{\frac{1}{a_A} + \frac{1-\tilde{\mu}}{a_B^L} + \frac{\tilde{\mu}}{a_B^H}} \right)^2,$$

and employee B has a type-dependent effort strategy, which is given as follows:

$$x_B(a_B) = \sqrt{a_B x_A} - x_A, \text{ for } a_B \in \left\{a_B^H, a_B^L\right\}.$$

For notational convenience, we define $K(\tilde{\mu}) := \sqrt{x_A}$. The ex ante expected total effort of the contest, which we denote by $TE\left(\mu, \tilde{\mu}\right)$, is given by

$$TE\left(\mu, \tilde{\mu}\right) = \mathbb{E}_\mu\left[x_B(a_B) + x_A\right] = \mathbb{E}_\mu\left[\sqrt{a_B x_A}\right] = \left[(1-\mu)\sqrt{a_B^L} + \mu\sqrt{a_B^H}\right] K(\tilde{\mu}), \quad (3)$$

where we use the notation $\mathbb{E}_\mu[\cdot]$ to denote the expectation under belief μ. It is noteworthy that employees' equilibrium efforts, x_A and $x_B(a_B)$, involve only employee A's perceived belief $\tilde{\mu}$. However, both μ and $\tilde{\mu}$ enter the expression of the an ex ante expected total effort $TE(\mu, \tilde{\mu})$, as it is aggregated over the true distribution described by μ.

We now explore the property of $K(\tilde{\mu})$. Taking the derivative of $K(\tilde{\mu})$ with respect to $\tilde{\mu}$ yields

$$K'(\tilde{\mu}) = \frac{\left(\sqrt{a_B^H} - \sqrt{a_B^L}\right)\left(a_A - \sqrt{a_B^H a_B^L}\right)}{a_A a_B^L a_B^H \left[\frac{1}{a_A} + \frac{a_B^H(1-\tilde{\mu}) + a_B^L \tilde{\mu}}{a_B^L a_B^H}\right]^2}.$$

The sign of $K'(\tilde{\mu})$ depends on that of $a_A - \sqrt{a_B^H a_B^L}$. Note that $\sqrt{a_B^H a_B^L}$ is the geometric mean of employee B's ability; the sign of $a_A - \sqrt{a_B^H a_B^L}$ thus indicates the ex ante comparison of

[15]Hurley and Shogren (1998) and Zhang and Zhou (2016) fully characterize the equilibrium of a lottery contest game with one-sided incomplete information, and their analysis extends to our setting.

the employees' abilities. Further,

$$K''(\tilde{\mu}) = \frac{2\left(\sqrt{a_B^H} - \sqrt{a_B^L}\right)^2 \left(a_A - \sqrt{a_B^H a_B^L}\right)}{a_A \left(a_B^L a_B^H\right)^2 \left[\frac{1}{a_A} + \frac{a_B^H(1-\tilde{\mu}) + a_B^L \tilde{\mu}}{a_B^L a_B^H}\right]^3}.$$

Again, its sign depends on that of $a_A - \sqrt{a_B^H a_B^L}$. It is straightforward to obtain the following.

Lemma 1 *The function $K(\cdot)$ is strictly increasing with its argument and convex if $a_A > \sqrt{a_B^H a_B^L}$, and is strictly decreasing and concave if $a_A < \sqrt{a_B^H a_B^L}$.*

2.3 Desirability of Persistent Misperception

Employees' efforts accrue to the firm's benefit. The equilibrium result allows us to explore one natural question: Does the firm benefit from employee A's misperception, i.e., $\mu \neq \tilde{\mu}$? Specifically, does the persistence of the uncommon priors boost the firm's productivity in terms of its expected total effort $TE(\mu, \tilde{\mu})$? Recall by (3) that the contest generates an expected total effort

$$TE(\mu, \tilde{\mu}) = \left[(1-\mu)\sqrt{a_B^L} + \mu\sqrt{a_B^H}\right] K(\tilde{\mu}).$$

With common prior, the expected total effort boils down to

$$TE(\mu, \mu) = \left[(1-\mu)\sqrt{a_B^L} + \mu\sqrt{a_B^H}\right] K(\mu),$$

as in Zhang and Zhou (2016). Therefore, the comparison hinges on the monotonicity of $K(\cdot)$. We obtain the following.

Proposition 1 ***(Value of Persistent Misperception)*** *Suppose that the firm aims to maximize the expected total effort in the contest. Then the following statements hold:*

(i) When $a_A < \sqrt{a_B^H a_B^L}$, the firm strictly benefits from employee A's misperception—i.e., $TE(\mu, \tilde{\mu}) > TE(\mu, \mu)$—if and only if employee A exhibits overconfidence—i.e., $\tilde{\mu} < \mu$;

(ii) *When* $a_A > \sqrt{a_B^H a_B^L}$*, the firm strictly benefits from employee A's misperception—i.e.,* $TE(\mu, \tilde{\mu}) > TE(\mu, \mu)$*—if and only if employee A exhibits underconfidence—i.e.,* $\tilde{\mu} > \mu$*;*

(iii) *When* $a_A = \sqrt{a_B^H a_B^L}$*, employee A's belief does not affect the expected total effort, i.e.,* $TE(\mu, \tilde{\mu}) = TE(\mu, \mu)$*.*

Proposition 1 states that the firm may either benefit or suffer from the incumbent employee's perceptional bias; neither overconfidence nor underconfidence necessarily harms the firm. This observation can largely be interpreted in light of the conventional wisdom whereby a more level playing fuels competition. To see that, let us first explore the impact of the incumbent employee's belief on the total effort $TE(\mu, \tilde{\mu})$, as given by (3). Clearly, it suffices to focus on how x_A varies with $\tilde{\mu}$, i.e., the property of $K(\tilde{\mu})$. We conveniently interpret employee A as an ex ante underdog in the case of $a_A < \sqrt{a_B^H a_B^L}$: Recall that a larger a_i implies less cost bidding; employee A is more likely to be the weaker (stronger) contender when a_A is smaller (larger) relative to $\sqrt{a_B^H a_B^L}$. Players' relative competency also depends on the perceived belief $\tilde{\mu}$.[16] Proposition 1(i) shows that in this case, his overconfidence boosts his morale, which narrows the gap in terms of ability and fuels the competition. Conversely, Proposition 1(ii) states that, if employee A is the favorite in the sense that $a_A > \sqrt{a_B^H a_B^L}$, then the firm suffers from his overconfidence: Employee A underestimates his opponent, which softens the competition and entices employee A to slack off. In the knife-edge case of $a_A = \sqrt{a_B^H a_B^L}$, these balancing forces cancel out in the ex ante even race.

The contest/contest literature espouses the productive role played by various design instruments that manipulate the balance of competition—e.g., favoritisms (Epstein, Mealem, and Nitzan, 2011; Franke, Kanzow, Leininger, and Schwartz, 2013, 2014; Fu and Wu, 2020, among others), headstarts (Kirkegaard, 2012; Konrad, 2002; Siegel, 2009; Drugov and Ryvkin, 2017, among others), and bidding caps (Che and Gale, 1998; Gavious, Moldovanu, and Sela, 2002; Olszewski and Siegel, 2019, among others).[17] Our analysis implies that the

[16]Employee A is more likely to be the weaker (stronger) contender when a_A is smaller (larger) relative to $\sqrt{a_B^H a_B^L}$. Players' relative competency also depends on the perceived belief $\tilde{\mu}$.

[17]See Mealem and Nitzan (2016), Chowdhury, Esteve-González, and Mukherjee (2023), and Fu and Wu (2019) for comprehensive surveys on discrimination in contests.

same can alternatively be achieved by a perceptional bias. The management may prefer to maintain the bias in some cases, since debiasing may weaken the competition and mute employees' incentives.

2.4 Implications of Proposition 1

Our analysis demonstrates the subtle roles played by employees' perceptional biases. It is broadly championed that confidence catalyzes success and that managers should foster confidence in their staff members. The economics and psychology literature has also identified the motivational effect that advocates the positive incentive effect of overconfidence. We nevertheless show that employees' incentives and productivity depend indeterminately on their (mis)perception about relative competitiveness when they engage in internal competitions, which are pervasive in modern workplace (Netessine and Yakubovich, 2012).

Proposition 1 demonstrates that employees' (mis)perceptions can be either productive or counterproductive, depending on the actual relative competitiveness between the incumbent and the new hire. The firm may sometimes benefit from persistent underconfidence. Consider, for instance, a startup that rose from successful grassroots innovations. Its early employees could underestimate their own abilities relative to better-educated junior recruits, despite the extensive experience and know-how they possess. Proposition 1 suggests that the firm may not want to "debias" the incumbent even if it is able to: For instance, if the firm is confident in the value of its early employees' human capital—i.e., $a_A > \sqrt{a_B^H a_B^L}$—which might have been critical in helping the firm navigate the startup stages, then underconfidence would incentivize employees and fuel greater competition. In contrast, consider an ambitious academic institution in the process of an aggressive expansion by recruiting from more prestigious peers. Its faculty members may be on average disadvantaged in their research capacity, i.e., $a_A < \sqrt{a_B^H a_B^L}$, but also underconfident about their skills relative to the new hires. Proposition 1 then suggests that it is helpful to restore the confidence of the incumbent faculty.

3 Internal Evaluation and Information Disclosure

In this section, we expand the model to explore the optimal information disclosure policy that modifies the information environment. As stated in the Introduction, the manager can acquire a noisy signal $s \in \{H, L\}$ regarding employee B's ability through an evaluation—e.g., an interim evaluation of the employee after he starts the job. The manager sets an information disclosure policy prior to the competition, which commits to either fully revealing the signal s or fully concealing it. For the moment, we assume that the firm equally values employees' contributions, so the manager aims to maximize the expected total effort.[18] The efforts expended by employees may directly contribute to the firm's output. Alternatively, the efforts can be viewed as human capital accumulated by employees to bolster the firm's productivity in the long run (see, e.g., Fu and Wu, 2022).

Specifically, we assume that the signal s is drawn as follows:

$$\Pr\left(s = H \,\middle|\, a_B = a_B^H\right) = \Pr\left(s = L \,\middle|\, a_B = a_B^L\right) = q, \tag{4}$$

where $q \in \left(\frac{1}{2}, 1\right]$ indicates the quality of the signal. When $q = 1$, the signal perfectly reveals employee B's ability. In the extreme case that $q = 1/2$, the signal is completely uninformative. Before the competition, the manager commits to her disclosure policy, i.e., whether the result of her private evaluation of employee A's ability—i.e., the realized signal s—is to be disclosed publicly or concealed.[19]

The signal would allow the manager and employee A to update their beliefs based on their own prior. For the manager, she would infer that employee B is of high type with a posterior probability μ_s, as given by

$$\mu_s = \frac{\mu \Pr\left(s | a_B = a_B^H\right)}{\mu \Pr\left(s | a_B = a_B^H\right) + (1-\mu) \Pr\left(s | a_B = a_B^L\right)}, \text{ for } s = H, L. \tag{5}$$

[18]We consider an extension in which the manager cares about the expected winner's effort in Section 4.

