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ORIGINAL PAPER

On interim performance evaluations and interdependent period outcomes

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Abstract

Performance feedback is an integral element of an accounting system, and firms provide this feedback at varying frequencies to their employees. This paper explicates the impact of an interim performance evaluation on the principal's surplus using a dynamic two-period agency model. Two settings are discussed: single-purpose use, wherein accounting information is used solely for control purposes, and dual-purpose use, in which accounting information is used for production and control. Results demonstrate that the optimality of interim performance evaluations depends on the use of information and the interdependence of period outcomes. Furthermore, neither setting entails strict dominance with regard to carrying out interim evaluations or not. It implies that an interim evaluation can be optimal even if the optimal course of action does not depend on it. It further suggests that refraining from the interim review can be optimal even if that information is required to determine the optimal effort level.

Keywords Agency · Aggregation · Frequency · Dual-purpose · Single-purpose · Interim evaluation · Accounting information

JEL Classification D86 · M12 · M41 · M52

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1 Introduction

Performance feedback is an integral element of an accounting system (Luckett & Eggleton, 1991). Nowadays, it is standard for employees at various levels in the hierarchy to be evaluated on the basis of their individual or their respective divisions' performance. Therefore, how frequently firms should evaluate interim performance and give feedback is a matter of genuine interest to them. Digitization of businesses may bring about the possibility to measure performance very frequently. Associated with the digitization of businesses is a dynamically changing environment wherein employees work. Consequently, deciding about the optimality of interim evaluations or, more generally, about performance evaluation frequency in dynamic work environments may be a problem of lasting relevance for firms.

The first objective of this study was to investigate performance evaluation frequency in a dynamic setting with interrelated periods. I assumed that outcomes in one period determine outcome probabilities in the next period. What characterizes situations wherein the firm should evaluate more frequently or less frequently? The second objective of this study was to ascertain whether there exists a connection between the use of accounting information and the evaluation frequency. Should performance be appraised more or less frequently if the information is used for both control and productive purposes (dual-purpose use) instead of solely for control (single-purpose use)? If the answer turns out to be "it depends," is it possible to identify settings where (in)frequent evaluations are optimal?

In firms, it is a management decision how often performance should be evaluated and rewarded. Pay patterns in firms differ with regard to the frequency of rewards (Gomez-Mejia et al., 2010), among other characteristics. A survey conducted by Joseph and Kalwani (1998) shows that 43% of firms in the survey pay bonuses to their sales force on an annual basis, while the remaining pay quarterly (32%), every month (15%), and on a biannual basis (11%).[1] Hence, firms exercise their option to generate and communicate performance information at varying frequencies. Two factors have been asserted to influence the choice of performance evaluation frequency: the interdependence of periods (Arya et al., 2004; Nikias et al., 2005; Lukas, 2010) and the actual usage of performance information (Feltham et al., 2006). Assume that periods are both technologically and stochastically independent, and the outcome distribution is binary. In that case, interim evaluations provide the same information as an overall aggregate evaluation at the end of the contractual relationship. Information aggregation is costless (Nikias et al. 2005, p. 63), but it provides a benefit as it restrains agent opportunism. Hence, less frequent evaluations are optimal (Arya et al., 2004). While the benefit of aggregation carries over to a dynamic setting, it remains to be ascertained if and when the costs fall short of the benefit. Researchers must address this issue to guide firms. Nikias et al. (2005) and Lukas (2010) considered (different) effort-dependent interaction effects between periods, i.e., the effort choice in a given period directly affected future effort choices and chances of success due to, e.g., learning effects or exhaustion. The present study

[1] Percentages do not sum to 100 in Joseph and Kalwani (1998).

deals with outcome-dependent interaction effects, which have not been analyzed in the literature. An example of such effects is the bandwagon effect when high sales in a given period make high sales in the next period more likely.

Analysis of outcome-dependent interaction effects is important because, as the example from above suggests, realized outcomes often provide essential clues to assess the future performance of business units. Moreover, even though Nikias et al. (2005) and Lukas (2010) used a similar model setup, results prove to be sensible to the assumption whether first-period effort in general (Lukas, 2010) or only high effort in the first period (Nikias et al., 2005) impact the productivity and the chances of success in the second period.[2] The difference in results for effort-dependent interaction effects ensuing from a seemingly minor modification of the setup could suggest that consequences of outcome-dependent interaction effects with regard to the choice of the evaluation regime may not be conspicuous and differ from those of effort-dependent interaction effects.

Firms have the choice to use performance-related information for control purposes only or control and productive purposes. Feltham et al. (2006) remarked that the two objectives are intertwined for practical matters. The same information firms use to evaluate an employee's performance ex-post may be used to plan future actions or production schedules. Only if specific actions are required exogenously, such as mandatory inspection work or laboratory tests, the control purpose is separate from the productive purpose. Separating the two purposes is somewhat didactic as soon as optimal future actions depend on their implementation costs. Nevertheless, information used for control purposes is rather retrospective, while it is prospective or forward-looking for productive purposes.

More frequent evaluations appear advantageous for productive purposes because decisions can be based on more information (Sprinkle, 2000; Northcraft et al., 2011),[3] For control purposes, less frequent evaluations limit the agent's access to information and, thus, the agent's opportunism (Arya et al., 2004, p. 644), leading to lower compensation costs. Heretofore, only a few studies have investigated the dual-purpose use of information despite their potential for generating major contributions (Van der Stede, 2015, p. 174). The present paper responds to this call by analyzing the dual-purpose use in a dynamic setting typical for today's work in firms. Therefore, two research gaps exist: the analysis of outcome-dependent interaction effects and a dual-purpose use of accounting information with regard to interim evaluations. The present paper contributes to the research required to fill these gaps.

For this purpose, I consider two settings: In the first setting, accounting information is used for the single purpose of control, whereas in the second, it serves the dual purpose of production and control. In the first setting, the optimal course of

[2] Specifically, weak positive complementarity between effort choices in period 1 and 2 leads to a weak preference for aggregate evaluation in Nikias et al. (2005). However, the extent of positive complementarity matters in Lukas (2010).

[3] Negative effects of higher performance evaluation frequency include gaming of the incentive system (Bouwens & Kroos, 2011) an increase of outcome effects (Frederickson et al., 1999), recency effects entailing less accurate earnings predictions (Pitre, 2012), cognitive overload, which in turn causes a decline in individual performance (Lurie & Swaminathan, 2009; Lam et al., 2011), or undesired behavior like manipulating information (Murphy, 2004; Jain, 2012).

action is fixed ex-ante, i.e., the optimal effort level in later periods does not depend on previous outcomes. In the second setting, the optimal effort level or production schedule in later periods is contingent on previous outcomes. For instance, if low sales in a given period indicate that sales effort in the next period comes with low chances of success, it may not be optimal to motivate high effort for the next period. In both settings, I focus on incentives for productive effort (ruling out any earning management issues). This would help answer the question of whether an interim performance evaluation can be optimal if costs of effort are the only costs to consider on the agent's side. In firms, the pressure to achieve short-term goals may lead to additional costs, e.g., psychological costs to justify poor or mediocre performance (Lukas et al., 2019). Suppose interim evaluations are not optimal without considering the additional costs. In that case, they likely will not be optimal if these costs, in addition to effort costs, are included in the analysis.

I analyze a dynamic two-period agency model with risk-neutral parties, where the agent is protected by limited liability. As a novel feature, the model shows stochastic interdependence of period outcomes. Conditional on the outcome in the first period, the probability of achieving a high outcome in the second period may increase or decrease. For instance, the sales in the current year could be a good indicator of how effective the sales effort will be in the next year. Moreover, the gross outcomes in the second period depend on the outcomes of the first period. This assumption helps to classify settings wherein the principal finds it optimal to make the course of action dependent on prior results. The modeling is general in the sense that quite different scenarios can be mapped.

The first result of this study is that in the setting with a single-purpose use of accounting information, refraining from the interim evaluation (i.e., infrequent performance evaluation, IPE) is optimal in many—but not all—parameter settings. Hence, it is often efficient to suppress early information. Nevertheless, carrying out an interim evaluation (i.e., frequent performance evaluation, FPE) can be optimal in this setting. IPE is optimal if the maximum outcome is sufficiently informative about agent effort. In contrast, FPE is optimal if the optimal pay scheme shifts (almost) all incentives into the final period of the agency. Hence, the pay scheme uses incentive spillover while preserving complete information.[4]

The second result states that given a dual-purpose use of accounting information, FPE emerges as the principal's optimal choice in a more extensive set of parameter constellations than in the setting with a single-purpose use. Surprisingly, IPE can be optimal even if accounting information serves two purposes, control and production. Together, the first and second results underscore the importance of using outcome information beyond control purposes for the optimality of an interim performance evaluation.

[4] Incentive spillover refers to contractual settings where, e.g., an outcome-dependent payment in a later period provides effort incentives for earlier periods. Technically, that payment relaxes incentives constraints in earlier periods so that lower incentives suffice to establish incentive compatibility. If aggregate performance over several periods is rewarded and the agent does not get to know interim outcomes, the benefit of incentive spillover becomes larger. A bonus for maximum aggregate performance provides effort incentives even if low interim performance precludes achievement of maximum performance.

The research presented herein deals with performance evaluation frequency and intertemporal aggregation of information in an agency. It is most closely related to analytical research by Lizzeri et al. (2002); Arya et al. (2004); Nikias et al. (2005); Lukas (2010), and Chen and Chiu (2013). All authors studied the principal's choice between FPE and IPE in two-period settings and—except for Lizzeri et al. (2002)—employed an agency model with binary action choice and binary outcome distribution in each period. In these models, IPE not only entails a delay in access to information but also the aggregation of information. Arya et al. (2004) demonstrated a benefit of aggregation—which is essentially a benefit of delaying information as in Gigler and Hemmer (1998) and of a spillover of incentives—in a setting with stationary production technology and absent time preferences. Lizzeri et al. (2002) obtained a result similar to Arya et al. (2004) for continuous agent effort. Nikias et al. (2005); Lukas (2010), and Chen and Chiu (2013) further added effort-dependent interaction effects between periods to the picture. They found that IPE could be optimal even in dynamic settings, though their results are sensitive to task characteristics.[5] The underlying force that drives the results continues to be the benefit of aggregation, or, more precisely, the benefit of withholding performance information from the agent, as in Arya et al. (2004).

This paper differs from Lizzeri et al. (2002) and Arya et al. (2004) as it considers interdependent periods. Interdependency was also considered by Nikias et al. (2005); Lukas (2010), and Chen and Chiu (2013), but they investigated effort-dependent interaction effects. In their work, the agent's effort choice in the first period directly determined the probability of success in the second period. The model in this paper features outcome-dependent interaction effects as an innovation: Interdependence of periods is caused by period outcomes. Consequently, realized outcomes determine future success probabilities. The agent's effort has only an indirect effect as it influences the likelihood for low or high outcomes.

As a second innovation, I analyze a dual-purpose use of accounting information and its impact on the frequency of performance evaluations. While the literature mainly restricts attention to control problems, i.e., a single-purpose use of accounting information, only a limited number of studies simultaneously consider both a decision problem and a control problem (Arya et al., 1997; Schmitz, 2005; Feltham et al., 2006; Hofmann & Rothenberg, 2019). Yet, no study has investigated a dual-purpose use of accounting information concerning interim performance evaluations to the best of my knowledge.

In sum, this paper contributes to the extant literature in two ways. First, it analyzes the benefit of an interim performance evaluation in a general dynamic model with the novel effect of outcome-dependent interaction between periods. Second, it advances knowledge related to the single- versus dual-purpose use of accounting information concerning performance evaluation frequency.

[5] If the agent expends effort only once at the beginning of the agency, the principal prefers more frequent evaluations (Kim, 2005) More evaluations translate into more random draws from a normally distributed output measure in that model. More evaluations allow for variance reductions, which decrease the agent's risk premium.

The remainder of this paper is structured as follows. Section 2 introduces the model, and the benchmark analysis follows in Sect. 3. Section 4 discusses the interaction effect and its implication for the optimal performance evaluation frequency. The section includes two subsections for the analysis of unconditional effort implementation (Sect. 4.1) and conditional effort implementation (Sect. 4.2). The final section summarizes and concludes this study.

2 The model

Herein, I explicate a dynamic principal-agent relationship that lasts for two periods. A principal (he) hires an agent (she) to perform the same task in each period t, $t = 1, 2$. The agent's unobservable productive effort is assumed to be binary, $e_t \in \{0, 1\}$, at costs $C(e_t) = ce_t$, $c > 0$. The verifiable economic outcome x_t has a binary distribution. Outcome distributions are common knowledge, and the principal and agent know these distributions before they sign the contract.

The first-period outcome x_1 can be high, H, or low, L, with $H > L$. In the second period, the outcome $x_2(x_1)$ can again be either high, $H(x_1)$, or low, $L(x_1)$, with $H(x_1) > L(x_1)$ for $x_1 = L, H$. The second-period outcome may be contingent on the first-period outcome. For example, the effects of a growing or shrinking market share in the first period may materialize as comparably higher or lower outcomes in the second period. Differences in gross outcomes are needed to analyze conditional effort schedules in Sect. 4.2, but differences per se do not drive the results.[6] Low outcomes are normalized so that $L = L(H) = L(L) = 0$.