[19]As stated in Footnote 11, our model abstracts away the firm's decision to recruit new hires. The evaluation is conducted after the new hire starts his job.

Similarly, employee A's posterior belief, denoted by $\tilde{\mu}_s$, is given by

$$\tilde{\mu}_s = \frac{\tilde{\mu}\Pr\left(s|a_B = a_B^H\right)}{\tilde{\mu}\Pr\left(s|a_B = a_B^H\right) + (1-\tilde{\mu})\Pr\left(s|a_B = a_B^L\right)}, \text{ for } s = H, L. \tag{6}$$

It is straightforward to verify that both μ_s and $\tilde{\mu}_s$ strictly increase with the priors, μ and $\tilde{\mu}$, respectively, for $q < 1$. When the signal is perfectly informative—i.e., $q = 1$—both parties' posterior beliefs would jump to one upon receiving $s = H$ and would drop to zero upon receiving $s = L$, independent of their priors.

3.1 Optimal Information Disclosure Policy

We denote by $TE^C(\mu, \tilde{\mu})$ the expected total effort when the signal s is withheld, where the superscript C indicates "concealment." The expected total effort $TE^C(\mu, \tilde{\mu})$ is the same as (3) and given by[20]

$$TE^C(\mu, \tilde{\mu}) = \left[(1-\mu)\sqrt{a_B^L} + \mu\sqrt{a_B^H}\right] K(\tilde{\mu}). \tag{7}$$

When the signal $s \in \{H, L\}$ is disclosed, the expected total effort is given by

$$TE\left(\mu_s, \tilde{\mu}_s\right) = \left[(1-\mu_s)\sqrt{a_B^L} + \mu_s\sqrt{a_B^H}\right] K(\tilde{\mu}_s).$$

where μ_s and $\tilde{\mu}_s$, with $s \in \{H, L\}$, are given by (5) and (6), respectively.

Further, the actual probabilities that $s = H$ and $s = L$ occur amount to $\mu q + (1-\mu)(1-q)$ and $\mu(1-q) + (1-\mu)q$, respectively. This allows us to calculate the expected equilibrium total effort when the manager commits to disclosing the signal, $TE^D\left(\mu, \tilde{\mu}\right)$, where we use

[20] Recall that our contest model does not require that the employees know exactly the manager's prior μ. Note that the choice of disclosure policy would allow the employee to make an inference about μ if he is uncertain about the manager's prior, which is assumed away in our setting. Further, as previously stated, the parties in our setting "agree to disagree," which is in line with Fang and Moscarini (2005). They assume that each believes the other party to be wrong when their priors diverge. Our assumption is also consistent with Squintani's (2006) notion of naïve equilibrium, which allows players to hold biased beliefs and behave rationally—i.e., maximizing their own utilities and forming rational expectations of others' strategies—at the same time.

superscript D to indicate “disclosure”:

$$\begin{aligned} TE^D(\mu,\tilde{\mu}) &= \Big[\mu q+(1-\mu)(1-q)\Big]\times\Big[(1-\mu_H)\sqrt{a_B^L}+\mu_H\sqrt{a_B^H}\Big]K(\tilde{\mu}_H) \\ &\quad +\Big[\mu(1-q)+(1-\mu)q\Big]\times\Big[(1-\mu_L)\sqrt{a_B^L}+\mu_L\sqrt{a_B^H}\Big]K(\tilde{\mu}_L). \end{aligned} \tag{8}$$

We then investigate the manager's choice of disclosure policy. For expositional convenience, we define Θ as

$$\Theta := \left[\sqrt{a_B^H a_B^L}-a_A\right]\times\left[\frac{(a_B^L)^{\frac{3}{2}}\left(a_A+a_B^H\right)}{(a_B^H)^{\frac{3}{2}}\left(a_A+a_B^L\right)}-\frac{\mu\left(1-\tilde{\mu}\right)}{\tilde{\mu}\left(1-\mu\right)}\right]. \tag{9}$$

Proposition 2 ***(Concealment vs. Disclosure)*** *Suppose $q\in(\frac{1}{2},1]$ and that the manager aims to maximize the expected total effort in the contest. Then the following statements hold:*

(i) When $\Theta>0$, it is optimal for the manager to commit to disclosing her private signal, i.e., $TE^D(\mu,\tilde{\mu})>TE^C(\mu,\tilde{\mu})$;

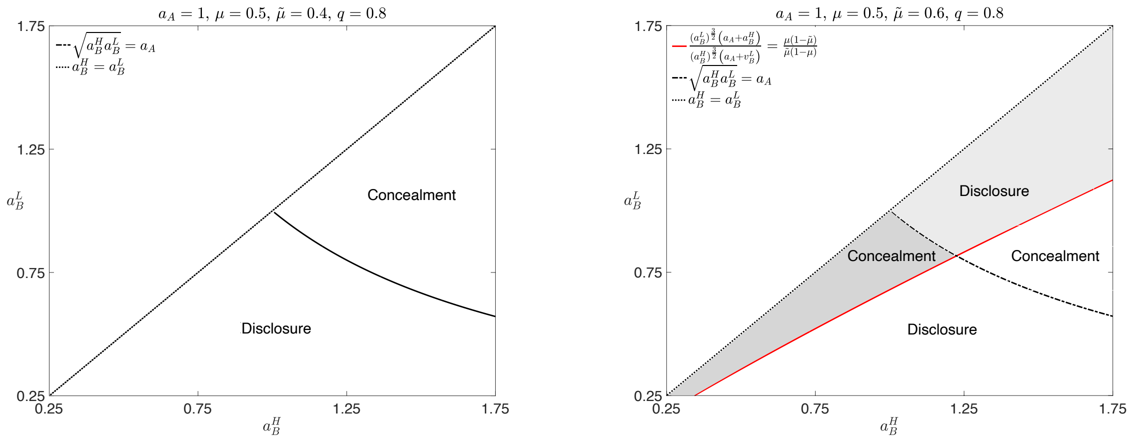
(ii) When $\Theta<0$, it is optimal for the manager to conceal the signal, i.e., $TE^D(\mu,\tilde{\mu})<TE^C(\mu,\tilde{\mu})$;

(iii) When $\Theta=0$, the manager is indifferent between disclosing the signal and concealing it, i.e., $TE^D(\mu,\tilde{\mu})=TE^C(\mu,\tilde{\mu})$.

Proposition 2 states that the optimal information disclosure policy hinges on the sign of Θ.[21] To interpret this proposition, it is key to identify the condition that determines the sign of Θ. Note that that the second term in (9) is always negative when employee A exhibits (weak) overconfidence, i.e., $\tilde{\mu}\le\mu$. To see that, note that $[\mu(1-\tilde{\mu})]/[\tilde{\mu}(1-\mu)]\ge 1$ in this case, which in turn implies

$$\frac{(a_B^L)^{\frac{3}{2}}(a_A+a_B^H)}{(a_B^H)^{\frac{3}{2}}(a_A+a_B^L)}-\frac{\mu(1-\tilde{\mu})}{\tilde{\mu}(1-\mu)}\le\frac{a_B^L(a_A+a_B^H)}{a_B^H(a_A+a_B^L)}-1=\frac{a_A(a_B^L-a_B^H)}{a_B^H(a_A+a_B^L)}<0.$$

[21] It is useful to point out that Θ is independent of $q\in(1/2,1]$.



(a) Rationality and Overconfidence ($\tilde{\mu} \leq \mu$)

(b) Underconfidence ($\tilde{\mu} > \mu$)

Figure 1: Optimal Effort-Maximizing Information Disclosure Policy

This observation allows us to infer that with overconfidence ($\tilde{\mu} < \mu$) or rational belief ($\tilde{\mu} = \mu$), disclosure is optimal if $\sqrt{a_B^H a_B^L} - a_A < 0$, or equivalently, employee A is the ex ante favorite; conversely, concealment is optimal if $\sqrt{a_B^H a_B^L} - a_A > 0$, or equivalently, employee A is the ex ante underdog.

The optimum is illustrated in Figure 1(a). The horizontal axis traces a_B^H and the vertical axis measures a_B^L. Therefore, the area under the diagonal collects all relevant parameterizations with $a_B^L < a_B^H$. Assuming $(a_A, \mu, \tilde{\mu}, q) = (1, 0.5, 0.4, 0.8)$, the dashed curve splits the area into two regions: The upper portion depicts the case of $\sqrt{a_B^H a_B^L} - a_A > 0$ such that $\Theta < 0$, in which concealment is preferred; the lower portion represents $\sqrt{a_B^H a_B^L} - a_A < 0$ such that $\Theta > 0$, in which case full disclosure prevails.

In the scenario of underconfidence, the terms $\sqrt{a_B^H a_B^L} - a_A$ and $[(a_B^L)^{\frac{3}{2}}(a_A + a_B^H)]/[(a_B^H)^{\frac{3}{2}}(a_A + a_B^L)] - [\mu(1-\tilde{\mu})/\tilde{\mu}(1-\mu)]$ jointly determine the sign of Θ. The optimal disclosure policy is depicted in Figure 1(b), and four scenarios would arise. Fixing $(a_A, \mu, \tilde{\mu}, q) = (1, 0.5, 0.6, 0.8)$, the solid curve in the figure is defined by $[(a_B^L)^{\frac{3}{2}}(a_A + a_B^H)]/[(a_B^H)^{\frac{3}{2}}(a_A + a_B^L)] = [\mu(1-\tilde{\mu})/\tilde{\mu}(1-\mu)]$. The area above the curve depicts the case with $[(a_B^L)^{\frac{3}{2}}(a_A + a_B^H)]/[(a_B^H)^{\frac{3}{2}}(a_A + a_B^L)] - [\mu(1-\tilde{\mu})/\tilde{\mu}(1-\mu)] > 0$, in which case the optimum overturns that under overconfidence or rational belief. Below the solid curve, the term continues to be negative, which preserves the optimum under overconfidence or rational belief.

Proposition 2 and Equation (9) enable comparative statics with respect to the degree of employee underconfidence. Fix a_A and $\tilde{\mu} > \mu$. Let us define

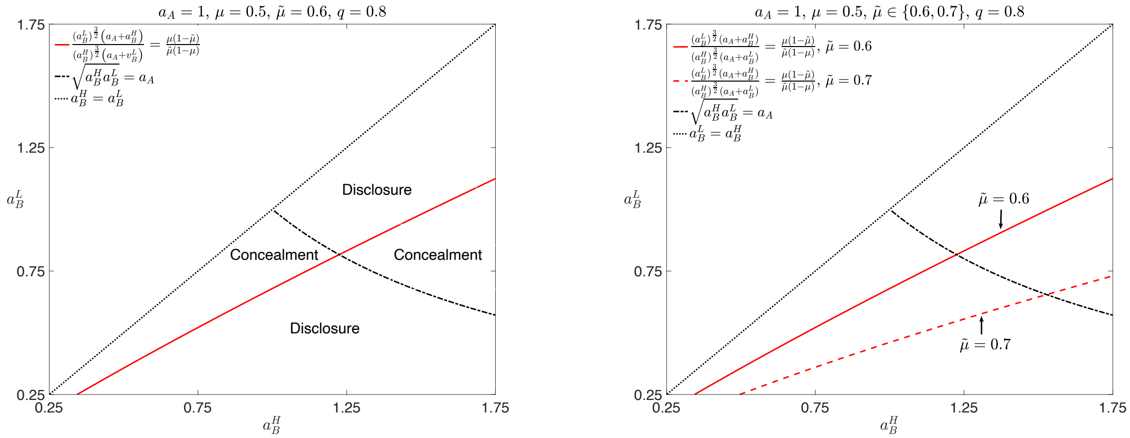
$$\Upsilon(\tilde{\mu}) := \left\{ (a_B^H, a_B^L) \,\middle|\, \frac{(a_B^L)^{\frac{3}{2}} \left(a_A + a_B^H\right)}{(a_B^H)^{\frac{3}{2}} \left(a_A + a_B^L\right)} - \frac{\mu\,(1-\tilde{\mu})}{\tilde{\mu}\,(1-\mu)} > 0, a_B^H > a_B^L \geq \frac{a_A}{4} \right\},$$

as the set of parameters (a_B^H, a_B^L) under which the optimal information disclosure policy with underconfidence differs from that with overconfidence or rational belief. The following proposition can be obtained:

Proposition 3 ***(Impact of Increasing Underconfidence)*** *Suppose that $\tilde{\mu}^\dagger > \tilde{\mu} > \mu$. Then $\Upsilon(\tilde{\mu}) \subset \Upsilon(\tilde{\mu}^\dagger)$ and the inclusion is strict.*

For given (a_A, a_B^L, a_B^H), the sign of Θ is determined by the size of $\tilde{\mu}$ relative to μ in the case of underconfidence. For a $\tilde{\mu}$ that is mildly above μ, i.e., moderate underconfidence, the optimum is more likely to coincide with that under overconfidence or rational belief, as the sign of $[(a_B^L)^{\frac{3}{2}}(a_A + a_B^H)]/[(a_B^H)^{\frac{3}{2}}(a_A + a_B^L)] - [\mu(1-\tilde{\mu})/\tilde{\mu}(1-\mu)]$ remains negative. In the case of severe underconfidence, i.e., a large $\tilde{\mu}$ relative to μ, the sign would turn positive, and the optimum under overconfidence or rational belief would be overturned, which is formally stated as $\Upsilon(\tilde{\mu}) \subset \Upsilon(\tilde{\mu}^\dagger)$ for $\tilde{\mu}^\dagger > \tilde{\mu} > \mu$ by Proposition 3.

Figure 2 illustrates how a change in the degree of underconfidence affects the optimal information disclosure policy. Figure 2(a) depicts the same scenario as Figure 1(b), which shows the optimum with underconfidence under $(\mu, \tilde{\mu}) = (0.5, 0.6)$. Figure 2(b) demonstrates the comparative statics when $\tilde{\mu}$ increases from 0.6 to 0.7. The curve that defines $[(a_B^L)^{\frac{3}{2}}(a_A + a_B^H)]/[(a_B^H)^{\frac{3}{2}}(a_A + a_B^L)] - [\mu(1-\tilde{\mu})/\tilde{\mu}(1-\mu)] = 0$ is shifted downward, with the lower dashed curve representing the case with $\tilde{\mu} = 0.7$. Clearly, the increase in $\tilde{\mu}$ enlarges the set of parameterizations under which the optimal information disclosure policy differs from that in the case of overconfidence or rational belief.



(a) Underconfidence: $(\mu, \tilde{\mu}) = (0.5, 0.6)$

(b) Underconfidence: $(\mu, \tilde{\mu}) = (0.5, 0.7)$

Figure 2: Impact of Underconfidence on Optimal Information Disclosure Policy

3.2 Intuition for Propositions 2 and 3

We now interpret the logic that underlies Propositions 2 and 3. Recall that by Proposition 2, the optimal information disclosure policy under rational belief coincides with that under overconfidence, but may not for the case of underconfidence. We begin with the benchmark case of common prior and expound the role played by information disclosure, which gives rise to an *information effect* without the complications caused by misperception. We then elaborate on the role played by misperception, which catalyzes a *morale effect*. Their combination determines the optimum. Recall that the sign of Θ defined by expression (9) predicts the optimum: The two terms included in Θ each reflect one effect:

$$\Theta := \underbrace{\left[\sqrt{a_B^H a_B^L} - a_A\right]}_{\text{information effect}} \times \underbrace{\left[\frac{(a_B^L)^{\frac{3}{2}}\left(a_A + a_B^H\right)}{(a_B^H)^{\frac{3}{2}}\left(a_A + a_B^L\right)} - \frac{\mu\left(1 - \tilde{\mu}\right)}{\tilde{\mu}\left(1 - \mu\right)}\right]}_{\text{morale effect}}.$$

A rationale about the morale effect would explain how and why the optimum with underconfidence may depart from that with overconfidence or rational belief.

Common Prior: Information Effect The additional information conveyed by the signal $s \in \{H, L\}$ can lead employee A's belief to be revised either upward or downward, depending on the realization of the signal. The update causes the equilibrium in the contest to diverge across states.

The dispersion across states triggered by the signal occurs regardless of the perceptional bias. We thus focus on the case of common prior—i.e., $\mu = \tilde{\mu}$—to illustrate its implications. Our rationale is largely aligned with that of Zhang and Zhou (2016). Define

$$TE_R^C(\mu) := TE^C(\mu, \mu) = \left[(1-\mu)\sqrt{a_B^L} + \mu\sqrt{a_B^H}\right] K(\mu),$$

to be the expected total effort in the case of concealment, where the subscript R indicates the rational benchmark. When the signal is revealed, employee A's belief will be revised to either μ_H or μ_L, and the expected total effort of the contest ends up as either $TE_R^C(\mu_H)$ or $TE_R^C(\mu_L)$; the corresponding ex ante expected total effort with common prior—which is similarly defined as $TE_R^D(\mu, \tilde{\mu}) := TE^D(\mu, \mu)$—aggregates over the two states. Simple algebra would verify that

$$\frac{d\,TE_R^C}{d\mu} = \left(\sqrt{a_B^H} - \sqrt{a_B^L}\right) K(\mu) + \left[(1-\mu)\sqrt{a_B^L} + \mu\sqrt{a_B^H}\right] K'(\mu),$$

and

$$\frac{d^2\,TE_R^C}{d\mu^2} = 2\left(\sqrt{a_B^H} - \sqrt{a_B^L}\right) K'(\mu) + \left[(1-\mu)\sqrt{a_B^L} + \mu\sqrt{a_B^H}\right] K''(\mu).$$

Recall from Lemma 1 that (i) $K(\mu)$ is increasing if $a_A > \sqrt{a_B^H a_B^L}$, and decreasing if $a_A < \sqrt{a_B^H a_B^L}$; and (ii) $K(\mu)$ is convex if $a_A > \sqrt{a_B^H a_B^L}$ and concave if $a_A < \sqrt{a_B^H a_B^L}$. Hence, $TE_R^C(\mu)$ perfectly preserves the concavity/convexity of $K(\mu)$.

Carrying out the algebra, we can obtain the ex ante expected total effort

$$TE_R^D(\mu) = \left[\mu q + (1-\mu)(1-q)\right] TE_R^C(\mu_H) + \left[\mu(1-q) + (1-\mu)q\right] TE_R^C(\mu_L).$$

Because $\left[\mu q + (1-\mu)(1-q)\right]\mu_H + \left[\mu(1-q) + (1-\mu)q\right]\mu_L \equiv \mu$ by the martingale property of beliefs, the function $TE_R^D(\mu)$ is simply a weighted average of $TE_R^C(\mu)$ over two different states. As a result, the comparison depends on the concavity/convexity of the function

$TE_R^C(\mu)$. We can immediately infer the following by Jensen's inequality.

Remark 1 *$TE_R^D(\mu) > (<) TE_R^C(\mu)$ if and only if $TE_R^C(\mu)$ is strictly convex (concave).*

That is, full disclosure (concealment) outperforms concealment (full disclosure) if and only if employee A is the ex ante favorite (underdog), which explains Proposition 2 for the case of $\mu = \tilde{\mu}$.

Uncommon Priors: Morale Effect We now explore the case of uncommon priors, i.e., $\mu \neq \tilde{\mu}$. We need to compare $TE^C(\mu, \tilde{\mu})$ as in (7) to $TE^D(\mu, \tilde{\mu})$ as in (8). For the sake of expositional convenience, we focus on the case of $\mu = 1/2$, in which case the ex ante probabilities of receiving $s = H$ and $s = L$ are simply $1/2$ and do not depend on q. As a result, $TE^C(\mu, \tilde{\mu})$ and $TE^D(\mu, \tilde{\mu})$ can be simplified (respectively) as

$$\begin{aligned} TE^C\left(\frac{1}{2}, \tilde{\mu}\right) &= \frac{1}{2}\left[\sqrt{a_B^L} + \sqrt{a_B^H}\right] K(\tilde{\mu}), \text{ and} \\ TE^D\left(\frac{1}{2}, \tilde{\mu}\right) &= \frac{1}{2}\left[(1-q)\sqrt{a_B^L} + q\sqrt{a_B^H}\right] K(\tilde{\mu}_H) + \frac{1}{2}\left[q\sqrt{a_B^L} + (1-q)\sqrt{a_B^H}\right] K(\tilde{\mu}_L). \end{aligned}$$

The comparison boils down to

$$TE^D\left(\frac{1}{2}, \tilde{\mu}\right) - TE^C\left(\frac{1}{2}, \tilde{\mu}\right) = \frac{1}{2}\left\{ \begin{array}{c} \left[(1-q)\sqrt{a_B^L} + q\sqrt{a_B^H}\right] \times \left[K(\tilde{\mu}_H) - K(\tilde{\mu})\right] \\ -\left[q\sqrt{a_B^L} + (1-q)\sqrt{a_B^H}\right] \times \left[K(\tilde{\mu}) - K(\tilde{\mu}_L)\right] \end{array} \right\}.$$

Upon observing the signal s, employee A revises his belief, which affects his effort incentive in the contest. His morale can be either boosted—i.e., $\tilde{\mu}$ dropping to $\tilde{\mu}_L$—or be busted—i.e., $\tilde{\mu}$ rising to $\tilde{\mu}_H$. The comparison highlighted above hinges on the change of $\left[K(\tilde{\mu}_H) - K(\tilde{\mu})\right]$ vis-à-vis $\left[K(\tilde{\mu}) - K(\tilde{\mu}_L)\right]$. The magnitude of his belief adjustment in response to a given signal depends on the nature of his initial misperception, i.e., whether employee A exhibits overconfidence or underconfidence.