Agent effort influences the probability distribution of outcomes in the following way:

$$P(x_1 = H) = p_{e_1}, \quad 0 < p_0 < p_1 < 1 \tag{1}$$

$$P(x_2 = H \mid x_1 = H) = g_{e_2}, \quad 0 < g_0 < g_1 < 1 \tag{2}$$

$$P(x_2 = H \mid x_1 = L) = b_{e_2}, \quad 0 < b_0 < b_1 < 1 \tag{3}$$

Higher effort increases the probability of a high outcome in any given period. Periods are interrelated. The interrelation results from the first-period outcome and is evident in (2) and (3).[7] Given that the assumptions in (1)–(3) are very general, many different cases or scenarios are possible. For (i), $b_1 \le p_1 < g_1$, chances to succeed in the second period are higher if the first-period outcome was high ("good"), $g_1 > p_1$, and the chances decrease following a low ("bad") outcome in the first period,

[6] Note that no ranking of gross outcomes H, $H(L)$, and $H(H)$ is imposed.

[7] Given that first-period outcome in turn depends on agent effort, the ex-ante probability (before the first period) of a high outcome in the second period depends on first-period effort, i.e., $P(x_2 = H \mid e_1, e_2) = p_{e_1} g_{e_2} + (1 - p_{e_1}) b_{e_2}$. As long as an effort incentive problem in the first period exists, this effect cannot be avoided. However, before the second period, the ex-ante probability of a high outcome in the second period is independent of prior effort choices as (2) and (3) show.

$b_1 < p_1$. Therefore, (i) represents a positive interaction effect. Examples may be a bandwagon effect or the effect of an increased market share that results from a high outcome in the first period. For (ii), $b_1 \geq p_1 > g_1$, second-period success becomes less likely with a high outcome in the first period. Thus, (ii) represents a negative interaction effect. For (iii), $p_1 < b_1 < g_1$, there is a positive trend in the sense that a high outcome in the second period is in general more likely than in the first period (in a growing market). For (iv), a negative trend with $p_1 > b_1 > g_1$ would be possible as well. The relations could also mirror the success/failure of project work conditional on the interim project outcome.[8] Note that the relations in (i)–(iv) are established for high effort in both periods. Therefore, no restriction is imposed on the level of informativeness, measured by the likelihood of outcomes in both periods.[9] I assume $b_1 + g_1 > 1$ implying the agent has, on average, at least a fair chance to succeed in the second period 2. The assumption is needed as a sufficient condition to prove Lemma 1.

To establish an incentive problem, the principal may want to induce high effort in every period. This setting is labeled unconditional effort implementation, and performance information serves the control purpose only. In contrast, the principal may want to induce high effort in the first period but an effort contingent on a specific first-period outcome in the second period. The label for this setting is conditional effort implementation, and performance information serves productive purposes and control. Throughout the paper I assume that a high first-period outcome $x_1 = H$ is sufficiently valuable so that the principal always finds it optimal to induce high effort in the first period.

Owing to the unobservability of the agent's effort, the principal offers outcome-contingent compensation to motivate the former. The agent is eligible for payment s^{ij} provided that the outcome sequence $(x_1 = i, x_2(i) = j(i))$, $i, j \in \{L, H\}$, is achieved. The corresponding probabilities $P(x_1 = i, x_2 = j) = P(x_1 = i) \cdot P(x_2 = j \mid x_1 = i)$ contingent on the agent's effort follow directly from (1) to (3).

Both parties are assumed to be risk-neutral and interested in maximizing their expected payoffs. Contractual frictions result from the agent's limited liability. It requires that all payments to the agent are non-negative, $s^{ij} \geq 0, i, j = L, H$. Without this assumption, the model would be devoid of any tension, and the first-best contract becomes feasible. Furthermore, the agent's utility from compensation and effort is separable so that $U(s^{ij}, e_1, e_2) = s^{ij} - C(e_1) - C(e_2)$. To concentrate on incentive effects of performance evaluation frequency, I assume zero discounting and no time preference so that timing of payments leaves utility unaffected.

The principal may choose between two different evaluation regimes.[10] The first is FPE, where interim performance after the first period is measured so that the contract specifies four payments, one for each outcome sequence. The second is IPE,

[8] The list of interaction effects is not exhaustive, and a wide variety of cases can be contrived.

[9] For example, the likelihood ratio for the high outcome in the first period equals $LR(x_1 = H) = \frac{p_1 - p_0}{p_1}$ so that irrespective of whether p_1 is higher or lower than g_1 and b_1, $LR(x_1 = H)$ varies between 0 (if $p_0 \to p_1$) and 1 (if $p_0 \to 0$). Thus, irrespective of the assumed scenario, the informativeness of x_1 varies between pure noise and perfect information.

[10] The labels are adopted from Arya et al. (2004).

where no interim performance is measured but total performance at the end of the second period. The contract specifies three payments, one for each aggregate output level. Thus, switching from FPE to IPE generates two distinct effects: information delay and aggregation. To provide intuition, one can think of the performance evaluation system as one determining whether the agent's performance in the first (second) period has been a "success," i.e., above a minimum or target level of performance, which is set to $x_1 = L$ in the first-period and $x_2 = L(x_1)$ in the second period. Alternatively, the agent's exact contribution to firm value may not be verifiable, but the evaluation system reliably determines whether it exceeds pre-specified thresholds. Then, compensation depends either on the sequence of successes (FPE) or the aggregate number of successes (IPE).[11] In what follows, a high outcome in any period is synonymous with a success in that period for performance evaluation purposes.

To formalize the principal's program for FPE, let the agent's expected utility when selecting effort levels e_1 in the first period, and $\{e_2(H), e_2(L)\}$ in the second period be denoted:

$$E(S_{e_1,e_2(H),e_2(L)}) = \sum_i \sum_j P(x_1 = i, x_2 = j | e_1, e_2(H), e_2(L)) \cdot s^{ij} - c \cdot [e_1 + p_{e_1} e_2(H) + (1 - p_{e_1}) e_2(L)].$$

The agent's expected utility in IPE is denoted:

$$E(S_{[e_1,e_2]}) = \sum_i \sum_j P(x_1 = i, x_2 = j | e_1, e_2) \cdot s_{i+j} - c \cdot (e_1 + e_2).$$

Notice the slight modification in the compensation function under IPE such that $(i + j)$ refers to aggregate output (number of successes) resulting from outcome $x_1 = i$ in the first period and outcome $x_2 = j(i)$ in the second period, $i, j = L, H$, and s_{i+j} denotes the corresponding payment.[12] In IPE, the agent chooses her second-period action without knowing the first-period outcome so that $e_2(H) = e_2(L)$ holds. Stated differently, e_2 cannot be conditioned on x_1 as in FPE.

The analysis of conditional production schedules requires the specification of the principal's expected gross profit from the agency. It amounts to:

$$E[GP(e_1, e_2(H), e_2(L))] = p_{e_1} \cdot H + p_{e_1} g_{e_2(H)} \cdot H(H) + (1 - p_{e_1}) b_{e_2(L)} \cdot H(L). \quad (4)$$

The optimal evaluation regime is the one that maximizes the expected net profit for the principal, i.e., expected gross profit less expected compensation. Let $(e_1^*; e_2^*(H), e_2^*(L))$ denote the principal's desired production schedule given FPE. Note that the principal cannot implement a conditional production schedule (as a

[11] If differing gross outcomes would allow the principal to contract on four different aggregate outcome levels in IPE–which is equivalent to contracting on the sequence of outcomes, so that, essentially, information is only delayed but not aggregated–results would not change qualitatively. Only the thresholds for transition between the optimality of IPE and FPE change.

[12] To ease the distinction between payments under each regime, FPE-payments have a superscript and IPE-payments a subscript.

pure strategy) under IPE because no interim performance is measured. Therefore, I assume the principal implements high effort in each period under IPE. The principal's programs can now be specified.

Frequent performance evaluation (FPE)

$$E[GP(e_1^* = 1; e_2^*(H), e_2^*(L))] - \min_{s^{ij} \in \{L,H\}} \sum_{i,j} P(x_1 = i, x_2 = j | e_1^* = 1, e_2^*(H), e_2^*(L)) s^{ij}, \tag{5}$$

subject to

$$E(S_{e_1^*=1, e_2^*(H), e_2^*(L)}) \geq 0 \tag{6}$$

$$E(S_{e_1^*=1, e_2^*(H), e_2^*(L)}) \geq E(S_{e_1, e_2(H), e_2(L)}) \; \forall e_1, e_2(H), e_2(L) \tag{7}$$

$$s^{ij} \geq 0. \tag{8}$$

The principal must ensure the agent's participation given a reservation wage of $\underline{s} = 0$ (Constraint (6)). Condition (7) denotes incentive compatibility constraints to make the agent prefer the principal's desired production schedule $(e_1^* = 1; e_2^*(H), e_2^*(L))$ to all other effort combinations. Equation (8) denotes the liability constraint, which requires that payments to the agent must be non-negative.

Infrequent performance evaluation (IPE)

$$E[GP(e_1^* = 1; e_2^* = 1)] - \min_{s_{i+j}} \sum_{i,j \in \{L,H\}} P(x_1 = i, x_2 = j | e_1^* = e_2^* = 1) s_{i+j} \tag{9}$$

subject to

$$E(S_{[1,1]}) \geq 0 \tag{10}$$

$$E(S_{[1,1]}) \geq E(S_{[0,1]}) \tag{11}$$

$$E(S_{[1,1]}) \geq E(S_{[0,0]}) \tag{12}$$

$$E(S_{[1,1]}) \geq E(S_{[1,0]}) \tag{13}$$

$$s_{i+j} \geq 0. \tag{14}$$

Constraints imposed on the principal's compensation contract comprise the agent's participation constraint, (10), and the incentive constraints so that high effort twice is preferred to all other effort combinations, (11)–(13). The liability constraint (14) restricts the set of payments s_{i+j} to non-negative payments.

The timeline in the agency is as follows:

- The principal offers a two-period contract that specifies the performance evaluation regime and payments to the agent.
- Then the agent decides whether to accept or decline the contract offer. Declining the offer ends the agency.
- After contract acceptance, the base salary s^{LL} (s_{2L}) is paid. Then, the agent selects the first-period effort.
- In FPE, the interim performance evaluation is carried out, and payment of the first-period bonus ($s^{HL} - s^{LL}$) occurs if $x_1 = H$.
- The agent selects second-period effort with knowledge of interim performance (FPE) or without it (IPE).
- After the second-period outcome is realized, (remaining) payments are made according to the contract.

3 Benchmark: independent period outcomes

To proceed with the analysis of interdependent period outcomes, it is useful to recapitulate the benchmark of independent periods. Let $p_1 = b_1 = g_1$ and $p_0 = b_0 = g_0$ so that periods are independent and the production technology is stationary. The principal's problems in Eqs. (5) and (9) simplify accordingly. It is straightforward to solve the problems. Given FPE, all three incentive constraints bind, implying $E(S_{1,1(x_1)}) = E(S_{0,1(x_1)}) = E(S_{1,0(x_1)}) = E(S_{0,0(x_1)})$, the liability constraint is binding for s^{LL} so that the participation constraint is slack, and the agent earns a rent. Expected compensation (EC) amounts to $EC_{FPE}(1, 1(x_1)) = 2c\frac{p_1}{p_1 - p_0}$. Given IPE, only incentive constraint (12) binds, $E(S_{[1,1]}) = E(S_{[0,0]})$. The liability constraint is binding for s_{2L} so that the participation constraint is slack. The expected wage bill for the principal is $EC_{IPE}([1, 1]) = 2c\frac{p_1^2}{p_1^2 - p_0^2}$. The relation $EC_{FPE}(1, 1(x_1)) > EC_{IPE}([1, 1])$ follows, implying the agent's rent is higher under FPE, and the principal strictly prefers IPE. The principal benefits from suppressing information or later access to information because it curbs the agent's opportunism. Incentive constraints for the second period do not condition on the first-period outcome. Notably, the result holds regardless of how informative single-period outcomes are.

Independent period outcomes entail no loss of information under IPE because the outcome sequence $\{H, L(H)\}$ is as informative as $\{L, H(L)\}$. The outcome distributions in both periods are identical and independent so that the total number of high outcomes is a sufficient statistic for the sequence of outcomes. IPE entails the benefit of delayed information, and the principal prefers IPE over FPE. When the assumption of independent and identically distributed period outcomes is relaxed, the principal faces a different tradeoff before possibly deciding in favor of IPE: the benefit of delayed information has to be traded-off against the loss of information because outcome sequences $\{H, L(H)\}$ and $\{L, H(L)\}$ differ with regard to information content. Technically, moving from independent to interdependent period outcomes could change binding incentive constraints so that IPE or FPE can represent the principal's optimal decision.

4 Interdependent period outcomes

In this section, I analyze interdependent period outcomes in two different setups. The first setup assumes optimality of inducing high effort in the second period, regardless of the first-period outcome. In the second setup, optimality of high effort in the second period is contingent on a specific first-period outcome.[13] It raises the question what are the conditions such that high effort in the second period is (not) contingent on the first-period outcome?

High effort in the second period contingent on $x_1 = L$, $e_2(L) = 1$, is optimal as long as the following holds valid:

$$(1 - p_1)(b_1 - b_0) \cdot H(L) \geq EC_{FPE}(e_1 = e_2(H) = e_2(L) = 1) - EC_{FPE}(e_1 = e_2(H) = 1, e_2(L) = 0). \tag{15}$$

That is, the additional expected gross profit from providing $e_2(L) = 1$ instead of $e_2(L) = 0$, $(1 - p_1)(b_1 - b_0) \cdot H(L)$, equals or exceeds the associated increase in expected compensation cost if $e_2(L) = 1$ is to be implemented instead of $e_2(L) = 0$. Note that the left-hand side of (15) also represents the expected gross profit difference between IPE and FPE in the conditional effort setting, as the former implements $(e_1 = e_2(H) = e_2(L) = 1)$ and the latter $(e_1 = e_2(H) = 1, e_2(L) = 0)$.