Suppose that employee A is overconfident, so he underestimates his opponent, i.e., $\tilde{\mu} < \mu$. His posterior tends to respond to a high signal more sensitively—i.e., with a significant jump from the initially underestimated $\tilde{\mu}$ to $\tilde{\mu}_H$—compared to the response to a low signal, i.e., a relatively mild decrease from $\tilde{\mu}$ to $\tilde{\mu}_L$. This follows from the properties of Bayesian updating: A new signal impacts the posterior more if it is more unexpected under the prior.[22] Thus, in the case of overconfidence, the incumbent's perception of the competitor would be substantially revised upward when a high signal refutes his initial underestimate of the competitor, while the revision would be more incremental when a low signal simply reinforces the existing bias. The opposite holds for the case of underconfidence with $\tilde{\mu} > \mu$, but the intuition is analogous. The upward revision of the posterior in response to a high signal tends to be muted compared to that in the presence of a low signal. A low signal would sharply overturn the initial overestimates, causing a significant drop from $\tilde{\mu}$ to $\tilde{\mu}_L$; in contrast, a high signal only confirms the initial overestimate, so the rise from $\tilde{\mu}$ to $\tilde{\mu}_H$ tends to be moderate.

For expositional efficiency, let us focus on the case with $a_A > \sqrt{a_B^H a_B^L}$, as the case with $a_A < \sqrt{a_B^H a_B^L}$ is simply its mirror image. Recall that in this case $K(\cdot)$ is strictly increasing in its argument by Lemma 1, and $K(\tilde{\mu}_H) - K(\tilde{\mu})$ and $K(\tilde{\mu}) - K(\tilde{\mu}_L)$ are both positive. Further, $TE^D\left(\frac{1}{2}, \tilde{\mu}\right) - TE^C\left(\frac{1}{2}, \tilde{\mu}\right)$ is positive when $\tilde{\mu} = \mu = 1/2$ by the information effect.

With overconfidence, the argument laid out above implies that $K(\tilde{\mu}_H) - K(\tilde{\mu})$ tends to outweigh $K(\tilde{\mu}) - K(\tilde{\mu}_L)$: A high signal overturns employee A's initial misperception, while a low signal marginally confirms his bias. This implies that $TE^D(\frac{1}{2}, \tilde{\mu}) - TE^C(\frac{1}{2}, \tilde{\mu})$ tends to be positive, and thus information disclosure outperforms concealment. The effect of his asymmetric morale response to high and low signals coincides with the information effect laid out above. The comparison between disclosure and concealment under overconfidence remains the same as that under rationality, as Figure 1(a) shows.

Consider, alternatively, the case of underconfidence. Although both $K(\tilde{\mu}_H) - K(\tilde{\mu})$ and $K(\tilde{\mu}) - K(\tilde{\mu}_L)$ are positive, $K(\tilde{\mu}_H) - K(\tilde{\mu})$ tends to be outsized by $K(\tilde{\mu}) - K(\tilde{\mu}_L)$: In this case, a low signal tends to overturn the initial underconfidence, whereas a high signal only mildly endorses the misperception. As a result, $TE^D(\frac{1}{2}, \tilde{\mu}) - TE^C(\frac{1}{2}, \tilde{\mu})$ is less likely to be

[22]This property of Bayesian updating is also exploited in Fang and Moscarini (2005) in a principal-agent setting, in which they refer to this effect the *morale hazard*.

positive, and thus concealment is more likely to prevail. The morale effect runs into conflicts with the aforementioned information effect and could outweigh the latter and overturn the optimum predicted by information effect, as Figure 1(b) shows.

Intuitively, the more biased the belief, the stronger this morale effect. This rationale thus sheds light on the observation of Proposition 3: A larger $\tilde{\mu}$ relative to μ—which corresponds with greater underconfidence—would amplify the morale effect and could more than offset the information effect, diverting the optimum away from that under overconfidence and rational belief, as shown in Proposition 3.

3.3 Implications of Propositions 2 and 3

Our results in Section 3.1 provide a playbook for firms' internal information management practices. The optimal information disclosure policy is sensitive to the specific environment, which can be summarized as follows:

	Overconfidence	Moderate Underconfidence	Significant Underconfidence
Weak Incumbent ($a_A < \sqrt{a_B^H a_B^L}$)	Concealment	Concealment	Disclosure
Strong Incumbent ($a_A > \sqrt{a_B^H a_B^L}$)	Disclosure	Disclosure	Concealment

The table demonstrates that the optimal disclosure policy depends solely on employees' ex ante relative competitiveness—i.e., the comparison between a_A and $\sqrt{a_B^H a_B^L}$—when the incumbent employee is overconfident or has rational beliefs. However, additional cautions are required when the incumbent is underconfident: Mild underconfidence preserves the optimum under the previous case, while significant underconfidence overturns it.

Let us first consider the scenario of overconfidence. Imagine a rapidly-growing firm whose employees excessively attribute the firm's success to their own talent and contributions, and thus exhibit overconfidence. If the firm is confident in the quality of its search effort, i.e., $a_A < \sqrt{a_B^H a_B^L}$, then Proposition 2 would recommend that the firm refrain from granting employees access to the information about their peers, as the table shows. Conversely, imagine a seasoned teaching star in a business school: The wealth of classroom experience and industry knowledge accumulated over the years not only ensures reliable delivery in teaching, but also breeds complacency. Proposition 2, as well as the table, clearly indicates that allowing the faculty members to access peers' teaching feedback reports may increase the school's aggregate teaching quality.[23]

Next, consider a case of underconfidence. Imagine a startup that poaches a veteran executive from an industry leader to upgrade its managerial talent. The early employees may grossly overestimate the external hire who possesses a stellar career record, thereby exhibiting severe underconfidence; by Propositions 2 and 3, the firm should embrace transparent internal information management. At first, the recommendation appears to be counterintuitive. In this scenario, an existing employee suffers from both deficiency in competence and a severe lack of confidence. When additional observation from the evaluation allows him to infer more about relative competitiveness, his morale can either be elevated or degraded, depending on the realization of the signal. Ex ante, however, the possible boost in his confidence outweighs the possible "bust." The logic will be further unveiled when we delve in depth into the underlying logic for our results in the next subsection.

4 Maximizing the Expected Winner's Effort

In this section, we consider an alternative context in which the firm is concerned about the expected winner's effort and not about the the total effort (e.g., Moldovanu and Sela, 2006; Serena, 2017; and Barbieri and Serena, 2019). This objective is sensible in many scenarios. For instance, when a firm solicits a technical solution internally, only the quality of the chosen entry accrues to its benefit. A CEO succession race motivates candidates to develop their managerial skills when carrying out assigned tasks: Large public firms—e.g., GE and HP—often have difficulty retaining losing candidates, which would lead them to focus only on the acquisition of human capital from the winner (Fu and Wu, 2022).

[23] The practice of NUS business school exemplifies a system of transparent internal feedback and competitive performance evaluation. See Introduction and Footnote 4 for details.

Denote the expected winner's effort, fixing $(\mu, \tilde{\mu})$, by $WE(\mu, \tilde{\mu})$. Similar to Equation (3), $WE(\mu, \tilde{\mu})$ can be derived as

$$WE(\mu, \tilde{\mu}) = \mathbb{E}_{\mu} \left[\frac{(x_A)^2 + [x_B(a_B)]^2}{x_A + x_B(a_B)} \right] = \mathbb{E}_{\mu} \left[x_A + x_B(a_B) - 2\frac{x_A \cdot x_B(a_B)}{x_A + x_B(a_B)} \right].$$

Because total effort $TE(\mu, \tilde{\mu})$ is simply given by $\mathbb{E}_{\mu}\big[x_A + x_B(a_B)\big]$, the expression can alternatively be written as

$$WE(\mu, \tilde{\mu}) = TE(\mu, \tilde{\mu}) - 2\mathbb{E}_{\mu} \left[\frac{x_A \cdot x_B(a_B)}{x_A + x_B(a_B)} \right].$$

Thus, maximizing $WE(\mu, \tilde{\mu})$ is equivalent to maximizing the total effort minus the term $2\mathbb{E}_{\mu}\big[\frac{x_A \cdot x_B(a_B)}{x_A + x_B(a_B)}\big]$. The additional non-linear term adds complications. However, we show below that the prediction under total effort maximization remains qualitatively robust to a large extent.

We first evaluate the desirability of persistent misperception, as in Section 2.3. The following result can be obtained.

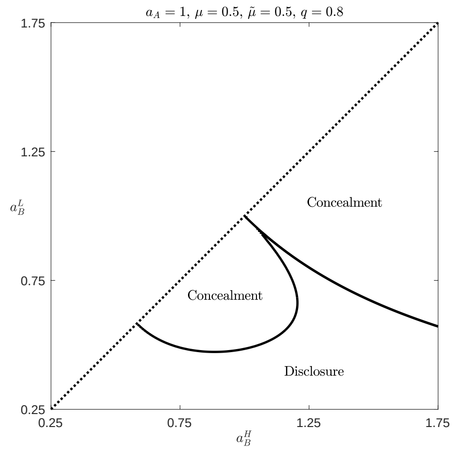
Proposition 4 ***(Value of Persistent Misperception)*** *Suppose that the firm is concerned about the expected winner's effort in the contest. Then the following statements hold:*

(i) When $a_A < \sqrt{a_B^H a_B^L}$, the firm strictly benefits from employee A's misperception—i.e., $WE(\mu, \tilde{\mu}) > WE(\mu, \mu)$—if and only if employee A exhibits overconfidence—i.e., $\tilde{\mu} < \mu$;

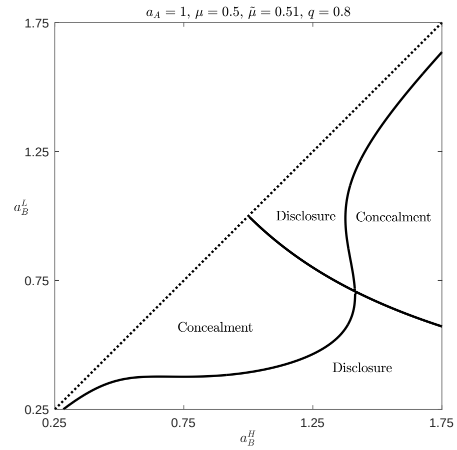
(ii) When $a_A > \sqrt{a_B^H a_B^L}$, the firm strictly benefits from employee A's misperception—i.e., $WE(\mu, \tilde{\mu}) > WE(\mu, \mu)$—if and only if employee A exhibits underconfidence—i.e., $\tilde{\mu} > \mu$;

(iii) When $a_A = \sqrt{a_B^H a_B^L}$, employee A's prior does not affect the expected total effort, i.e., $WE(\mu, \tilde{\mu}) = WE(\mu, \mu)$.

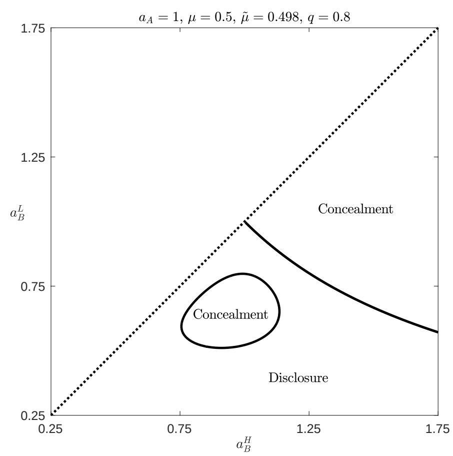
Proposition 4 states that the prediction of Proposition 1 is perfectly preserved in this alternative setting. Further, we explore the question that leads to Proposition 2: Suppose



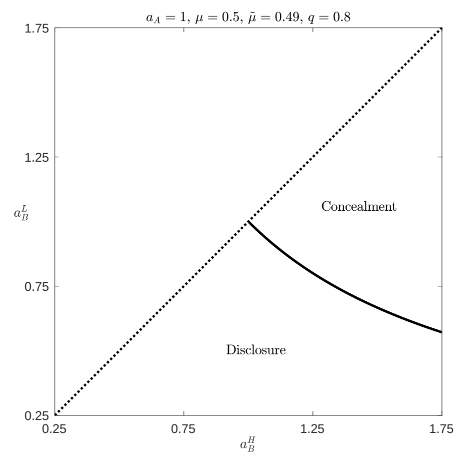
(a) Rationality ($\tilde{\mu} = 0.5$)



(b) Underconfidence ($\tilde{\mu} = 0.51$)



(c) Slight Overconfidence ($\tilde{\mu} = 0.498$)



(d) Significant Overconfidence ($\tilde{\mu} = 0.49$)

Figure 3: Optimal Information Disclosure Policy: Maximizing Winner's Effort

that an informative signal of quality $q \in (\frac{1}{2}, 1]$ is available. Would the manager disclose it to the employees? We resort to numerical exercises and hereby report the observations. Specifically, we compare the expected winner's effort under disclosure and under concealment. To proceed, we set $(a_A, \mu, q) = (1, 0.5, 0.8)$.

Figure 3 illustrates our numerical results for different cases. Three observations are worth highlighting. First, a comparison between Figure 3(a) and Figure 1(a) shows that the manager is more likely to hide information under the rational benchmark when the objective is to maximize the expected winner's effort, than when the objective is to maximize total effort. Second, as employee A becomes more overconfident, the manager tends to disclose information more often, which can be seen by comparing Figure 3(c) to Figure 3(d), i.e., $\tilde{\mu}$ dropping from 0.498 to 0.49: In the latter case, the resultant pattern for the optimum coincides with that in the case of maximizing total effort as is depicted in Figure 1(a). Third, when employee A exhibits underconfidence, the pattern for the optimum is similar to that in the case of total effort, which can be seen by comparing Figure 3(b) to Figure 1(b). In summary, the result of Section 3 qualitatively remains in place, despite the fact that the objective function of expected winner's effort causes nonlinearity.

5 Concluding Remarks and Extensions

In this paper, we investigate the impact of perceptional bias—i.e., overconfidence or underconfidence on an opponent's ability—on a promotion contest and on the optimal information disclosure in a firm. Rich implications can be inferred from our results.

First, we demonstrate that a persistent misperception may either benefit or harm the firm's performance. As a result, debiasing its employees can potentially be counterproductive. Second, we fully characterize the conditions under which disclosing an informative signal of an employee's ability, or concealing it, can prevail.

The intricate role played by the perceptional bias sheds light on the extensive discussion of confidence or morale management and workplace culture building, which casts doubt on any universal recipe given the complexity. The analysis also speaks to the debate about organizational transparency. The information fed to employees changes their belief and perception, which in turn affects their incentives subtly and indeterminately.

In an online appendix, we further explore three variations of the model. First, we examine the case of private disclosure—i.e., allowing the firm to disclose the signal to the incumbent employee only. Second, we endogenize the information structure and allow the firm to design its evaluation system flexibly. Third, we allow the new hire's ability to take three or more values. We demonstrate that the main findings in the baseline setting are robust to these extensions.

Large room remain for extensions. In this paper, we focus on the impact of perceptional bias on contenders' effort incentive and its implications for the optimal information disclosure policy. A firm can be subject to other concerns in practice, e.g., selecting and promoting a more competent candidate (Ryvkin and Ortmann, 2008; Brown and Minor, 2014). It would be interesting to extend our analysis to such an alternative context. That is, the manager's objective can be modeled as a weighted sum of total effort and the benefit of selection efficiency—i.e., the probability of selecting the more competent employee.

In this paper, we focus on a simple lottery CSF as specified in Equation (1) for the sake of tractability.[24] Footnote 8 states that a general Tullock contest model—in which a contestant wins with a probability $(x_i)^\gamma/[(x_A)^\gamma + (x_B)^\gamma]$, $\gamma \in (0,1)$—would prevent a closed-form solution and causes a technical challenge, since our model involves incomplete information. However, the primary insights of our paper are not sensitive to the specific form of the contest model. The optimal disclosure policy in our model depends on the tension between the information and morale effects. Neither of these effects conceptually relies on the specific form of the contest mechanism. We thus expect our main predictions to remain qualitatively intact when a more general noisy contest model is in place, which is confirmed by our numerical exercises in a Tullock contest with $\gamma \neq 1$. We show that the firm may benefit from biased beliefs because the perceptional biases can help balance the competition and incentivizes contenders. This prediction is primarily underpinned by the conventional wisdom of leveling the playing field in contest-like competitions (Dixit, 1987), which is not an artifact of a lottery contest model.

However, analysis of a more general contest model is definitely worthwhile despite the technical difficulty. For instance, it would be interesting to examine the role of the parameter γ of a generalized Tullock contest in our context. The size of this parameter can be viewed as a measure of the noisiness of the contest: The larger the γ, the more significant the role played by efforts—instead of random factors—in selecting the winner. Fu, Wu, and Zhu

[24]The literature typically adopts lottery contest settings for tractability when modeling noisy contests with incomplete information (see, e.g., Zhang and Zhou, 2016; Denter, Morgan, and Sisak, 2022).

(2023) show that noise in contests can help level the playing field because a larger effort is less able to ensure a win when the contest is more random, which erodes the favorite's advantage. They demonstrate that noise can substitute away the use of instruments that level the playing field. Such comparative statics remain intriguing in our context—i.e., how the balancing role played by employees' perceptional biases can be moderated by noise. We leave this for future analysis.

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Appendix: Proofs

Proof of Proposition 1

Proof. Recall that

$$TE(\mu,\tilde{\mu}) = \left[(1-\mu)\sqrt{a_B^L} + \mu\sqrt{a_B^H}\right] K(\tilde{\mu}).$$

The result immediately follows from the monotonicity of $K(\cdot)$, which is characterized by Lemma 1. ■

Proof of Proposition 2

Proof. For notational ease, we include q as an argument of $TE^D(\mu,\tilde{\mu})$

$$\begin{aligned} TE^D(\mu,\tilde{\mu};q) =& \left[\mu q + (1-\mu)(1-q)\right] \times \left[(1-\mu_H)\sqrt{a_B^L} + \mu_H\sqrt{a_B^H}\right] K(\tilde{\mu}_H) \\ &+ \left[\mu(1-q) + (1-\mu)q\right] \times \left[(1-\mu_L)\sqrt{a_B^L} + \mu_L\sqrt{a_B^H}\right] K(\tilde{\mu}_L). \end{aligned}$$

Note that concealment is equivalent to disclosure with $q=\frac{1}{2}$: $TE^C(\mu,\tilde{\mu}) = TE^D\left(\mu,\tilde{\mu};\frac{1}{2}\right)$.

Define $G(q)$ as

$$G(q) := \left[\mu q + (1-\mu)(1-q)\right] \times \left[\big(1-\mu_H(q)\big)\sqrt{a_B^L} + \mu_H(q)\sqrt{a_B^H}\right] K\big(\tilde{\mu}_H(q)\big).$$

Recall that $\mu_H = \frac{\mu q}{\mu q + (1-\mu)(1-q)}$ and $\tilde{\mu}_H = \frac{\tilde{\mu} q}{\tilde{\mu} q + (1-\tilde{\mu})(1-q)}$. In defining $G(\cdot)$, we treat μ_H and $\tilde{\mu}_H$ as functions of q.

It is easy to verify that $TE^D(\mu,\tilde{\mu};q) = G(q) + G(1-q)$. Then,

$$\frac{\partial TE^D(\mu,\tilde{\mu};q)}{\partial q} = G'(q) - G'(1-q), \text{ and } \frac{\partial^2 TE^D(\mu,\tilde{\mu};q)}{\partial q^2} = G''(q) + G''(1-q).$$

Simple algebra yields that

$$G''(q) = \left[K'\left(\tilde{\mu}_H(q)\right)\tilde{\mu}_H''(q) + K''\left(\tilde{\mu}_H(q)\right)[\tilde{\mu}_H'(q)]^2\right] \times \left[\mu q\sqrt{a_B^H} + (1-\mu)(1-q)\sqrt{a_B^L}\right]$$

$$+ 2K'\left(\tilde{\mu}_H(q)\right)\tilde{\mu}_H'(q)\left[\mu\sqrt{a_B^H} - (1-\mu)\sqrt{a_B^L}\right]$$

$$= -\underbrace{\frac{2\sqrt{a_B^H}\left(\frac{1}{a_B^L} + \frac{1}{a_A}\right)\tilde{\mu}(1-\mu)}{\frac{(1-\tilde{\mu})(1-q)+\tilde{\mu}q}{a_A} + \frac{(1-\tilde{\mu})(1-q)}{a_B^L} + \frac{\tilde{\mu}q}{a_B^H}}}_{>0} \times \underbrace{\tilde{\mu}_H'(q)}_{>0} \times K'\left(\tilde{\mu}_H(q)\right) \times \left[\frac{(a_B^L)^{\frac{3}{2}}(a_A + a_B^H)}{(a_B^H)^{\frac{3}{2}}(a_A + a_B^L)} - \frac{\mu(1-\tilde{\mu})}{\tilde{\mu}(1-\mu)}\right].$$