High effort in the second period contingent on $x_1 = H$, $e_2(H) = 1$, is optimal as long as the following holds valid:

$$p_1(g_1 - g_0) \cdot H(H) \geq EC_{FPE}(e_1 = e_2(H) = e_2(L) = 1) - EC_{FPE}(e_1 = e_2(H) = 0, e_2(L) = 1). \tag{16}$$

Again, if the additional expected gross profit at least offsets the additional expected compensation costs, effort schedule $\{e_1 = 1; e_2(H) = 1, e_2(L) = 1\}$ is more profitable to the principal than $\{e_1 = 1; e_2(H) = 0, e_2(L) = 1\}$.

Conditions (15) and (16) simplify to $H(L) \geq (s^{LH} - s^{LL})$ and $H(H) \geq (s^{HH} - s^{HL})$. As intuition would suggest, high effort in the second period turns out to be profitable when the generated gross profit equals or exceeds the payment necessary to induce high effort. The simplified conditions demonstrate that, conditional on high effort in the first period, optimality of $e_2(H) = 1$ does not depend on $e_2(L) = 1$ being optimal, and vice versa.

4.1 Unconditional implementation of high effort in period 2

Assume conditions (15) and (16) hold so that the principal finds it optimal to induce high effort in the second period irrespective of the first-period outcome.

Optimal payments Before determining the optimal performance evaluation regime, the principal's program for each regime is solved. Starting with FPE, the principal's program obtains by setting $e_1^* = e_2^*(H) = e_2^*(L) = 1$ in Eq. (5). Derivations of optimal payments and explicit statements of constraints and payments are given in the appendix. Table 1 presents the solution to this program. It lists binding

[13] I assume that the outcome in the first period always generates enough value so that the principal finds it optimal to induce $e_1 = 1$.

incentive constraints —where numbers refer to constraints listed in the appendix— and nonzero payments.

In Table 1, case (ii) is noteworthy. Here, incentive constraint (23), $E(S_{1,1}) \geq E(S_{1,0})$, singly binds. The condition for that case to occur is[14]:

$$\frac{g_1}{g_1 - g_0} \geq \left(\frac{1}{p_1 - p_0} + \frac{b_1}{b_1 - b_0} \right) \Leftrightarrow g_0 \geq \frac{(b_1 - b_0) + b_0(p_1 - p_0)}{(b_1 - b_0) + b_1(p_1 - p_0)} \equiv g_{0(3IC-FPE)} \tag{17}$$

The threshold $g_{0(3IC-FPE)}$ marks the transition from three binding incentive constraints to only one binding incentive constraint under FPE. Condition (17) relates the information content of different outcomes to each other. As evident from case (ii) in Table 1, if condition (17) holds, $s^{HL} = 0$, which implies no incentives in the first period are needed to induce high effort in that period. When does this happen? Whenever $x_2(x_1) = H(H)$ is not very informative (represented by a high value of the inverse of the likelihood on the left-hand side of (17)), all effort incentives can be placed on second-period outcomes in FPE. One intuitive interpretation could be project work where project initiation (effort in the first period) matters to a large extent, but project completion (effort in the second period) has limited impact on eventual success. Then, high effort in the second period does not lead to a substantially higher probability of succeeding than low effort does because the success probability is already high given low effort. In that case, rewarding only the project's eventual success makes sense. It ensures the proper effort choice by the agent in the project initiation phase and in its final phase (second period).

The optimal nonzero payments in IPE contingent on the relevant incentive constraint(s) for the program (9) are presented in Table 2.

As evident from Table 2, the optimal contract may not restrict rewards to the most informative total outcome ("top performance") as in the benchmark case. Thus, the solution is different from the usually optimal contract form in models with risk neutrality and limited liability where only top performance is rewarded (Demougin & Fluet, 1998; Innes, 1990; Nikias et al., 2005). The reason is the stochastic interaction of outcomes. Although the effort choice under IPE may be perceived as a single-period problem (because no interim outcome is observed before the agent selects second-period effort), the "dynamics" in the outcome determination cannot be neglected. That means, even though effort strategies $\{e_1 = 1, e_2 = 0\}$ and $\{e_1 = 0, e_2 = 1\}$ lead to the same total effort (costs), they represent different effort strategies with respect to incentive compatibility requirements. When the information contents of outcomes differ, so will the likelihood ratios. Furthermore, if top performance is no longer associated with the highest likelihood ratio, two nonzero payments become optimal. It mirrors the fact that

[14] Condition (17) never holds if either (a) single-period problems are identical as in the benchmark setting, $p_i = g_i = b_i, i = 0, 1$, or (b) if the interaction effect is modeled less generally such that $g_{e_2} = \gamma p_{e_2}$ and $b_{e_2} = \beta p_{e_2}, 0 < \beta, \gamma < \frac{1}{p_{e_2}}$. With (a) or (b), constraints (23), (24), and (25) always bind jointly in FPE, and only top performance is rewarded in IPE.

Table 1 Binding incentive constraints and nonzero payments given FPE

Case	Binding constraint(s)	Nonzero payments
(i)	(23), (24), (25)	s^{HL}, s^{LH}, s^{HH}
(ii)	(23)	s^{LH}, s^{HH}

two incentive constraints are jointly binding in IPE instead of only one. Table 2 summarizes these three cases.

Comparison of performance evaluation regimes In both evaluation regimes, the principal induces high effort in each period regardless of the first-period outcome. Hence, the expected gross profit—determined according to (4)—is the same for both regimes. Then the optimal evaluation regime is the one that features the lowest expected compensation costs to the principal. Six distributional parameters influence expected compensation costs. It would be a cumbersome endeavor to incorporate all of them in an analysis of changing interdependence between periods. For this reason, only parameter g_0 is considered, i.e., optimality conditions for either evaluation regime are formulated with respect to this parameter. Varying g_0 allows for variation in the informativeness of $x_2 = H(H)$ compared to x_1 and $x_2 = H(L)$. Thresholds for g_0 depend on the other parameters, and all parameters are considered when interpreting the results. Proposition 1 provides clarification on which performance evaluation regime is optimal.

Proposition 1 *If actions to be induced are* $\{e_1 = 1, e_2 = 1\}$, *a lower threshold* $\underline{g_0}$ *and an upper threshold* $\overline{g_0}$ *exist such that the principal prefers FPE if* $\underline{g_0} < g_0 < \overline{g_0}$; *in all other cases*, *the principal prefers IPE.*

Proof All proofs are presented in the appendix. □

Corollary 1 $\frac{g_1}{g_1-g_0} < \left(\frac{p_1}{p_1-p_0} + \frac{b_1}{b_1-b_0}\right)$ *is a sufficient condition such that IPE ≻ FPE.*

Corollary 2 $\frac{g_1}{g_1-g_0} > \left(\frac{p_1}{p_1-p_0} + \frac{b_1}{b_1-b_0}\right)$ *is a necessary condition such that FPE ≻ IPE.*

Corollary 1 provides a sufficient condition so that the principal always prefers IPE to FPE. This condition— which creates a relation between (the inverses of) the likelihood ratios in the two periods—helps define interdependence between periods. If single-period problems are identical (recall the benchmark case), so are the likelihoods, and there is no interdependence. In this case, the condition in corollary 1 is always satisfied and IPE is optimal because aggregation is costless (Nikias et al. 2005, p. 63), and the benefit of information delay takes effect. Here, the delay fully accounts for the difference in expected compensation costs between FPE and IPE. When single-period problems differ, an interaction arises, and adequately allocating incentives across periods may become a necessity.

Table 2 Binding incentive constraints and nonzero payments given IPE

Case	Binding constraint(s)	Nonzero payments
(i)	(11)	s_{2H}
(ii)	(12)	s_{2H}
(iii)	(13)	s_{2H}
(iv)	(11), (13)	s_{H+L}, s_{2H}
(v)	(11), (12)	s_{H+L}, s_{2H}
(vi)	(12), (13)	s_{H+L}, s_{2H}

Intuition and the two conditions in corollaries 1 and 2 might suggest that parameters fall into two subsets where either IPE or FPE is optimal. Yet, as evident in proposition 1, the set is divided into *three* subsets.[15] In general, FPE is optimal when the costs of information aggregation are high and the benefit of incentive spillover in IPE is low. Correspondingly, IPE is optimal in two cases. First, whenever the highest total outcome is sufficiently informative about the agent's effort choices. Then, the costs of information aggregation are low and knowing the sequence of outcomes does not provide more information than the total outcome. Second, IPE is optimal when the highest total outcome approaches non-informativeness about the agent's (second-period) effort choice. Then, incentive spillover under IPE represents the key to its optimality.

Figure 1 visualizes proposition 1. It keeps parameters constant except for p_0 and g_0; varying these two parameters allows for variation in the likelihood ratios $LR(H)$ and $LR(H|H)$, i.e., in the informativeness of outcomes $x_1 = H$ and $x_2 = H(H)$.

The large white area represents cases where $x_2 = H(H)$ is informative so that costs of aggregation are low. Here, the contract given IPE contains only one nonzero payment, the payment s_{2H} for top performance. In equilibrium, medium performance is not rewarded ($s_{H+L} = 0$) because the principal does not lose much information from being unable to distinguish outcome sequence $\{H, L(H)\}$ from $\{L, H(L)\}$. Given an unconditional production schedule, optimal actions do not condition on previous outcomes so that delaying information does not lead to costs for the principal. However, doing so creates a benefit because it relaxes incentive constraints. Thus, costs of aggregation fall short of the benefit of denying the agent access to interim performance information, and IPE is optimal.

For parameter settings covered by the small white area, costs of aggregation under IPE are relatively high because the maximum output—or, precisely, $x_2 = H(H)$ —ceases to be a reliable indicator for high effort in both periods. The principal reacts and rewards medium performance in IPE in addition to top performance, $s_{H+L}, s_{2H} > 0$. Yet, the costs of providing incentives in period 2 under FPE, given the interim outcome $x_1 = H$, are also high. Stated differently, the incentive-compatible bonus ($s^{HH} - s^{HL}$) under FPE is high. IPE allows for an incentive spillover, and

[15] It contrasts with the model of effort-dependent interaction effects in Lukas (2010) where— conditional on the informativeness of the first-period outcome—the set is divided in only two subsets.

according to proposition 1, this benefit looms larger than the costs of aggregation so that IPE is again optimal. Only if both $x_1 = H$ and $x_2 = H(L)$ are informative (so that the condition in corollary 2 holds) and sufficient informativeness of $x_2 = H(H)$ due to $g_0 < \overline{g_0}$ goes along with it, carrying out the interim evaluation is optimal (see the gray area in Fig. 1). In this case, the pay scheme in FPE places (almost) all incentives on second-period outcomes.[16]

The gray area in Fig. 1 comprises parameter settings where condition (17) holds such that constraint (23) singly binds, implying $(s^{HL} - s^{LL}) = 0$ is optimal in the first period. In addition, it includes the setting where all three incentive constraints bind in FPE, but the first-period bonus $(s^{HL} - s^{LL})$ is close to zero. Interestingly, even though the principal carries out an interim evaluation, no bonus may be needed in the first period. It implies the pay scheme in FPE makes use of an incentive spillover so that the benefit of doing so under IPE necessarily decreases relative to FPE. Costs of aggregation paired with the reduced benefit of incentive spillover then account for optimality of FPE.

As a rule of thumb, one could summarize the result in proposition 1 as follows: If maximum output is sufficiently informative, IPE is optimal; otherwise, FPE is optimal contingent on maximum output not becoming pure noise. Finally, to illustrate the general nature of the result of proposition 1, the different settings mentioned in the model description can be taken up. For all these settings, the result of proposition 1 holds. The relative informativeness of the first-period outcome and the conditional second-period outcomes represent the driver of the result. Absolute levels of distributional parameters that characterize the different settings are not decisive.

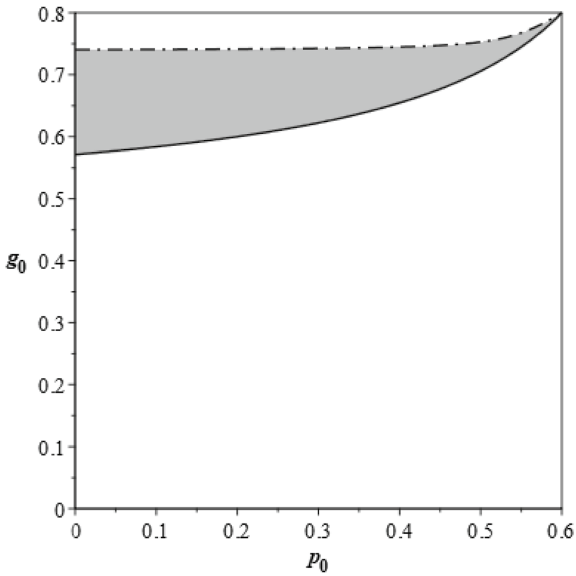
4.2 Conditional implementation of high effort in period 2

The model in the previous section features an exogenous optimal course of action: the principal induces high effort irrespective of the first-period outcome. Yet, flexible planning characterizes business practice. It implies an endogenous path of optimal actions and decisions. Different production plans or (strategic) decisions may become optimal, depending on observed outcomes, competitors' actions, or changes in the environment. Therefore, this section considers the case wherein the optimal effort choice depends on previous outcomes, specifically, on the interim evaluation.[17] The general problem is implementing a conditional effort schedule in contrast to the unconditional effort schedule considered in the previous section. When implementing a conditional effort schedule, outcome information serves two purposes: a control purpose using information retrospectively, and a productive purpose using information prospectively. Conditions are derived under which an intertemporal aggregation of dual-purpose accounting information is optimal.

[16] This is similar to Ohlendorf and Schmitz (2012). In their model, the principal makes the project continuation decision after period 1 and the high expected rent in period 2 motivates the agent to expend effort in period 1.

[17] It may be a matter of taste whether the label endogenous effort choice would be justified. Path dependence of optimal effort argues for endogenous effort choice, but the ex-ante determination of path-dependent effort choices represents an argument against it.

Fig. 1 Unconditional effort implementation and optimal evaluation regime



Given the assumed binary outcome distribution, conditional implementation can manifest itself in two settings: inducing high effort in the second period (i) contingent on a high outcome in the first period, or (ii) contingent on a low outcome in the first period 1. To provide intuition for (i), for example, consider a situation where high demand in the first period signals that extra sales effort may pay off in the next period. In contrast, observing low demand in the first period indicates low-profit opportunities in the second period. Consequently, it is not worthwhile to incentivize the agent to expend high effort to attract additional customers in the second period. An example for setting (ii) would be a specific demand potential realizable within two consecutive periods. A low outcome in the first period could signal a potentially high return to sales effort in the next period. A setting applicable for scenarios (i) and (ii) would be an agent working on a project. Here, the first-period outcome—be it $x_1 = H$ or $x_1 = L$—could provide a reliable indicator for eventual project returns. Generally, scenarios (i) and (ii) can be characterized as follows: While the agent may see ambiguity in the first-period outcome, the management has oversight and signals through the incentive system when a high effort is worthwhile.[18] The argument becomes even more relevant if the contribution to firm value is non-verifiable or non-observable for the agent.

To ensure the appropriate conditional effort choice by the agent in the second period, observation of the interim outcome is essential. While FPE meets this requirement, IPE does not. Consequently, in the latter evaluation regime, the high action may be selected when the low action is optimal or vice versa. Therefore,

[18] A specific example for ambiguity would be an inventory increase in the first period that may be a good sign because there is an anticipated demand increase, or it may be a bad sign because of product obsolescence.

one could say that IPE shows “effort implementation with error.” I assume that IPE continues to implement high effort in each period, and I refrain from enforcing a mixed strategy that leads to the same expected effort as in the conditional production schedule in FPE.[19] Doing so requires accounting for different gross outcomes under IPE and FPE. An intuitive reason for restricting attention to pure strategies could be the implausibility of mixed strategies for practical purposes. Employees (usually) do not toss a coin to decide their course of action.[20]

Before proceeding with the analysis, it may be helpful to return briefly to the benchmark case. Expected compensation under IPE amount to $EC_{IPE} = 2c\frac{p_1^2}{p_1^2-p_0^2}$, and high effort in each period is implemented. Given conditional effort under FPE, expected compensation is $EC_{FPE}(1, 1(H), 0(L)) = c(1+p_1)\frac{p_1}{p_1-p_0}$ or $EC_{FPE}(1, 0(H), 1(L)) = c(1+(1-p_1))\frac{p_1}{p_1-p_0}$. One can easily verify that $EC_{IPE} > EC_{FPE}(1, 1(H), 0(L)), EC_{FPE}(1, 0(H), 1(L))$ for p_0 sufficiently small, and the inverse relation holds if p_0 becomes sufficiently large. Moreover, since all expected compensation terms are strictly increasing in p_0, there are unique thresholds of p_0 where $EC_{IPE} = EC_{FPE}(1, 1(H), 0(L))$ and $EC_{IPE} = EC_{FPE}(1, 0(H), 1(L))$ holds, respectively. Thresholds decrease when the additional expected gross output under IPE rises above zero relative to FPE, because the additional gross output acts like a reduction in expected compensation for IPE. In general, a high informativeness of outcomes makes FPE optimal - and a low informativeness IPE. In the static benchmark setting, variation in informativeness affects every outcome $\{x_1, x_2(H), x_2(L)\}$ in the same way. Adding interdependency between period outcomes to the picture moves the model closer to practice. It allows for a more detailed investigation of the association between informativeness of individual outcomes and the optimal choice of IPE or FPE.

4.2.1 Conditional effort $e_2(H) = 1, e_2(L) = 0$ optimal in the second period

Under FPE, let the production schedule $e_2(H) = 1, e_2(L) = 0$ be optimal in the second period. Optimality of the conditional schedule ensues as long as (15) does not hold, but (16) holds.

In principle, FPE and IPE could be compared for any $H(L)$ level such that (15) does not hold. In my analysis, I focus on two boundary cases represented by $\underline{H(L)} = 0 \equiv H(L)$ as the (natural) lower bound and $\overline{H(L)}$ as the upper bound. At $\overline{H(L)}$, condition (15) holds as an equality, and the principal would be indifferent between the two production schedules $(e_1 = e_2(H) = e_2(L) = 1)$ and $(e_1 = e_2(H) = 1, e_2(L) = 0)$ given FPE. Note that although only two boundary cases are analyzed, the other cases are in between these two. Each will feature two threshold levels of g_0 as in proposition 2(ii), so that no qualitative difference between results for each case occurs.

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[19] See Sect. 4.2.3 for a discussion of using mixed strategies under IPE and a numerical example.

[20] Moreover, I do not consider implementing production schedules $e_1 = 1, e_2 = 0$ or $e_1 = 0, e_2 = 1$ under IPE. Assuming a sufficiently high productive outcome in period 2 or 1, respectively, would render the production schedules less profitable than the conditional production schedule under FPE.

Frequent performance evaluation (FPE) The principal's program obtains by setting $e_1^* = e_2^*(H) = 1, e_2^*(L) = 0$ in (5). The program is explicitly stated and solved in Appendix A.5. Optimal nonzero payments for FPE are enumerated in Table 3.

The condition for (45), $E(S_{1;1(H),0(L)}) \geq E(S_{1;0(H),0(L)})$, to be the only binding incentive constraint in FPE is:

$$\frac{g_1}{g_1 - g_0} \geq \frac{1}{(p_1 - p_0)} + 1. \tag{18}$$

It is similar to condition (17) for unconditional effort implementation.[21]

Infrequent performance evaluation (IPE) The principal's program (9) remains unchanged. Therefore, payments listed in Table 2 remain optimal.

Comparison of performance evaluation regimes Owing to the differences in production schedules, the optimal evaluation regime does not follow from a comparison of expected compensation costs. The gross profit generated under each regime needs to be part of the comparison. As noted before, the difference in expected gross profit between IPE and FPE amounts to $E[GP_{IPE} - GP_{FPE}] = (1 - p_1)(b_1 - b_0)H(L)$. It equals the additional gross profit generated in the second period following a low outcome in the first period conditional on high effort in IPE (b_1) instead of low effort in FPE (b_0). Hence, IPE is the optimal evaluation regime if $(E[GP_{IPE}] - EC_{IPE}) > (E[GP_{FPE}] - EC_{FPE})$, which holds if:

$$EC_{IPE} - (1 - p_1)(b_1 - b_0)H(L) < EC_{FPE}(e_1 = e_2(H) = 1, e_2(L) = 0). \tag{19}$$

At $\overline{H(L)}$, (15) holds as equality:

$$(1 - p_1)(b_1 - b_0) \cdot \overline{H(L)} = EC_{FPE}(e_1 = e_2(H) = e_2(L) = 1) - EC_{FPE}(e_1 = e_2(H) = 1, e_2(L) = 0),$$

so that (19) obtains as:

$$EC_{IPE} - (1 - p_1)(b_1 - b_0)\overline{H(L)} < EC_{FPE}(e_1 = e_2(H) = 1, e_2(L) = 0), \tag{20}$$

$$EC_{IPE} < EC_{FPE}(e_1 = e_2(H) = 1, e_2(L) = 1). \tag{21}$$

Condition (21) implies the following: With $x_2 = H(L)$ increasing from zero to its maximum value, the comparison between IPE and the conditional effort schedule under FPE in (19) converges to the comparison of expected compensation costs given unconditional effort schedules under both IPE and FPE. The latter comparison is the subject matter of proposition 1 and will be used in this section's analysis.

Proposition 2 clarifies which performance evaluation regime is optimal.

Proposition 2 *Let the optimal production schedule in FPE be* $\{e_1 = 1, e_2(H) = 1, e_2(L) = 0\}$.

[21] Since $e_2(L) = 0$ is optimal, the likelihood ratio $(b_1 - b_0)/b_1$ for $x_2(x_1) = H(L)$ does not play a role and it enters (18) with its maximum of 1.

Table 3 Conditional effort—binding constraints and optimal nonzero payments given FPE

Case	Binding constraint(s)	Nonzero payments
(i)	(45), (47), (48)	s^{HL}, s^{HH}
(ii)	(45)	s^{HH}

(i) *For* $\underline{H(L)}$, *a lower threshold* $\dot{g}_0$ *and an upper threshold* $\ddot{g}_0$ *exist such that the principal prefers FPE if* $\dot{g}_0 < g_0 < \ddot{g}_0$; *in all other cases, the principal prefers IPE.*

(ii) *For* $\overline{H(L)}$, *according to proposition* 1, *a lower threshold* $\underline{g_0}$ *and an upper threshold* $\overline{g_0}$ *exist such that the principal prefers FPE if* $\underline{g_0} < g_0 < \overline{g_0}$; *in all other cases, the principal prefers IPE.*

Intuitively, one might posit that conditional effort implementation invariably leads to optimality of FPE because the information required to condition the effort choice is only available in FPE. Proposition 2 proves intuition right—with exceptions. It asserts that actual parameter constellations determine the optimal performance evaluation regime, and the principal may prefer IPE. Figure 2 visualizes Proposition 2. For comparison purposes, parameters are identical to the ones chosen for Fig. 1.

The difference between panel (a) in Fig. 2 and the unconditional effort setting in section 4.1 is a reduction of expected effort costs under FPE due to the conditional effort schedule. Hence, the set of parameters where FPE is optimal must grow relative to the unconditional effort setting. IPE remains optimal, however, when the information content of the highest total performance is low (because either x_1 or $x_2 = H(H)$ show low informativeness). In this case, the benefit of incentive spillover under IPE is high. A peculiarity of this result should not be missed: A contingent effort schedule is optimal, but the principal optimally refrains from an interim evaluation. Even though IPE induces more effort than FPE (without generating extra output), it does so at lower costs.

As $H(L)$ increases above zero and eventually approaches $\overline{H(L)}$, a higher difference in expected gross profit between IPE and FPE ensues. It leads to a higher likelihood that IPE creates the highest surplus for the principal (since effort costs do not change). In contrast to panel (a), the larger white area in panel (b) of Fig. 2 exemplifies the higher likelihood. (Panel (b) is identical to Fig. 1, but having panels (a) and (b) next to each other eases direct comparison of results based on $\underline{H(L)}$ and $\overline{H(L)}$.) Here, the threshold levels for optimality of IPE or FPE from Proposition 1 apply. Therefore, for further intuition, I refer to Sect. 4.1.

On a more fundamental level, information delay and aggregation play a role in this conditional effort setting. Since IPE delays information availability, "too much" effort is implemented in this evaluation regime because high effort $e_2(x_1 = L) = 1$ is induced although $e_2(x_1 = L) = 0$ would be optimal with information available. Information aggregation under IPE still curbs agent opportunism, but it could lead to compensation for an outcome sequence, $\{x_1 = L, x_2 = H(L)\}$, which will not be rewarded under FPE. Hence, delaying information now has both a benefit and a cost, implying that information aggregation under IPE is more costly given the conditional production schedule. It provides an intuitive explanation of why FPE is now more likely to be optimal compared with unconditional effort implementation.

Proposition 2 can be related to the settings described in Sect. 2. Again, as for the case of unconditional effort implementation, the result holds for all settings, be it a bandwagon effort or a negative trend. Therefore, the finding generally holds that the principal may not find it beneficial to carry out an interim performance evaluation even if it is needed for the agent to pick the correct effort level.

4.2.2 Conditional effort $e_2(H) = 0, e_2(L) = 1$ optimal in the second period

Assume condition (15) holds, but (16) does not hold. Then, the production schedule $e_2(H) = 0, e_2(L) = 1$ is optimal in the second period under FPE. As in the previous section, I focus on two boundary cases concerning the second-period outcome $x_2 = H(H)$. A natural lower bound of $H(H)$ in (16) is $\underline{H}(H) = 0$. At the upper bound, $\overline{H}(H)$, condition (16) holds as equality.

Frequent performance evaluation (FPE) The principal's program is obtained by setting $e_1^* = 1, e_2^*(H) = 0, e_2^*(L) = 1$ in (5). Optimal nonzero payments for FPE are s^{HL}, s^{LH} and $s^{HH} = s^{HL}$ and constraints (61), (63) and (64) bind. (See Table 9 in A.7.)

Infrequent performance evaluation (IPE) The principal's program (9) remains unchanged. Therefore, payments listed in Table 2 remain optimal.

Comparison of performance evaluation regimes Differing production schedules between FPE and IPE require to compare the principal's net benefit under either control instead of compensation costs only. Again, IPE is optimal if condition $(E[GP_{IPE}] - EC_{IPE}) > (E[GP_{FPE}] - EC_{FPE})$ holds. Equivalently, $(EC_{IPE} - p_1(g_1 - g_0)H(H) < EC_{FPE}(e_1 = 1, e_2(H) = 0, e_2(L) = 1)$ must hold if the principal is to prefer IPE. Similar to the previous section, a limit case results if (16) holds as equality. At $\overline{H}(H)$, the comparison in (16) is equivalent to the comparison of expected compensation costs given unconditional effort schedules under both IPE and FPE. The latter comparison is the subject matter of proposition 1 and will be used again in this section's analysis.