It can be verified that $\tilde{\mu}_H'(q) = \frac{(1-\tilde{\mu})\tilde{\mu}}{\left[(1-\tilde{\mu})(1-q)+\tilde{\mu}q\right]^2} > 0$. Moreover, it follows from Lemma 1 that $K'(\tilde{\mu}_H) \gtreqless 0$ is equivalent to $a_A - \sqrt{a_B^H a_B^L} \gtreqless 0$. Therefore, $G''(q) \gtreqless 0$ is equivalent to

$$\Theta := \left[\sqrt{a_B^H a_B^L} - a_A\right] \times \left[\frac{(a_B^L)^{\frac{3}{2}}(a_A + a_B^H)}{(a_B^H)^{\frac{3}{2}}(a_A + a_B^L)} - \frac{\mu(1-\tilde{\mu})}{\tilde{\mu}(1-\mu)}\right] \gtreqless 0.$$

Similarly, we can show that $G''(1-q) \gtreqless 0$ is equivalent to $\Theta \gtreqless 0$. Therefore, we can obtain that

$$\frac{\partial^2 TE^D\left(\mu, \tilde{\mu}; q\right)}{\partial q^2} \gtreqless 0 \Leftrightarrow \Theta \gtreqless 0.$$

Next, note that $\frac{\partial TE^D\left(\mu,\tilde{\mu};\frac{1}{2}\right)}{\partial q} = G'(\frac{1}{2}) - G'(\frac{1}{2}) = 0$. Consequently, when $\Theta > 0$, $TE^D\left(\mu, \tilde{\mu}; q\right)$ is strictly increasing in q and hence $TE^D\left(\mu, \tilde{\mu}; q\right) > TE^D\left(\mu, \tilde{\mu}; \frac{1}{2}\right) = TE^C\left(\mu, \tilde{\mu}\right)$ for all $\frac{1}{2} < q \leq 1$. When $\Theta < 0$, $TE^D\left(\mu, \tilde{\mu}; q\right)$ is strictly decreasing in q and hence $TE^D\left(\mu, \tilde{\mu}; q\right) < TE^D\left(\mu, \tilde{\mu}; \frac{1}{2}\right) = TE^C\left(\mu, \tilde{\mu}\right)$ for all $\frac{1}{2} < q \leq 1$. When $\Theta = 0$, $TE^D\left(\mu, \tilde{\mu}; q\right)$ is constant in q and thus the firm is indifferent between disclosure and concealment. ■

Proof of Proposition 3

Proof. In the case of underconfidence, for every given $\mu \in (0,1)$, the term $[\mu(1-\tilde{\mu})]/[\tilde{\mu}(1-\mu)]$ strictly decreases with $\tilde{\mu}$, with $[\mu(1-\tilde{\mu})]/[\tilde{\mu}(1-\mu)]\big|_{\tilde{\mu}=\mu} = 1$ and $[\mu(1-\tilde{\mu})]/[\tilde{\mu}(1-\mu)]\big|_{\tilde{\mu}=1} = 0$. Note that the term $\left[(a_B^L)^{\frac{3}{2}}(a_A + a_B^H)\right]/\left[(a_B^H)^{\frac{3}{2}}(a_A + a_B^L)\right] < 1$. Therefore, fixing (a_A, a_B^L, a_B^H), there exists a unique cutoff $\tilde{\mu}^* \in (\mu, 1)$ such that

$$\frac{(a_B^L)^{\frac{3}{2}}\left(a_A + a_B^H\right)}{(a_B^H)^{\frac{3}{2}}\left(a_A + a_B^L\right)} - \frac{\mu\left(1-\tilde{\mu}\right)}{\tilde{\mu}\left(1-\mu\right)} \lesseqgtr 0, \text{ if and only if } \tilde{\mu} \lesseqgtr \tilde{\mu}^*. \tag{10}$$

Proposition 3 follows instantly from (10) and Proposition 2. ■

Proof of Proposition 4

Proof. First we simplify $WE(\mu, \tilde{\mu})$.

$$\begin{aligned} WE(\mu, \tilde{\mu}) &= \mathbb{E}_\mu \left[x_A + x_B(a_B) - 2\frac{x_A \cdot x_B(a_B)}{x_A + x_B(a_B)} \right] \\ &= \mathbb{E}_\mu \left[\sqrt{a_B x_A} - 2\frac{x_A \left(\sqrt{a_B x_A} - x_A\right)}{\sqrt{a_B x_A}} \right] \\ &= \mathbb{E}_\mu \left[F\left(a_B, K(\tilde{\mu})\right) \right], \end{aligned}$$

where $F(a_B, K) := \frac{2K^3}{\sqrt{a_B}} + \sqrt{a_B}K - 2K^2$. Note that

$$\frac{\partial F(a_B, K)}{\partial K} = \frac{6K^2}{\sqrt{a_B}} + \sqrt{a_B} - 4K \geq \left(2\sqrt{6} - 4\right) K > 0.$$

Therefore, $WE(\mu, \tilde{\mu})$ is increasing in K. From Lemma 1, $K(\cdot)$ is strictly decreasing in $\tilde{\mu}$ if $\sqrt{a_B^H a_B^L} > a_A$ and $K(\tilde{\mu})$ is strictly increasing in $\tilde{\mu}$ otherwise. This completes the proof. ■

Confidence Management in Contests

ONLINE APPENDIX

(Not Intended for Publication)

Shanglyu Deng* Hanming Fang† Qiang Fu‡ Zenan Wu§

In this online appendix, we consider three variations to the baseline model mentioned in the main text.[1] Online Appendix A extends the model to allow for private disclosure, in which the manager can choose to disclose the signal to the incumbent only. Online Appendix B applies a Bayesian persuasion approach to endogenize the information structure of the internal evaluation. Online Appendix C allows the new hire's ability to take three or more values. Online Appendix D collects the proofs of propositions.

A Private Disclosure

In the main text, we have assumed that the signal is revealed to both the incumbent and the newbie when the manager chooses to disclose it. Next, we consider an alternative disclosure format: The manager can disclose the signal $s \in \{H, L\}$ as specified in Section 3 to the incumbent only. With private disclosure, the baseline model with one-sided incomplete

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[1] This note is not self-contained; it is the online appendix of the paper "Confidence Management in Contests."

information turns into one with two-sided incomplete information à la Fang and Morris (2006), in which employee A's estimate about employee B's type upon receiving the signal is privately known to himself.[2,3]

Denote by $\langle(x_A^H, x_A^L), (x_B^H, x_B^L)\rangle$ the equilibrium effort profile: x_A^H and x_A^L are employee A's effort supply upon receiving a high and a low signal respectively; while x_B^H and x_B^L are employee B's effort level given that his ability is a_B^H and a_B^L respectively.

Upon observing the signal s, employee A updates his belief $\tilde{\mu}_s$ according to (6) and chooses his signal-dependent effort, which we denote by $x_A^s \geq 0$, to maximize his expected payoff

$$\left[\tilde{\mu}_s \frac{x_A^s}{x_A^s + x_B^H} + (1 - \tilde{\mu}_s) \frac{x_A^s}{x_A^s + x_B^L}\right] a_A - x_A^s.$$

Note that employee A's effort decision under private disclosure is signal-dependent as under public disclosure.

Recall that under public disclosure, employee B's equilibrium effort depends on both the public signal $s \in \{H, L\}$ and his private type $a_B \in \{a_B^H, a_B^L\}$. In contrast, under private disclosure, his equilibrium effort can only depend on his own ability a_B. Specifically, a type-a_B^z employee B, with $z \in \{H, L\}$, chooses $x_B^z \geq 0$ to maximize

$$\left\{\Pr\left(s = H \,\middle|\, a_B = a_B^z\right) \frac{x_B^z}{x_A^H + x_B^z} + \left[1 - \Pr\left(s = H \,\middle|\, a_B = a_B^z\right)\right] \frac{x_B^z}{x_A^L + x_B^z}\right\} a_B^z - x_B^z,$$

where $\Pr(s = H | a_B = a_B^H) = 1 - \Pr(s = H | a_B = a_B^L) = q \in (1/2, 1)$ by (4).[4]

A closed-form solution to the contest game is unavailable in general when it involves two-sided incomplete information (see, e.g., Hurley and Shogren, 1998; and Serena, 2022), which substantially complicates the model.[5] However, it should be noted that the information

[2]This kind of private disclosure scheme is also considered by Chen (2021) in all-pay auctions.

[3]It is noteworthy that the contest game under private disclosure differs from the usual independent private value (IPV) frameworks assumed in auction and contest literature. Employee A's private type concerns the additional information he receives from the signal, while employee B's is about his true ability; their types differ in nature but are correlated.

[4]In the extreme case of $q = 1$, private disclosure is equivalent to public disclosure.

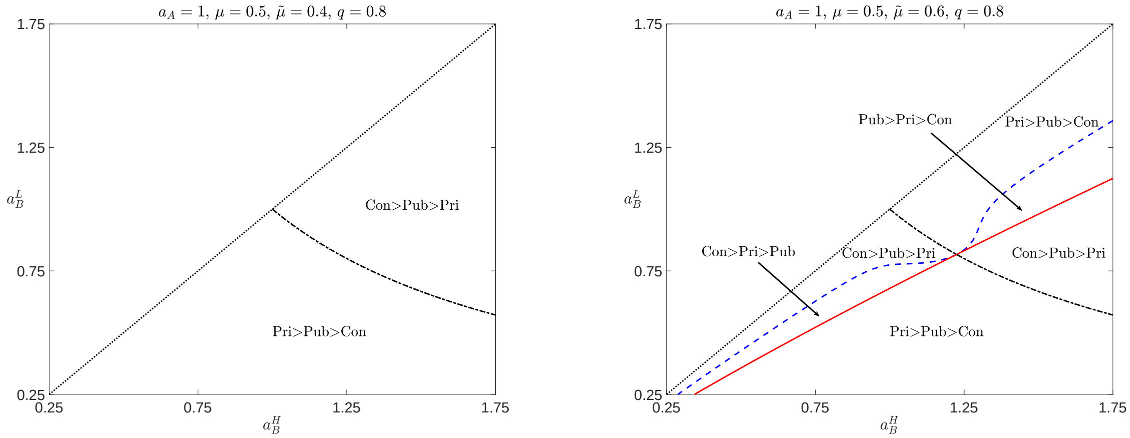
[5]Several papers overcome the lack of a closed-form solution by either imposing more structure on the type distribution (Malueg and Yates, 2004; Fey, 2008; and Ewerhart, 2010) or modifying the CSF (Wasser, 2013).

effect and the morale effect featured in our baseline model also exist under this alternative information structure. The information effect arises when the additional information revealed by the signal s causes employee A to have diverging posterior beliefs and thus diverging effort decisions in the contest, depending on the specific realization of the signal. This effect prevails regardless of whether the signal is publicly or privately disclosed. The morale effect is driven by the fact that the biased incumbent adjusts his perception of the new hire asymmetrically in response to high vis-à-vis low signal, depending on the nature of his initial misperception. This effect is preserved under private disclosure, given that the incumbent conducts the same Bayesian updating that he would under public disclosure. As a result, the trade-off between disclosure and concealment should not be sensitive to the specific mode of disclosure. This conjecture is confirmed by our numerical exercises, which are presented in Figure A1.