Proposition 3 *Let the optimal production schedule in FPE be* $\{e_1 = 1, e_2(H) = 0, e_2(L) = 1\}$.

(i) *For* $\underline{H}(H)$, *a threshold* $\hat{g}_0$ *exists such that the principal prefers FPE if* $g_0 > \hat{g}_0$; *otherwise, the principal prefers IPE.*
(ii) *For* $\overline{H}(H)$, *according to proposition 1, a lower threshold* $\underline{g}_0$ *and an upper threshold* $\overline{g}_0$ *exist such that the principal prefers FPE if* $\underline{g}_0 < g_0 < \overline{g}_0$; *in all other cases, the principal prefers IPE.*

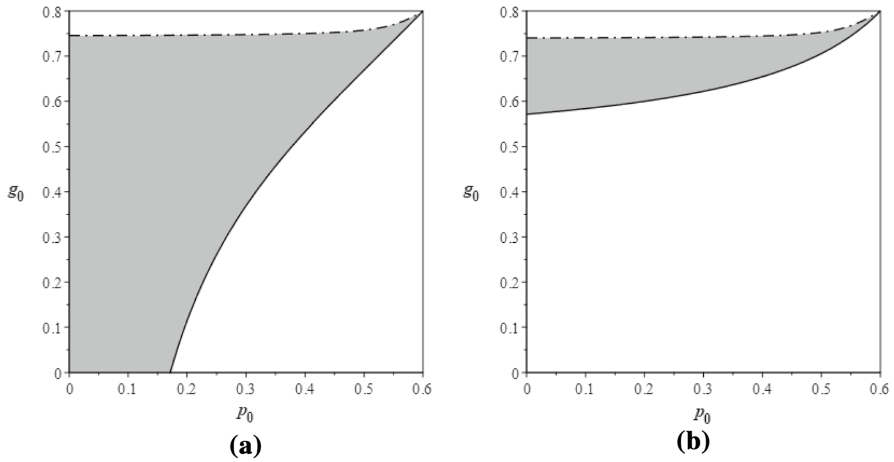

Fig. 2 Conditional effort $\{e_2(H) = 1, e_2(L) = 0\}$ and optimal evaluation regime

Figure 3 exemplifies results stated in Proposition 3 using the same parameters as before. Similar to the result in the previous section, a conditional production schedule could lead to the optimality of FPE or IPE. Neither regime is unconditionally optimal. One could be perplexed by the fact that parameter g_0 (and, therefore, the information content of $x_2 = H(H)$) still has an impact on the result although $e_2^*(H) = 0$. IPE incentivizes the agent to select $e_2 = 1$ irrespective of the (unknown) first-period outcome x_1. Therefore, the information content of $x_2 = H(H)$) continues to matter. Note, however, that IPE no longer represents the optimal evaluation regime when outcome $x_2 = H(H)$ becomes pure noise, i.e., when $g_0 \to g_1$. Given FPE, the information content of $x_2(H)$ is of no concern since $e_2(H) = 0$ is optimal.

What is the intuition behind Proposition 3? Think of a setting showing $b_1 \geq p_1 > g_1$, or $p_1 > b_1 > g_1$, a negative interaction effect is present or even a negative trend of a shrinking market. In a shrinking market, if high sales can reduce inventory in the first period, there is no need to induce high effort in the second period. Yet, if inventory remains high after the first period because sales are low (the low outcome), it takes high effort in the second period to try (again) to reduce inventory. Alternatively, one could think of a scenario of "damage containment"—following a low outcome (and a loss in reputation) in the first period it takes high effort to prevent further damage (reputation loss) to the company. In these settings or if situations like these are expected, IPE is optimal. Given that the costs of aggregation again increase with a contingent production schedule, FPE is more likely to be optimal than in the unconditional effort setting. Moreover, intuition provided in Sect. 4.2.1 applies here as well.

A comparison between propositions 2 and 3 reveals some overlap in optimality regions for IPE. Hence, there are parameter settings where the optimal evaluation regime does not depend on the single- or dual-purpose use of accounting information. In that sense, results generalize. Furthermore, the comparison suggests that optimality of FPE or IPE in the conditional effort settings does not depend on the

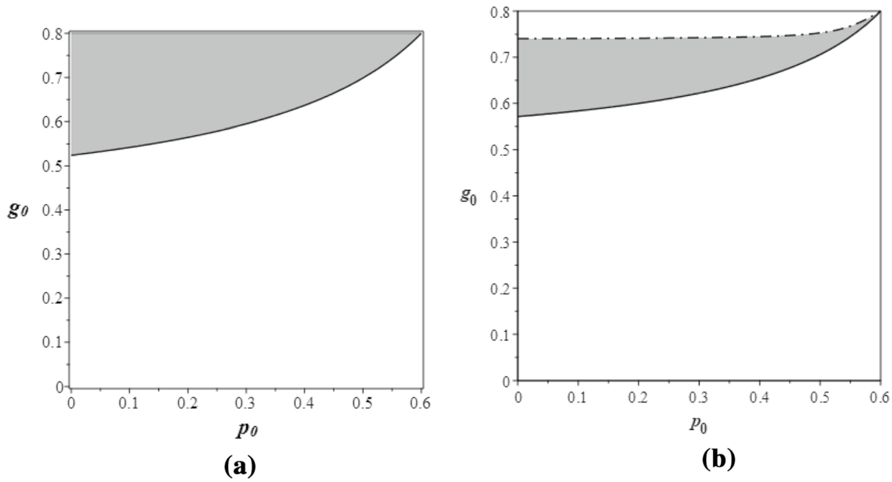

Fig. 3 Conditional effort $\{e_2(H) = 0, e_2(L) = 1\}$ and optimal regime: white—IPE; gray—FPE (color figure online)

first-period outcome's implication. If the high outcome in period 1 is a "good sign," the production schedule $\{e_2(H) = 1; e_2(L) = 0\}$ is optimal in period 2, and if it is a "bad sign," $\{e_2(H) = 0; e_2(L) = 1\}$ is optimal in the second period. Surprisingly, there are a number of parameter settings (represented by white areas) where IPE is optimal even though the principal implements a contingent production schedule given an observable interim outcome. This finding does not depend on the first-period outcome being a "good sign" or a "bad sign."

4.2.3 Conditional effort and mixed strategies

Expected compensation costs become valid again as the criterion for comparison between evaluation regimes if both regimes implement the same expected effort levels from an ex-ante perspective. While the effort combination $\{e_1 = 1; e_2(x_1 = H) = 1; e_2(x_1 = L) = 0\} \equiv \{1;1,0\}$ can be implemented as a pure strategy given FPE (due to observability of x_1 before e_2 is chosen), it can only be implemented as a mixed strategy in IPE due to the unobservability of the first-period outcome. Consequently, I now assume the agent plays a mixed strategy under IPE.

Assume the conditional effort schedule $\{e_1 = 1; e_2(H) = 1, e_2(L) = 0\}$ is optimal. Under IPE, the agent selects high effort in the second period with the probability of a high outcome in the first period, $P(x_1 = H|e_1 = 1) = p_{e_1=1} = p_1$; and low effort with probability $P(x_1 = L|e_1 = 1) = (1 - p_{e_1=1}) = (1 - p_1)$. In other words, under IPE, the agent is supposed to select effort strategy $\{e_1 = 1, e_2 = 1\}$ with probability p_1 and effort strategy $\{e_1 = 1, e_2 = 0\}$ with probability $(1 - p_1)$.[22]

[22] In the setting where $\{e_1 = 1; e_2(H) = 0, e_2(L) = 1\}$ is optimal, the agent opts for strategy $\{e_1 = 1, e_2 = 0\}$ with probability p_1 and strategy $\{e_1 = 1, e_2 = 1\}$ with probability $(1 - p_1)$.

Given that the agent cannot observe the first-period outcome, the assumption that the agent selects high effort in period 2 with probability p_1 is the only way in which the principal can ensure the same expected effort under FPE and IPE. Technically, under IPE, it requires to add incentive compatibility constraints such that the mixed strategy $\{p_1 \cdot \{e_1 = 1, e_2 = 1\}, (1 - p_1) \cdot \{e_1 = 1, e_2 = 0\}$ is not inferior to pure strategies $\{e_1 = 1, e_2 = 1\}$ or $\{e_1 = 1, e_2 = 0\}$. In the optimal solution, these constraints bind. Nevertheless, the agent cannot "play" the conditional effort schedule under IPE as a pure strategy because, in contrast to FPE, the agent does not observe the interim outcome.

Intuitively, one would expect the mixed strategy to work in favor of IPE because it induces less effort than the pure strategy in the previous two sections. If the optimal production schedule in FPE is implemented as a mixed strategy in IPE, however, FPE may represent the principal's optimal choice for a larger subset of parameter constellations. The reason is that implementing the conditional production schedule as a mixed strategy in IPE can be even more expensive than implementing high effort in both periods. I demonstrate this effect by example (see Table 4). See the online supplementary material for a formal proof. For comparison purposes, I use the same parameters as in the figures above.

Table 4 shows that with g_0 increasing, the optimal evaluation regime can change. The observation is in agreement with the findings from the previous Sect. 4.2.1 and 4.2.2. Notable is the case where $g_0 = 0.20$. FPE is optimal for both conditional effort scenarios if the agent plays a mixed strategy under IPE. In contrast, IPE would be optimal if the principal offers a contract under IPE that implements high effort in each period as a pure strategy (expected compensation costs amount to 6.00 in this case). Dissuading the agent from playing a mixed strategy can pay off for the principal.

4.2.4 Conditional effort and external cause

So far, conditional effort schedules ensue from (the "meaning" of) the first-period outcome the agent generates. A conditional schedule, however, may also be a consequence of an external stochastic factor, where external refers to an influence outside the agency.[23] For example, problems occurring in other business units during the first period could render high effort in the agency noneconomical in the second period irrespective of the first-period's outcome in that agency. Concretely, one can assume a signal $\mathcal{S} \in \{\beta, \gamma\}$ is observable after the first period such that the "bad" signal β implies low effort is optimal in the second period and high effort if the signal is "good," γ. Let $P(\mathcal{S}) = p_{\mathcal{S}} \le 1$ denote the probability of signal $\mathcal{S}$ with $p_\gamma = (1 - p_\beta)$.

Two essential differences exist between a conditional effort schedule being a consequence of (a) the agent's output or (b) an external factor. First, the relevance of the agent's effort and, second, the observability of the outcome or signal required to select the optimal effort in the second period. In (a), the agent's first-period effort

[23] I would like to thank one of the referees for suggesting this setup.

choice affects the likelihood of a high effort as the optimal choice in the second period; in (b), the agent's first-period effort has no impact on it. Moreover, observation of the first-period outcome relevant for choosing the appropriate effort level in period 2 is restricted to FPE in (a), but in (b), signal $\mathcal{S}$ is observable under FPE and IPE.[24] As a consequence, the principal would not be willing to provide further effort incentives as soon as the principal knows $\mathcal{S} = \beta$. Observation of the latter is an impetus for the principal to conduct a performance evaluation after period 1, even under IPE. Hence, bonuses $(s^{HH} - s^{HL})$ and $(s^{LH} - s^{LL})$ under FPE and $(s_{2H} - s_{H+L})$ under IPE are contingent on $\mathcal{S} = \gamma$. In two instances, I assume the agent is eligible for the bonus $(s_{H+L} - s_{2L})$ under IPE. First, if $\mathcal{S} = \gamma$ and the performance evaluation carried out after the second period shows a total performance of $\{H + L\}$. Second, if $\mathcal{S} = \beta$ and first-period outcome is H. Utilizing a numerical example, I explore the modified setup with the external stochastic factor (see Table 5). Again for comparison purposes, I use the same parameters as in the figures above.

As one would expect, if it becomes more likely that high effort will be viable in the second period, i.e., with p_γ increasing, expected compensation costs under FPE increase. Given binding incentive constraints in the second period, the principal reacts to an increasing p_γ by raising the first-period bonus $(s^{HL} - s^{LL})$ and compensation costs go up given all else equal. Here, the informativeness of the second-period outcome $H(H)$ does not matter.[25] Table 5 shows this result in the third column labeled "FPE." Under IPE, an increasing p_γ may have no effect, cause an increase in expected compensation costs, or lead to a non-monotonic cost behavior, as evident in the fourth column "IPE." Non-monotonicity follows from a change in the pay structure under IPE, switching from $s^{H+L} < s^{2H}$ to $s^{H+L} > s^{2H}$ for $g_0 = 0.75$.

Observations in Tables 4 and 5 and results analytically derived in this paper suggest the following effects of conditional effort schedules. Under FPE, conditional effort schedules lead to lower expected compensation costs than an unconditional schedule, which stipulates high effort in each period. Under IPE, the picture shows nuances. Suppose the conditional schedule represents the principal's optimal reaction to a signal generated outside the agency. In that case, the schedule's expected compensation costs are more likely to be lower than those implementing high effort in each period. Thus, FPE has the highest likelihood of being the principal's optimal choice if the conditional effort schedule ensues from a signal generated inside the agency and is implemented as a mixed strategy under IPE.

[24] Assume the signal is not observable under IPE because the impact of the stochastic factor is determined in conjunction with the performance evaluation (which does not occur under IPE at the end of the first period). Given the effect demonstrated in the present section, it will likely lead to higher expected compensation costs than the implementation of a pure strategy.

[25] I obtain a similar result if I vary the informativeness of $H(L)$.

Table 4 Conditional effort and mixed strategies given IPE

Effort	Parameter	Expected compensation	
$\{e_1;e_2(H),e_2(L)\}$	g_0	FPE	IPE
$\{1;1,0\}$	0.20	7.20	13.82
	0.50	7.20	10.00
	0.75	19.20	18.47
$\{1;0,1\}$	0.20	9.80	11.95
	0.50	9.80	9.59
	0.75	9.80	17.36

Parameters: $p_0 = 0.4, p_1 = 0.6, g_1 = 0.8, b_0 = 0.3, b_1 = 0.5, c = 2$

5 Summary and conclusion

This paper discusses the optimal frequency of performance evaluations if an outcome-dependent interaction effect between periods exists. It means that performance in the current period affects the probability of achieving high performance in the next period. The interaction effect is modeled in a very general fashion. It allows for mapping many different scenarios, e.g., positive or negative time trends in profit opportunities. I consider two settings: unconditional effort implementation, so that the optimal action does not depend on interim outcome information, and conditional effort implementation, where the optimal second-period effort depends on the interim outcome. Unconditional effort implementation implies a single use of accounting information—solely for a control purpose; conditional effort implementation implies a dual use of accounting information—for control and productive purposes.

In the setting with unconditional effort implementation, the benefit of information suppression (delaying access to information) and spillover of incentives pushes the principal's choice toward IPE. However, FPE could also be the optimal choice. It will be optimal whenever the optimal contract under FPE shifts all or almost all compensation into the second period.

In the setting with conditional effort implementation, information delay under IPE now comes at a cost. Hence, tailoring the effort choice to the interim outcome accounts for FPE being preferable to IPE. The extent of that benefit depends largely on the informativeness of outcomes. Different information contents of outcomes increase the costs associated with information aggregation under IPE. Therefore, FPE is more likely to be optimal given a dual-purpose use of accounting information as opposed to a single-purpose use. Optimality of IPE given a conditional production schedule represents a remarkable result. In expectation, IPE induces more effort, and the agent incurs higher costs than under FPE. Yet, the benefit of incentive spillover in IPE may loom large.

Summarizing the findings from both settings—unconditional production schedule and conditional production schedule—provides two insights into the interplay between a single or dual use of accounting information and the optimality of interim

Table 5 External stochastic influence and conditional effort

Parameter	Probability of	Expected compensation	
g_0	$\mathcal{S} = \gamma$	FPE	IPE
0.20	0.50	8.50	6.00
	0.80	10.00	6.00
	1.00	11.00	6.00
0.50	0.50	8.50	6.00
	0.80	10.00	6.17
	1.00	11.00	6.86
0.75	0.50	10.60	16.00
	0.80	16.96	22.96
	1.00	21.20	19.27

Parameters: $p_0 = 0.4, p_1 = 0.6, g_1 = 0.8, b_0 = 0.3, b_1 = 0.5, c = 2$

performance evaluations. First, the optimality of carrying out an interim performance evaluation often depends on the usage of outcome information. Second, there is no general result in either setting that FPE strictly dominates IPE or vice versa. It suggests a counter-intuitive result: generating and disclosing interim information could be optimal in a setting with *un*conditional effort implementation, but hiding the information can be advantageous in a setting with conditional effort implementation. Given that the findings in the paper hold for quite different business environments, such as positive or negative time trends, bandwagon effects, or increasing markets, the generality of results in that respect appears to be given.

Implications of this research relate to the benefits of interim evaluations and associated reward structures. The paper establishes a "rule of thumb": If maximum output is sufficiently informative about an employee's effort choice(s), IPE is optimal; otherwise, FPE is optimal. A testable prediction follows from the conclusion and rule of thumb. One reward structure preponderates given a single-purpose use of accounting information. If firms do not carry out interim evaluations, they (must) reward total performance.[26] Often, a single nonzero payment for the highest aggregate performance is optimal. However, if firms optimally decide for interim evaluations, no bonus should be associated with that evaluation. The interim evaluation is literally interim because the bonus-relevant performance assessment evaluation follows later. Therefore, regardless of the evaluation regime, the reward structure is similar in the sense that the bonus decision is made at the end of the project or year. It could help explain why some firms carry out interim evaluations, but others do not, yet firms resemble each other and pay annual bonuses.

FPE is more likely to be optimal in the case of a dual-purpose use of accounting information than in the case of a single-purpose use. It accords with intuition (or another "rule of thumb") that more frequent evaluations are required if that information influences the optimal course of action. Surprisingly, IPE can still be optimal,

[26] This is, of course, true by definition.

and the optimality is not restricted to extreme parameter settings in this paper's model.

Finally, the results suggest another practical implication. The actual use of accounting information and the interaction between periods influence the optimality of interim evaluations. However, the optimality of interim evaluations may also depend on the information system properties as reflected in the likelihood of outcomes. As profits accruing to the principal from both evaluation regimes are typically not simultaneously available to firms (since firms opt for one of the regimes), decision-makers might not be sufficiently sensitized for all facets of the decision to evaluate (in)frequently.

Appendix

In deriving optimal payments, expected compensation costs, and thresholds for the various performance evaluation regimes, the software "Maple 2017.0" was used to simplify and factor expressions.

A.1 Unconditional effort: derivation of payments in FPE

Optimal payments under FPE obtain from solving program (5) given $e_1^* = e_2^*(H) = e_2^*(L) = 1$. For purposes of derivation, the constraints to program (5) are stated explicitly:

$$E(S_{1,1(x_1)}) \geq 0 \tag{22}$$

$$E(S_{1,1(x_1)}) \geq E(S_{1,0(x_1)}), x_1 = L, H \tag{23}$$

$$E(S_{1,1(x_1)}) \geq E(S_{0,1(x_1)}), x_1 = L, H \tag{24}$$

$$E(S_{1,1(x_1)}) \geq E(S_{0,0(x_1)}), x_1 = L, H \tag{25}$$

$$s^{ij} \geq 0. \tag{26}$$

Set

$$(s^{HH} - s^{HL}) = \frac{c}{(g_1 - g_0)} \cdot v^H, \qquad v^H \geq 1, \tag{27}$$

$$(s^{LH} - s^{LL}) = \frac{c}{(b_1 - b_0)} \cdot v^L, \qquad v^L \geq 1, \tag{28}$$

such that (23) is satisfied. Plugging in (27) and (28) into (24) gives, after rearranging,

$$(s^{HL} - s^{LL}) \geq \frac{c}{p_1 - p_0} - c \cdot \frac{g_1}{g_1 - g_0} v^H + c \cdot \frac{b_1}{b_1 - b_0} v^L. \tag{29}$$

Given $(s^{HH} - s^{HL}), (s^{LH} - s^{LL}), (s^{HL} - s^{LL}) > 0$, it follows that $s^{LL} = 0$ and the participation constraint (10) is slack. Expected compensation is:

$$EC_{FPE} = p_1 \frac{c}{p_1 - p_0} + (p_1 \cdot g_1 - p_1 \cdot g_1) \frac{c}{(g_1 - g_0)} v^H + [p_1 \cdot b_1 + (1 - p_1) \cdot b_1] \frac{c}{(b_1 - b_0)} v^L. \tag{30}$$

Constraint (30) is minimized if $v^L = v^H = 1$. Constraints (27), (28), and (29) simplify accordingly and result in payments in Table 6. (Selecting $v^H > 1$ is possible but does not affect expected compensation.) It is easily verified that (25) is also binding given these payments. Expected compensation is:

$$EC_{FPE[(23),(24),(25)]} = c\left(\frac{p_1}{p_1 - p_0} + \frac{b_1}{b_1 - b_0}\right), \tag{31}$$

where the subscript indicates the relevant incentive constraints.

Now assume (23) is the only binding constraint. It implies that $(s^{HH} - s^{HL}) = \frac{c}{(g_1 - g_0)}$ and $(s^{LH} - s^{LL}) = \frac{c}{(b_1 - b_0)}$ suffice to make constraint (24) slack. Rearranging (24) given $(s^{HL} - s^{LL}) = 0$ leads to (17), the condition such that incentive constraint (24) is slack given FPE. It is easily verified that in this case (25) is also slack. Given $s^{LL} = s^{HL} = 0$, payments in Table 6 follow. Expected compensation is:

$$EC_{FPE[(23)]} = c\left[p_1 \frac{g_1}{g_1 - g_0} + (1 - p_1) \frac{b_1}{b_1 - b_0}\right]. \tag{32}$$

A.2 Derivation of payments in IPE

Whenever one of the incentive constraints (11), (12), or (13) singly binds, s_{2H} is the only nonzero payment, and this payment is easily determined by rearranging the respective incentive constraint (11), (12), or (13) given $s_{2L} = s_{H+L} = 0$. Table 7 lists all nonzero payments. Expected compensation costs amount to:

$$EC_{IPE[11]} = p_1 g_1 \frac{c}{p_1 g_1 - p_0 g_1}, \tag{33}$$

$$EC_{IPE[12]} = p_1 g_1 \frac{2c}{p_1 g_1 - p_0 g_0}, \tag{34}$$

$$EC_{IPE[13]} = p_1 g_1 \frac{c}{p_1 g_1 - p_1 g_0}, \tag{35}$$

where the subscript indicates the relevant incentive constraint.

Assume (11) and (13) jointly bind. Rearrange (13) and (11) so that:

Table 6 Binding incentive constraints, nonzero payments, and optimal contract given FPE

Case	Binding constraint(s)	Nonzero payments	Expected compensation
(i)	(23), (24), (25)	$s^{HL} = c\left(\frac{1}{p_1-p_0} - \frac{g_1}{(g_1-g_0)} + \frac{b_1}{(b_1-b_0)}\right)$ $s^{LH} = \frac{c}{b_1-b_0}$ $s^{HH} = s^{HL} + \frac{c}{g_1-g_0}$	$c\left(\frac{p_1}{p_1-p_0} + \frac{b_1}{b_1-b_0}\right)$
(ii)	(23)	$s^{LH} = \frac{c}{(b_1-b_0)}$ $s^{HH} = \frac{c}{g_1-g_0}$	$c\left(p_1\frac{g_1}{g_1-g_0} + (1-p_1)\frac{b_1}{b_1-b_0}\right)$

$$[(b_1 - b_0) - p_1(b_1 - b_0)](s_{H+L} - s_{2L}) + (g_1 - g_0)p_1(s_{2H} - s_{H+L}) = c \tag{36}$$

$$(s_{H+L} - s_{2L}) + (p_1 - p_0)g_1(s_{2H} - s_{H+L}) = c. \tag{37}$$

Solving the last equation for $(s_{2H} - s_{H+L})$ and substituting it into the previous equation leads to optimal payments as given in Table 7. Expected compensation amounts to:

$$EC_{IPE[(11),(13)]} = c\frac{p_1}{(p_1 - p_0)} + \frac{b_1[g_1(p_1 - p_0) - p_1(g_1 - g_0)] \cdot c}{(p_1 - p_0)[g_1(b_1 - b_0) - p_1(g_1 - g_0) - p_1(b_1g_0 - b_0g_1)]}. \tag{38}$$

The derivation proceeds similarly if incentive constraints (11) and (12) jointly bind or if (12) and (13) jointly bind. These derivations are not displayed.

It is useful for the proof of propositions to clarify when the respective incentive constraints (jointly) bind conditional on g_0. This is done in the following lemma. It also establishes the result that expected compensation is increasing or, at least, monotone in g_0. Figure 4 exemplifies the lemma.

Lemma 1 *In Scenario* (*I*):

(i) *For* $g_0 \in \left(0, \frac{(2p_0-p_1)g_1}{p_0}\right)$, *incentive constraint* (11) *binds.*
(ii) *For* $g_0 = \frac{(2p_0-p_1)g_1}{p_0} \equiv g_0[(11);(12)]$, *incentive constraints* (11) *and* (12) *bind jointly.*
(iii) *For* $g_0 \in \left(\frac{(2p_0-p_1)g_1}{p_0}, \frac{p_1g_1}{2p_1-p_0}\right)$, *incentive constraint* (12) *binds.*
(iv) *For* $g_0 = \frac{p_1g_1}{2p_1-p_0} \equiv g_0[(12);(13)]$, *incentive constraints* (12) *and* (13) *bind jointly.*
(v) *For* $g_0 \in \left(\frac{p_1g_1}{2p_1-p_0}, \frac{(p_1+(1-p_1)b_0)g_1}{p_1+(1-p_1)b_1}\right)$, *incentive constraint* (13) *binds.*

Table 7 Binding incentive constraints, nonzero payments, and optimal contract given IPE