Figure A1 assumes $(a_A, \mu, \tilde{\mu}, q) = (1, 0.5, 0.4, 0.8)$, as in Figure 1. It provides a ranking among private disclosure, public disclosure, and concealment for different combinations of (a_B^H, a_B^L). As in Figure 1(a), the relevant parameterizations in Figure 1(a)—i.e., those below the diagonal—are split into two regions by the dashed curve defined by $a_A = \sqrt{a_B^H a_B^L}$; the solid curve in Figure 1(b)—as in Figure 1(b)—traces all parameterizations that satisfy $\left[(a_B^L)^{\frac{3}{2}} \left(a_A + a_B^H\right) / (a_B^H)^{\frac{3}{2}} \left(a_A + a_B^L\right)\right] = \left[\mu \left(1 - \tilde{\mu}\right) / \tilde{\mu} \left(1 - \mu\right)\right]$. Comparing Figure A1 with Figure 1, we observe that the ranking between disclosure and concealment is *independent* of the mode of disclosure: Whenever public disclosure generates more (less) expected total effort than concealment, so does private disclosure. This confirms the rationale laid out above, although the comparison between public and private disclosure depends subtly on the specific setting and parameterization.

B Optimal Design of Internal Evaluation

In the main text, we have assumed that the quality of the internal evaluation—i.e., q—is exogenous. In practice, a firm has the discretion to set the scope and format of the evaluation in the workplace or choose the evaluator, which presumably affects the quality of



(a) Rationality and Overconfidence ($\tilde{\mu} \leq \mu$)

(b) Underconfidence ($\tilde{\mu} > \mu$)

Figure A1: Public Disclosure vs. Private Disclosure vs. Concealment

the exercise. For instance, a more experienced supervisor can assess his employee's ability more accurately.

We now allow the firm to flexibly design and precommit to the information structure of the evaluation exercise before the contest begins, which is referred to as the Bayesian persuasion approach in the literature, and was pioneered by Kamenica and Gentzkow (2011). Zhang and Zhou (2016) study the optimal information design in a similar setting but with common prior. Alonso and Camara (2016) explore Bayesian persuasion while allowing the sender and (single) receiver to possess heterogeneous beliefs. We borrow their approach and apply it to a contest setting.

An information structure consists of a signal space $\mathcal{S}$ and a pair of likelihood distributions $\left\{\pi(\cdot|a_B^H), \pi(\cdot|a_B^L)\right\}$ over $\mathcal{S}$. We allow the manager to freely set the information structure of the evaluation; she is thus endowed with full control over the amount of information to be revealed through the evaluation and the form of the signal to be disclosed to employees. Obviously, the evaluation exercise depicted in Section 3 involves a simple information structure with a binary signal space $\mathcal{S} = \{H, L\}$ and a conditional likelihood distribution for each underlying state—i.e., a_B^H or a_B^L—parametrized by a variable q [see Equation (4)].

In their seminal paper, Kamenica and Gentzkow (2011) show that searching for the optimal disclosure policy is equivalent to solving for the concave closure of a value function defined on the set of all posteriors—i.e., μ_s in our notation—assuming that all agents share a common prior (i.e., $\tilde{\mu} = \mu$) over the underlying states. Alonso and Camara (2016) generalize the tools in Kamenica and Gentzkow (2011) and allow for heterogeneous priors. According to Alonso and Camara (2016), it is without loss of generality to consider a binary signal space in our setting, i.e., $\mathcal{S} = \{H, L\}$; the search for the optimal effort-maximizing signal structure $\left\{\pi(\cdot|a_B^H), \pi(\cdot|a_B^L)\right\}$ can be reduced to the following optimization problem:

$$\max_{\{\lambda,\mu_H,\mu_L\}} \lambda TE(\mu_H, \tilde{\mu}_H) + (1-\lambda)TE(\mu_L, \tilde{\mu}_L) \tag{A1}$$

subject to

$$\lambda\mu_H + (1-\lambda)\mu_L = \mu, \tag{A2}$$

$$\tilde{\mu}_s = \frac{t\mu_s}{t\mu_s + r(1-\mu_s)}, \text{ for } s \in \{H, L\}, \tag{A3}$$

$$0 \leq \lambda, \mu_H, \mu_L \leq 1, \tag{A4}$$

where r and t are defined as $r := (1-\tilde{\mu})/(1-\mu)$ and $t := \tilde{\mu}/\mu$ respectively and capture the likelihood ratios of prior beliefs. As defined above, the variable μ_s in the objective function (A1) is the manager's posterior about employee B's ability as inferred upon observing signal $s \in \{H, L\}$; $\tilde{\mu}_s$ in expression (A3), accordingly, refers to employee A's posterior.

Given the priors $(\mu, \tilde{\mu})$ and manager's belief (μ_H, μ_L), employee A's posterior belief can be derived from (A3). To be more specific, it follows from (5) and (6) that

$$\tilde{\mu}_s = \frac{t\frac{\mu \Pr\left(s|a_B=a_B^H\right)}{\mu \Pr\left(s|a_B=a_B^H\right)+(1-\mu)\Pr\left(s|a_B=a_B^L\right)}}{t\frac{\mu \Pr\left(s|a_B=a_B^H\right)}{\mu \Pr\left(s|a_B=a_B^H\right)+(1-\mu)\Pr\left(s|a_B=a_B^L\right)} + r\frac{(1-\mu)\Pr\left(s|a_B=a_B^L\right)}{\mu \Pr\left(s|a_B=a_B^H\right)+(1-\mu)\Pr\left(s|a_B=a_B^L\right)}} = \frac{t\mu_s}{t\mu_s + r(1-\mu_s)}.$$

When the manager and the employees share a common prior (i.e., $\tilde{\mu} = \mu$), we have $r = t = 1$ and they share the same Bayesian update (i.e., $\mu_s = \tilde{\mu}_s$ for $s \in \{H, L\}$).

Condition (A2) requires $\mathbb{E}_\mu(\mu_s) = \mu$, which is identical to the one in Kamenica and Gentzkow (2011) and is commonly referred to as the Bayes-plausibility constraint. Condition

(A4) simply requires that the posterior belief μ_H and μ_L and the probability λ be bounded between zero and one. It is useful to point out that a perfectly informative evaluation corresponds to $(\mu_H, \mu_L) = (1, 0)$ with $\lambda = \mu$, and a completely uninformative evaluation (i.e., no information disclosure) corresponds to $(\mu_H, \mu_L) = (\mu, \mu)$ with $\lambda \in [0, 1]$.

Kamenica and Gentzkow (2011) and Alonso and Camara (2016) show that the indirect value function from the above maximization problem boils down to the value of the concave closure of $TE\big(\mu_s, \tilde{\mu}_s(\mu_s)\big)$ at the firm's prior μ. Simple algebra yields

$$TE\left(\mu_s, \tilde{\mu}_s(\mu_s)\right) = \left[(1-\mu_s)\sqrt{a_B^L} + \mu_s\sqrt{a_B^H}\right] \times K\left(\frac{t\mu_s}{t\mu_s + r(1-\mu_s)}\right).$$

Proposition A1 ***(Optimal Design of Evaluation with Heterogeneous Priors)*** *Suppose that the manager aims to maximize the expected total effort in the contest and can flexibly design the internal evaluation. Then the following statements hold:*

(i) When $\Theta > 0$, full disclosure with a perfectly revealing evaluation—i.e., $(\mu_H, \mu_L) = (1, 0)$—is optimal;

(ii) When $\Theta < 0$, a completely uninformative evaluation—i.e., $(\mu_H, \mu_L) = (\mu, \mu)$—is optimal;

(iii) When $\Theta = 0$, the expected total effort is the same across all evaluation designs.

Proposition A1 states that the optimal evaluation is either perfectly revealing or completely uninformative. The firm has a polarized preference regarding its evaluation, either maximizing the transparency in the contest or simply minimize it, i.e., forgoing the evaluation. The condition for perfect revelation or no evaluation coincides with that for fully disclosing or concealing a noisy signal of quality $q \in (\frac{1}{2}, 1]$ in Proposition 2.

C Multiple Types

The baseline setting in the main text assumes that the new hire B's ability a_B follows a Bernoulli distribution and can take two values. Next, we generalize the model to allow a_B to take multiple values and show that our main results remain qualitatively unchanged. Specifically, we allow a_B to take $N \geq 3$ values, $0 < a_B^1 < \cdots < a_B^N$, with $\Pr(a_B = a_B^i) = \mu^i > 0$ for all $i \in \{1, \ldots, B\}$. The manager's prior about a_B is described by a distribution $\boldsymbol{\mu} := (\mu^1, \ldots, \mu^N) \in int(\Delta^{N-1})$, and employee A's belief is denoted by $\tilde{\boldsymbol{\mu}} := (\tilde{\mu}^1, \ldots, \tilde{\mu}^N) \in \Delta^{N-1}$.

This generalization complicates the analysis. With multiple types of possible, employee A's belief is a vector instead of a single variable as in the baseline model. Definition of overconfidence or underconfidence is thus more nuanced. To simplify the modeling of the incumbent's perceptional bias, we focus on the case of extreme overconfidence—i.e., employee A's belief is given by $\tilde{\boldsymbol{\mu}}_O := (1, 0, \ldots, 0)$—and that of extreme underconfidence—i.e., employee A's belief is $\tilde{\boldsymbol{\mu}}_U := (0, \ldots, 0, 1)$. Further, when comparing the performance of different information disclosure policies, we assume that the manager receives a perfectly informative signal about the incumbent's ability.[6]

In parallel with Assumption 1, we assume $a_B^1 \geq a_A/4$ throughout the subsection. Simple algebra would then verify that

$$TE(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}) = \frac{\mathbb{E}_{\boldsymbol{\mu}}[\sqrt{a_B}]\mathbb{E}_{\tilde{\boldsymbol{\mu}}}\left[\frac{1}{\sqrt{a_B}}\right]}{\frac{1}{a_A} + \mathbb{E}_{\tilde{\boldsymbol{\mu}}}\left[\frac{1}{a_B}\right]}.$$

In particular,

$$TE(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O) = \frac{\mathbb{E}_{\boldsymbol{\mu}}[\sqrt{a_B}]a_A\sqrt{a_B^1}}{a_A + a_B^1}, \text{ and } TE(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_U) = \frac{\mathbb{E}_{\boldsymbol{\mu}}[\sqrt{a_B}]a_A\sqrt{a_B^N}}{a_A + a_B^N}.$$

The following result can then be obtained.

[6] A comprehensive analysis under general beliefs and information structures is definitely worthwhile and should be attempted in future studies.

Proposition A2 ***(Value of Persistent Misperception with Multiple Types)*** *Suppose that $a_B^1 \geq a_A/4$. Then the following statements hold:*

(i) If employee A exhibits extreme overconfidence—i.e., $\tilde{\boldsymbol{\mu}} = \tilde{\boldsymbol{\mu}}_O$—then there exists a threshold $a^\dagger \in (0, 4a_B^1]$ such that $TE(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O) > TE(\boldsymbol{\mu}, \boldsymbol{\mu})$ if and only if $a_A < a^\dagger$.

(ii) If employee A exhibits extreme underconfidence—i.e., $\tilde{\boldsymbol{\mu}} = \tilde{\boldsymbol{\mu}}_U$—then there exists a threshold $a^{\dagger\dagger} \in (0, 4a_B^1]$ such that $TE(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_U) > TE(\boldsymbol{\mu}, \boldsymbol{\mu})$ if and only if $a_A > a^{\dagger\dagger}$.

Proposition A2 is in line with Proposition 1: Employee A's overconfidence (underconfidence) benefits an effort-maximizing firm when he is weak (strong) relative to the new hire.

Next, we consider how the incumbent's perceptional bias affects the firm's disclosure policy. As previously mentioned, we assume that the manager has access to a perfectly informative signal and decides whether to publicly disclose or conceal it. Disclosure would turn the posterior game into a complete-information lottery contest, given that the vector of the incumbent's belief $\tilde{\boldsymbol{\mu}}$ is in the interior of Δ^{N-1}.[7] The expected total effort can be obtained as follows:

$$TE^D(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}) = \mathbb{E}_{\boldsymbol{\mu}}\left[\frac{a_A a_B}{a_A + a_B}\right], \text{ for all } \tilde{\boldsymbol{\mu}} \in int\big(\Delta^{N-1}\big).$$

If the manager commits to concealing the signal, the corresponding expected total effort amounts to

$$TE^C(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}) = TE(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}).$$

Let $\{\tilde{\boldsymbol{\mu}}_O^k\}_{k=1}^\infty$ and $\{\tilde{\boldsymbol{\mu}}_U^k\}_{k=1}^\infty$ be two sequences of beliefs that converge to $\tilde{\boldsymbol{\mu}}_O$ and $\tilde{\boldsymbol{\mu}}_U$ in norm, respectively. The following result ensues.

Proposition A3 ***(Concealment vs. Disclosure with Multiple Types)*** *Suppose that $a_B^1 \geq a_A/4$. Then the following statements hold:*

[7] In the extreme case that $\tilde{\boldsymbol{\mu}} = \tilde{\boldsymbol{\mu}}_O$ or $\tilde{\boldsymbol{\mu}} = \tilde{\boldsymbol{\mu}}_U$, information disclosure will not affect the incumbent's belief.

(i) *There exists a threshold* $a^\star \in (0, 4a_B^1]$ *such that* $\lim_{k\to\infty} TE^D(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O^k) > \lim_{k\to\infty} TE^C(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O^k)$ *if and only if* $a_A > a^\star$.

(ii) *There exists a threshold* $a^{\star\star} \in (0, 4a_B^1]$ *such that* $\lim_{k\to\infty} TE^D(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_U^k) > \lim_{k\to\infty} TE^C(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_U^k)$ *if and only if* $a_A < a^{\star\star}$.

By Proposition A3, the comparison between (public) disclosure and concealment with multiple types resembles that in Proposition 2. Note that from Proposition 2, if employee A is sufficiently overconfident (i.e., if $\tilde{\mu}$ is close to 0), disclosure outperforms concealment when the incumbent is relatively strong, i.e., $a_A > \sqrt{a_B^H a_B^L}$. The optimal disclosure policy is reversed if employee A is sufficiently underconfident (i.e., if $\tilde{\mu}$ is close to 1): Disclosure generates a larger amount of expected total effort than concealment when the incumbent is relatively weak, i.e., $a_A < \sqrt{a_B^H a_B^L}$. Proposition A3 demonstrates that these predictions can be preserved when multiple types are allowed.

D Proofs

Proof of Proposition A1

Proof. Recall that

$$\tilde{\mu}_s(\mu_s) = \frac{t\mu_s}{t\mu_s + r(1-\mu_s)}.$$

It follows immediately that

$$\tilde{\mu}_s'(\mu_s) = \frac{rt}{[t\mu_s + r(1-\mu_s)]^2} > 0, \text{ and } \tilde{\mu}_s''(\mu_s) = \frac{-2(t-r)rt}{[t\mu_s + r(1-\mu_s)]^3}.$$

Denote $TE(\mu_s, \tilde{\mu}_s(\mu_s))$ by $\widehat{TE}_s(\mu_s)$. The second-order derivative of $\widehat{TE}_s(\mu_s)$ with respect to

μ_s is

$$\begin{aligned}\widehat{TE}_s''(\mu_s) &= \left\{K''\left(\tilde{\mu}_s(\mu_s)\right)\left[\tilde{\mu}_s'(\mu_s)\right]^2 + K'\left(\tilde{\mu}_s(\mu_s)\right)\tilde{\mu}_s''(\mu_s)\right\} \times \left[(1-\mu_s)\sqrt{a_B^L} + \mu_s\sqrt{a_B^H}\right] \\ &\quad + 2K'\left(\tilde{\mu}_s(\mu_s)\right)\tilde{\mu}_s'(\mu_s)\left(\sqrt{a_B^H} - \sqrt{a_B^L}\right) \\ &= -\underbrace{\frac{2\tilde{\mu}_s'(\mu_s)\sqrt{a_B^H}\left(\frac{1}{a_B^L} + \frac{1}{a_A}\right)t}{\frac{t\mu_s + r(1-\mu_s)}{a_A} + \frac{r(1-\mu_s)}{a_B^L} + \frac{t\mu_s}{a_B^H}}}_{>0} \times K'\left(\tilde{\mu}_s(\mu_s)\right) \times \left[\frac{(a_B^L)^{\frac{3}{2}}(a_A + a_B^H)}{(a_B^H)^{\frac{3}{2}}(a_A + a_B^L)} - \frac{\mu(1-\tilde{\mu})}{\tilde{\mu}(1-\mu)}\right].\end{aligned}$$

It follows from Lemma 1 that $K'\left(\tilde{\mu}_s(\mu_s)\right) \gtreqless 0$ is equivalent to $a_A \gtreqless \sqrt{a_B^H a_B^L}$. Therefore, $\widehat{TE}_s''(\mu_s) \gtreqless 0$ is equivalent to

$$\Theta = \left[\sqrt{a_B^H a_B^L} - a_A\right] \times \left[\frac{(a_B^L)^{\frac{3}{2}}(a_A + a_B^H)}{(a_B^H)^{\frac{3}{2}}(a_A + a_B^L)} - \frac{\mu(1-\tilde{\mu})}{\tilde{\mu}(1-\mu)}\right] \gtreqless 0.$$

When $\Theta > 0$, $TE_s(\mu_s)$ is strictly convex in μ_s, indicating the optimality of perfectly revealing signals. When $\Theta < 0$, $TE_s(\mu_s)$ is strictly concave in μ_s, indicating the optimality of completely uninformative signals. When $\Theta = 0$, $TE_s(\mu_s)$ is linear in μ_s, and thus all information disclosure policies lead to the same expected total effort. ■

Proof of Proposition A2

Proof. We focus on the case of overconfidence. The analysis for the case of underconfidence is similar and omitted for brevity. Carrying out the algebra, we have that

$$TE(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O) - TE(\boldsymbol{\mu}, \boldsymbol{\mu}) = \frac{a_A \mathbb{E}_{\boldsymbol{\mu}}\sqrt{a_B}}{1 + a_A \mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{a_B}\right]}\left\{\sqrt{a_B^1}\mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{a_B}\right]\frac{a_A + \frac{1}{\mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{a_B}\right]}}{a_A + a_B^1} - \mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{\sqrt{a_B}}\right]\right\}.$$

Therefore, $TE(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O) > TE(\boldsymbol{\mu}, \boldsymbol{\mu})$ is equivalent to

$$\phi(a_A) := \sqrt{a_B^1} \times \mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{a_B}\right] \times \frac{a_A + \frac{1}{\mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{a_B}\right]}}{a_A + a_B^1} - \mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{\sqrt{a_B}}\right] > 0.$$

Note that $\frac{1}{\mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{a_B}\right]} > a_B^1$ implies that $\phi(a_A)$ decreases with a_A. Evaluating $\phi(a_A)$ at $a_A = 0$ yields

$$\phi(0) = \sqrt{a_B^1} \times \mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{a_B}\right] \times \frac{0 + \frac{1}{\mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{a_B}\right]}}{0 + a_B^1} - \mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{\sqrt{a_B}}\right] = \frac{1}{\sqrt{a_B^1}} - \mathbb{E}_{\boldsymbol{\mu}}\left[\frac{1}{\sqrt{a_B}}\right] > 0.$$

Therefore, there exists a cutoff $a^\dagger \in (0, 4a_B^1]$ such that $TE(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O) > TE(\boldsymbol{\mu}, \boldsymbol{\mu})$ if and only if $a_A < a^\dagger$. This concludes the proof. ■

Proof of Proposition A3

Proof. We focus on the case of overconfidence. The analysis for the case of underconfidence is similar and omitted for brevity. Note that

$$\lim_{k\to\infty} TE^D(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O^k) - \lim_{k\to\infty} TE^C(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O^k) = \frac{a_A}{a_A + a_B^1}\left\{\mathbb{E}_{\boldsymbol{\mu}}\left[a_B \times \frac{a_A + a_B^1}{a_A + a_B}\right] - \sqrt{a_B^1} \times \mathbb{E}_{\boldsymbol{\mu}}\left[\sqrt{a_B}\right]\right\}.$$

Therefore, $\lim_{k\to\infty} TE^D(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O^k) - \lim_{k\to\infty} TE^C(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O^k) > 0$ is equivalent to

$$\psi(a_A) := \mathbb{E}_{\boldsymbol{\mu}}\left[a_B \times \frac{a_A + a_B^1}{a_A + a_B}\right] - \sqrt{a_B^1} \times \mathbb{E}_{\boldsymbol{\mu}}\left[\sqrt{a_B}\right] > 0.$$

It is straightforward to verify that $\psi(a_A)$ strictly increases with a_A. Moreover, we have that

$$\psi(0) = \mathbb{E}_{\boldsymbol{\mu}}\left[a_B^1\right] - \sqrt{a_B^1} \times \mathbb{E}_{\boldsymbol{\mu}}\left[\sqrt{a_B}\right] < 0.$$

Therefore, there exists a threshold $a^\star \in (0, 4a_B^1]$ such that $\lim_{k\to\infty} TE^D(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O^k) > \lim_{k\to\infty} TE^C(\boldsymbol{\mu}, \tilde{\boldsymbol{\mu}}_O^k)$ if and only if $a_A > a^\star$. This concludes the proof. ■

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