Case	Binding constraint(s)	Nonzero payments	Expected compensation
(i)	(11)	$s_{2H}=\frac{c}{p_1g_1-p_0g_1}$	$p_1g_1\frac{c}{p_1g_1-p_0g_1}$
(ii)	(12)	$s_{2H}=\frac{2c}{p_1g_1-p_0g_0}$	$p_1g_1\frac{2c}{p_1g_1-p_0g_0}$
(iii)	(13)	$s_{2H}=\frac{c}{p_1g_1-p_1g_0}$	$p_1g_1\frac{c}{p_1g_1-p_1g_0}$
(iv)	(11), (13)	$s_{H+L}=\frac{[g_1(p_1-p_0)-p_1(g_1-g_0)]\cdot c}{(p_1-p_0)\left[g_1(b_1-b_0)-p_1(g_1-g_0)+p_1(b_0g_1-b_1g_0)\right]}$ $s_{2H}=\frac{c}{g_1(p_1-p_0)}-\frac{1-b_1}{g_1}s_{H+L}+s_{H+L}$	$p_1\frac{c}{(p_1-p_0)}+b_1s_{H+L}$
(v)	(11), (12)	$s_{H+L}=\frac{[g_1(p_1-p_0)-p_0(g_1-g_0)]\cdot c}{(p_1-p_0)\left[g_1(b_1-b_0)-p_0(g_1-g_0)+p_0(b_0g_1-b_1g_0)\right]}$ $s_{2H}=\frac{c}{g_1(p_1-p_0)}-\frac{1-b_1}{g_1}s_{H+L}+s_{H+L}$	$p_1\frac{c}{(p_1-p_0)}+b_1s_{H+L}$
(vi)	(12), (13)	$s^{H+L}=\frac{[g_0(p_1-p_0)-p_1(g_1-g_0)]\cdot c}{(p_1-p_0)\left[g_0(b_1-b_0)-p_1(g_1-g_0)+p_1(b_0g_1-b_1g_0)\right]}$ $s_{2H}=\frac{c}{g_1(p_1-p_0)}-\frac{1-b_1}{g_1}s_{H+L}+s_{H+L}$	$p_1g_1\frac{2c}{(p_1g_1-p_0g_0)}+$ $\frac{\left[p_0p_1(g_1-g_0)+p_1g_1(1-p_0)b_0-p_0g_0(1-p_1)b_1\right]}{(p_1g_1-p_0g_0)}$ s_{H+L}

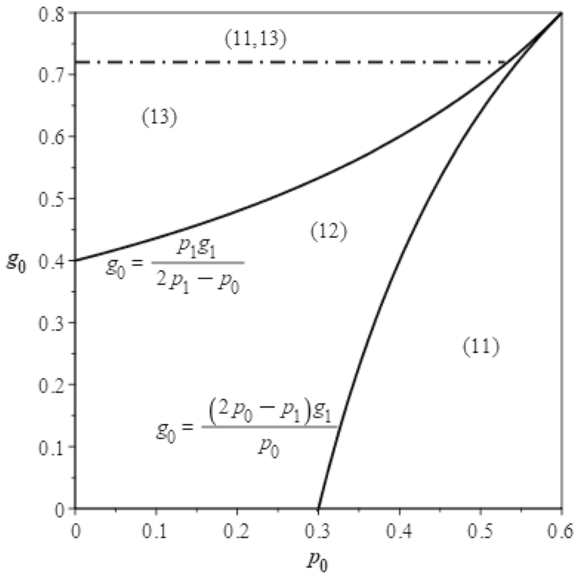

Fig. 4 Infrequent performance evaluation: Binding incentive constraints conditional on g_0

(vi) *For* $g_0\in\left(\frac{(p_1+(1-p_1)b_0)g_1}{p_1+(1-p_1)b_1},g_1\right)$, *constraints* (11) *and* (13) *jointly bind.* $g_0[(13);(11),(13)]\equiv g_0[LR(H+L)_{1,0}]=\frac{(p_1+(1-p_1)b_0)g_1}{p_1+(1-p_1)b_1}$ *marks the transition from* (13) *singly binding to constraints* (11) *and* (13) *jointly binding.*

(vii) $\frac{\partial EC_{IPE}}{\partial g_0}\geq 0$ *holds if a single constraint binds and if constraints* (11) *and* (13) *jointly bind.*

In Scenario (II):

(i) *The sequence of singly binding constraints from Scenario (I) is preserved until*

$g_0 > min\{g_{0[LR(H)_{1,0}]}, g_{0[LR(H)_{0,0}]}\}$

requires two nonzero payments to minimize expected compensation costs.

(ii) *For* $g_0 \rightarrow g_1$, *constraints* (13) *and* (11) *jointly bind.*

(iii) $\frac{\partial EC_{IPE}}{\partial g_0} \geq 0$ *holds if a single constraint binds and if two constraints* (11) *and* (12), *or* (12) *and* (13), *or* (11) *and* (13) *jointly bind.*

Proof of Lemma 1 **Scenario (I)**. Table 7 lists payments $s^{2H}_{[11]}$, $s^{2H}_{[12]}$, and $s^{2H}_{[13]}$ contingent on the relevant incentive constraint. Results in (i) - (v) obtain from rearranging the following inequalities:

- $s^{2H}_{[12]} \geq s^{2H}_{[11]} \Leftrightarrow \frac{g_1}{g_1-g_0} \geq \frac{p_0}{p_1-p_0}$
- $s^{2H}_{[12]} \geq s^{2H}_{[13]} \Leftrightarrow \frac{p_1}{p_1-p_0} \geq \frac{g_0}{g_1-g_0}$

The result in (vi) obtains from incentive constraint (13) and its associated expected compensation term:

$$EC_{IPE[(13)]} = \frac{g_1}{g_1 - g_0}c + \left[\frac{p_1(g_1 - g_0) + (1 - p_1)(g_1 b_0 - b_1 g_0)}{g_1 - g_0}\right]\left(s_{H+L} - s_{2L}\right).$$

Whenever the term in brackets is negative, choosing $\left(s^{H+L} - s^{2L}\right) > 0$ weakens the increase in expected compensation, and with two nonzero payments, constraints (11) and (13) jointly bind. The threshold $g_0[(13);(11),(13)]$ is the zero of the term in brackets above. At $g_0[(13);(11),(13)]$, $EC_{IPE[(11),(13)]} > EC_{IPE[(11),(12)]}, EC_{IPE[(12),(13)]}$ holds, that is, satisfying the relevant incentive constraints entails higher expected costs than satisfying other possible combinations of two jointly binding constraints.

If constraints (11) and (13) become jointly binding for (any) $\check{g}_0$, these constraints continue to be jointly binding for all $g_0 \in [\check{g}_0, g_1)$. This follows from **(a)** monotonicity of both $EC_{IPE[(11),(13)]}$, $EC_{IPE[(11),(12)]}$ and $EC_{IPE[(12),(13)]}$ in g_0, **(b)** the relations

$$\lim_{g_0 \rightarrow g_1} EC_{IPE[(11),(13)]} > \lim_{g_0 \rightarrow g_1} EC_{IPE[(12),(11)]},$$
$$\lim_{g_0 \rightarrow g_1} EC_{IPE[(11),(13)]} > \lim_{g_0 \rightarrow g_1} EC_{IPE[(12),(13)]};$$

(c) the fact that with g_0 increasing, satisfying constraint (13) becomes ever more costly than satisfying constraint (12); and **(d)** the fact that satisfying constraint (11) with a single nonzero payment s^H is impossible if, as a sufficient condition, $(g_1 + b_1) \geq 1$ holds.

Concerning **(a)**, derivatives are:

$$\frac{\partial EC_{IPE[(13),(11)]}}{\partial g_0} = \frac{p_1 g_1 b_1[(b_1 - b_0) - (p_1 - p_0) + p_1 b_0 - p_0 b_1]}{(p_1 - p_0)[g_1(b_1 - b_0) - p_1(g_1 - g_0) - p_1(b_1 g_0 - b_0 g_1)]^2} c,$$
$$\frac{\partial EC_{IPE[(11),(12)]}}{\partial g_0} = \frac{p_0 g_1 b_1[(b_1 - b_0) - (p_1 - p_0) + p_1 b_1 + p_0 b_0 - 2p_0 b_1]}{(p_1 - p_0)[g_1(b_1 - b_0) - p_0(g_1 - g_0) - p_0(b_1 g_0 - b_0 g_1)]^2} c,$$
$$\frac{\partial EC_{IPE[(12),(13)]}}{\partial g_0} = \frac{b_0 g_1 b_1[(b_1 - b_0) - (p_1 - p_0) - p_1 b_1 - p_0 b_0 + 2p_0 b_1]}{(p_1 - p_0)[g_0(b_1 - b_0) - p_1(g_1 - g_0) - p_1(b_1 g_0 - b_0 g_1)]^2} c.$$

Derivatives are monotone in g_0, since each nominator is independent of g_0. Moreover, derivatives must be positive because with g_0 increasing, incentive constraints (12) and (13) become more stringent while it leaves (11) unaffected. (36) and (37) show this for constraints (13) and (11), respectively; rearranging (12) in similar fashion proves the claim for (12).

Concerning **(b)**, for proving the postulated relation between expected compensation costs contingent on specific, binding constraints, it can be shown that:

$$\lim_{g_0 \to g_1} EC_{IPE[(11),(13)]} - \lim_{g_0 \to g_1} EC_{IPE[(11),(12)]} = \frac{p_1}{1 - p_1} \cdot c \qquad > 0,$$
$$\lim_{g_0 \to g_1} EC_{IPE[(11),(13)]} - \lim_{g_0 \to g_1} EC_{IPE[(12),(13)]} = \frac{(p_1 - p_0)b_1}{(b_1 - b_0)(1 - p_0)(1 - p_1)} \cdot c \quad > 0.$$

Concerning **(c)**, rearranging constraints (13) and (12) leads to:

$$(13) : (p_1 - p_0)(s_{H+L} - s_{2L}) + (p_1 g_1 - p_1 g_0)(s_{2H} - s_{H+L})$$
$$(12) : (p_1 - p_0)(s_{H+L} - s_{2L}) + (p_1 g_1 - p_0 g_0)(s_{2H} - s_{H+L})$$

It is evident that the "marginal tightening" of constraint (13) from an increase of g_0 is given by $-p_1(s_{2H} - s_{H+L})$, and it is larger (in absolute terms) than the one for constraint (12), which amounts to $-p_0(s_{2H} - s_{H+L})$.

Concerning **(d)**, for proving the claim, set $s_{2H} = 0$ and rearrange constraint (11) to obtain

$$(11) : [(p_1 - p_0)(1 - g_1) + (p_1 - p_0)b_1](s_{H+L} - s_{2L}) - c \geq 0.$$

(c) and (d) imply that if constraints (13) and (11) jointly bind at $\check{g}_0$ and two nonzero payments are optimal, constraint (12) remains slack for $g_0 > \check{g}_0$, and two nonzero payments are optimal. Given that $LR(H+L)_{e_1=1,e_2=0} > LR(2H)_{e_1=1,e_2=0}$ holds at $\check{g}_0$, the cost-minimizing way to satisfy constraint (13) is to set $s_{H+L} > 0$ and $s_{2H} = 0$. Since this pay structure would not satisfy constraint (11), $s_{H+L} > 0$ and $s_{2H} > 0$ are chosen such that constraints (11) and (13) are jointly satisfied at mimimum cost.

The result in (vii) is readily verified by inspection of expected compensation terms in Table 7 when a single constraint binds. If constraints (13) and (11) jointly bind, the result has been proven in (vi).

Scenario (II). (i), (ii), and (iii) follow from the proof for Scenario (I) above. □

A.3 Proof of Proposition 1

For purposes of exposition, it is useful to define two scenarios based on parameter g_0. Let $g_0[LR(H+L)_{e_1,e_2}]$ denote the threshold level of g_0 such that $LR(H+L)_{e_1,e_2} \geq LR(2H)_{e_1,e_2} \Leftrightarrow g_0 \geq g_0[LR(H+L)_{e_1,e_2}]$. Since $g_0[LR(H+L)_{1,0}] < g_0[LR(H+L)_{0,0}]$, the term $g_0[LR(H+L)_{1,0}]$ marks the lowest possible value of g_0 such that the optimal contract under IPE shows *two* nonzero payments. For $g_0 \geq g_0[LR(H+L)_{1,0}]$, the minimum cost solution to satisfy incentive constraint (13) would show $s_{H+L} > 0$ but $s_{2H} = 0$. For the other two incentive constraints (11) and (12), the relation $LR(H+L)_{e_1,e_2} < LR(2H)_{e_1,e_2}$ still holds which requires $s_{2H} > 0$ and $s_{H+L} = 0$ to satisfy these constraints at minimum cost. Hence, two nonzero payments could represent the optimal solution to satisfy all three constraints.

Definition 1 Scenario (I): $g_0[LR(H+L)_{1,0}) > \frac{p_1 g_1}{2p_1 - p_0}$. Scenario (II): $g_0[LR(H+L)_{1,0}) \leq \frac{p_1 g_1}{2p_1 - p_0}$.

In scenario (I), with g_0 increasing, the incentive constraints (11)–(13) will subsequently be singly binding and eventually, with $g_0 \to g_1$, constraints (11) and (13) jointly bind. (See Lemma 1 in A.2.) Scenario (II) covers all other possible sequences of cases from Table 2. For example, constraint (11) may be singly binding, then constraints (11) and (12) jointly bind, and eventually (11) and (13) jointly bind.

Scenario (I). Assume condition $\frac{g_1}{g_1 - g_0} < \left(\frac{p_1}{p_1 - p_0} + \frac{b_1}{b_1 - b_0}\right)$ holds. It implies (17) does *not* hold. Thus, constraints (23),(24), and (25) jointly bind in FPE. It is easily verified that

$$g_{0(3IC-FPE)} - g_0[(12);(13)] = \frac{[(1-p_1)(b_1-b_0) + (p_1-p_0)b_0](p_1-p_0)g_1}{(2p_1-p_0)[(1+p_1-p_0)b_1 - b_0]} > 0.$$

Therefore, the transition from three binding incentive constraints to a singly binding incentive constraint under FPE at $g_{0(3IC-FPE)}$ occurs when constraint (13) singly binds or (11) and (13) jointly bind under IPE.

(11) **Singly binds in IPE** Using (31) and (33) leads to

$$EC_{FPE[(23),(24),(25)]} - EC_{IPE[(11)]} = c\left(\frac{p_1}{p_1-p_0} + \frac{b_1}{b_1-b_0}\right) - c\frac{p_1}{(p_1-p_0)} > 0$$

(12) **Singly binds in IPE** In this case, the payment $s_{[(12)],2H}$ required to satisfy constraint (12) must be higher than the payment required to satisfy the constraint (13) and (11), respectively. Pairwise comparison of payments gives the following conditions:

$$s_{[(12)],2H} \geq s_{[(13)],2H} \Leftrightarrow \frac{g_1}{g_1 - g_0} \geq \frac{p_0}{p_1 - p_0}, \tag{39}$$

$$s_{[(12)],2H} \geq s_{[(11)],2H} \Leftrightarrow \frac{p_1}{p_1 - p_0} \geq \frac{g_0}{g_1 - g_0}. \tag{40}$$

Using (31) and (34), the difference in expected compensation is:

$$EC_{FPE[(23),(24),(25)]} - EC_{IPE[(12)]} = \frac{c\left\{\begin{array}{l} p_1 b_0[g_1(p_1 - p_0) - p_0(g_1 - g_0)] \\ +p_0 b_1[p_1(g_1 - g_0) - g_0(p_1 - p_0]\end{array}\right\}}{(p_1 - p_0)(b_1 - b_0)(p_1 g_1 - p_0 g_0)} > 0. \tag{41}$$

The terms in brackets in the nominator of (41) are positive given (39) and (40) so that the relation in (41) follows.

(13) **singly binds in IPE.** Using (31) and (35) gives:

$$\begin{aligned} EC_{FPE[(24),(25),(23)]} - EC_{IPE[(13)]} &= c\left(\frac{p_1}{p_1 - p_0} + \frac{b_1}{b_1 - b_0}\right) - c\frac{g_1}{g_1 - g_0} \\ &\geq 0 \Leftrightarrow c\frac{g_1}{g_1 - g_0} \leq c\left(\frac{p_1}{p_1 - p_0} + \frac{b_1}{b_1 - b_0}\right) \end{aligned} \tag{42}$$

At the threshold $\underline{g_0}^{(I)}$, $EC_{FPE[(23),(24),(25)]} = EC_{IPE[(13)]}$. The unique threshold $\underline{g_0}^{(I)}$ exists if constraint (13) is still the relevant incentive constraint under IPE at $\underline{g_0}^{(I)}$. This will be proven in the next step.

(13) **Singly binds or** (13) **and** (11) **jointly bind in IPE** If $\frac{g_1}{g_1 - g_0} > \left(\frac{p_1}{p_1 - p_0} + \frac{b_1}{b_1 - b_0}\right)$ holds, condition (17) may hold or not. If not, three incentive constraints (23)-(25) continue to be binding in FPE. It follows from (42) that FPE is preferred to IPE. If condition (17) holds, (23) singly binds in FPE. Then, under IPE, either (13) singly binds or constraints (13) and (11) bind jointly.

Assume (13) singly binds, then:

$$\begin{aligned} EC_{IPE[(13)]} - EC_{FPE[(23)]} &= c\left[\frac{g_1}{g_1 - g_0} - \frac{p_1 g_1}{g_1 - g_0} - \frac{(1 - p_1)b_1}{b_1 - b_0}\right] \\ &= c\left[\frac{(1 - p_1)g_1}{g_1 - g_0} - \frac{(1 - p_1)b_1}{b_1 - b_0}\right] > 0, \end{aligned}$$

due to (17).

If constraints (13) and (11) become jointly binding under IPE for $g_0 > \underline{g_0}^{(I)}$, the relation

$$EC_{IPE[(13)]} = EC_{IPE[(13,11)]} > EC_{FPE[(23)]}$$

holds at $g_0[(13);(11),(13)]$ - the point of transition from one binding constraint to two binding constraints. Lemma 1(vii) shows, $EC_{IPE[(13,11)]}$ is monotone in g_0. By inspection, $\frac{\partial EC_{FPE[(23)]}}{\partial g_0} > 0$. Since $\lim_{g_0 \to g_1} EC_{FPE[(23)]} = \infty$ while $\lim_{g_0 \to g_1} EC_{IPE[(13),(11)]} = \frac{p_1 c}{p_1 - p_0} + \frac{b_1 c}{(1 - p_1)(b_1 - b_0)}$, the unique threshold level $\overline{g_0}$ must exist if constraints (11) and (13) jointly bind at $\overline{g_0}$. Then - keeping all other parameters constant - the relation

$EC_{IPE[(13),(11)]} \gtrless EC_{FPE[(23)]}$ holds if $g_0 \lessgtr \overline{g_0}$. Solving $EC_{IPE[(13,11)]} = EC_{FPE[(23)]}$ for g_0 leads to $\underline{g_0}^{(I)}$.

Now it needs to be proven that constraint (13) binds at $\underline{g_0}^{(I)}$ while both (11) and (13) bind at $\overline{g_0}$. Assume (11) and (13) do *not* bind at $\overline{g_0}$. Then (13) would still be binding and $EC_{IPE[(13)]} > EC_{FPE[(23)]}$. It has been shown that (11) and (13) jointly bind if $g_0 \to g_1$ leading to $EC_{IPE[(11),(13)]} < EC_{FPE[(23)]}$; therefore (11) and (13) must be binding at $\overline{g_0}$ because it is the only intercept between the terms $EC_{IPE[(11),(13)]}$ and $EC_{FPE[(23)]}$. This observation and $EC_{IPE[(13)]} > EC_{FPE[(23)]}$ in turn imply that the other intercept $\underline{g_0}^{(I)}$ must be for a value of g_0 where three incentive constraints bind under FPE. Now if both (11) and (13) bind at $\underline{g_0}^{(I)}$, constraint (12) must be binding, too. This follows from the fact, that if the cost-minimizing contract under FPE - with three distinct nonzero payments being possible - is equally costly as the cost-minimizing contract under IPE - with two nonzero payments -, the FPE contract must show $s^{HL} = s^{LH}$. Hence, it effectively has only two distinct nonzero payments. And given that three incentive constraints bind in FPE, the same incentive constraints bind in IPE. Three binding constraints in IPE contradict the sequence of binding constraints established in Lemma 1. Therefore, constraint (13) singly binds at $\underline{g_0}^{(I)}$ and that threshold exists.

Scenario (II) Given the likelihood ratio condition $g_0[LR(H+L)_{1,0}] \leq \frac{p_1 g_1}{2p_1 - p_0} \equiv g_0[(12),(13)]$, two nonzero payments become optimal under IPE for $g_0 < g_0[(12),(13)]$. It follows that constraint (13) does not singly bind in Scenario (II). Depending on the parameters, three combinations of jointly binding constraints are possible: (11) and (12); (12) and (13); (11) and (13). The combinations can become relevant in different orders. (For purposes of the proof, it is not necessary to explicitly determine threshold levels of g_0 for all possible cases.)

Under FPE, the threshold for transition from three binding constraints to constraint (23) becoming singly binding is $g_{0(3IC-FPE)}$. It is readily verified that $g_{0(3IC-FPE)} > g_0[(12),(13)]$. It follows that the three constraints (23)–(25) bind in FPE if either (11) or (12) singly binds under IPE. Using the proof of results in Scenario (I), $EC_{IPE} < EC_{FPE}$ holds as long as either (11) or (12) singly bind under IPE.

As established in Lemma 1, for $g_0 \to g_1$, constraints (11) and (13) jointly bind. If neither (11) and (12) nor (12) and (13) jointly bind, the proof for Scenario (I) applies. If, however, (11) and (12) and/or (12) and (13) jointly bind for a subset $g_0 \in (0, g_1)$, there must exist a threshold $g_0^{(II)}$ at which both (11), (12), and (13) jointly bind—and constraints (11) and (13) bind for $g_0 > g_0^{(II)}$. Suppose the three incentive constraints (11)–(13) bind under IPE and two nonzero payments are to be determined. In that case, it is an over-determined system of linear equations (given that $s^{2L} = 0$ follows from the participation constraint in conjunction with the binding liability constraint). To find a unique solution, assume that three nonzero payments under IPE are possible, s^{HL}, s^{LH} and s^{2H}, which is equivalent to the principal's program under FPE (except for the delay in information provision). With three payments and three binding constraints, a unique solution exists—and for this solution to be feasible under IPE it must show $s^{HL} = s^{LH} \equiv s^H$. Hence, at $g_0^{(II)} \equiv \underline{g_0}^{(II)}$, $EC_{IPE} = EC_{FPE}$ holds. This proves the existence of the first threshold $\underline{g_0}^{(II)}$ in Scenario (II). The existence of the second threshold $\overline{g_0}^{(II)}$ can be proven in a similar way as for Scenario (I).■

A.4 Proof of Corollary 1 and Corollary 2

Given the sufficient condition, three incentive constraints (24)–(23) bind under FPE, and the claim in Corollary 1 follows from (42). The proof of Corollary 2 is obvious and therefore omitted. ■

A.5 Conditional effort $e_2(H) = 1, e_2(L) = 0$: derivation of payments in FPE

The principal's program obtains from setting $(e_1^* = e_2^*(H) = 1, e_2^*(L) = 0)$ in (5). To derive optimal payments it is useful to write constraints explicitly:

$$E(S_{1;1,0}) \geq 0 \tag{43}$$

$$E(S_{1;1,0}) \geq E(S_{1;1}) \tag{44}$$

$$E(S_{1;1,0}) \geq E(S_{1;0}) \tag{45}$$

$$E(S_{1;1,0}) \geq E(S_{0;1}) \tag{46}$$

$$E(S_{1;1,0}) \geq E(S_{0;0}) \tag{47}$$

$$E(S_{1;1,0}) \geq E(S_{0;1,0}) \tag{48}$$

$$E(S_{1;1,0}) \geq E(S_{0;0,1}) \tag{49}$$

$$E(S_{1;1,0}) \geq E(S_{1;0,1}) \tag{50}$$

$$s^{ij} \geq 0. \tag{51}$$

Assume constraints (45), (47), and (48) bind. From (45) one obtains:

$$(s^{HH} - s^{HL}) = \frac{c}{(g_1 - g_0)} \cdot v^H, v^H \geq 1,$$
$$(s^{LH} - s^{LL}) = \frac{c}{(b_1 - b_0)} \cdot v^L, v^L \geq 0.$$

The principal can set $v^L > 0$ even though no effort is to be induced following $x_1 = L$. Plugging the two terms into (48) gives, after rearranging:

$$(s^{HL} - s^{LL}) = \frac{c}{(p_1 - p_0)} + c - g_1(s^{HH} - s^{HL}) + b_0(s^{LH} - s^{LL}).$$

Due to the binding liability constraint, $s^{LL} = 0$. Expected compensation amounts to:

$$EC_{FPE[(45),(47),(48)]} = p_1\left[\frac{c}{(p_1 - p_0)} + c\right] + (p_1g_1 - p_1g_1)\frac{c}{(g_1 - g_0)}v^H + b_0\frac{c}{(b_1 - b_0)}v^L. \quad (52)$$

(52) is minimized if $v^L = 0$. Setting $v^H > 1$ does not influence (52). For $v^H = 1$ the payments in Table 8 obtain. It is readily verified that (47) also binds and that the other constraints are slack. Thus, expected compensation costs are:

$$EC_{FPE[(45),(47),(48)]} = c\left[\frac{p_1}{(p_1 - p_0)} + p_1\right]. \quad (53)$$

Now assume constraint (45) singly binds. It implies that $(s^{HH} - s^{HL}) = \frac{c}{g_1 - g_0}$ suffice to make (47) and (48) slack. Setting $(s^{HL} - s^{LL}) = (s^{LH} - s^{LL}) = 0$ and inserting $(s^{HH} - s^{HL}) = \frac{c}{g_1 - g_0}$ into (47) and (48), respectively, gives condition (18) for constraints (47) and (48) to be slack and, thus, for constraint (45) to be singly binding. Expected compensation costs amount to:

$$EC_{FPE[(45)]} = c\frac{p_1g_1}{(g_1 - g_0)}. \quad (54)$$

Other cases of binding incentive constraints are not possible. For any incentive-compatible pay scheme the following relations of expected utility levels are readily verified: $E(S_{0;1,1}) < E(S_{0;1,0})$; $E(S_{1;0,1}) < E(S_{1;1,0})$; $E(S_{0;0,1}) < E(S_{0;0,0})$. It implies that incentive constraints (46), (49) and (50) never bind.■

A.6 Proof of Proposition 2

Part (i). Scenario (I). Lemma 1 establishes that with g_0 increasing, the order of subsequently binding incentive constraints in IPE is as follows: (11), (12), (13), and then both (13) and (11) bind.

(i) If constraint (11) binds:

$$EC_{IPE[(11)]} - EC_{FPE[(45),(47),(48)]} = c\frac{p_1}{(p_1 - p_0)} - c\left[\frac{p_1}{(p_1 - p_0)} + p_1\right] < 0.$$

(ii) If constraint (12) binds:

$$EC_{IPE[(12)]} - EC_{FPE[(45),(47),(48)]} = 2c\frac{p_1g_1}{(p_1g_1 - p_0g_0)} - c\left[\frac{p_1}{(p_1 - p_0)} + p_1\right] \gtreqless 0. \quad (55)$$

If $EC_{IPE[(12)]} - EC_{FPE[(45),(47),(48)]} = 0$ holds for $g_0 > 0$, the threshold $\dot{g}_0^{(I)} > 0$ obtains from rearranging (55).

Table 8 Conditional effort—binding constraints and optimal contract given FPE

Case	Binding constraint(s)	Nonzero payments	Expected compensation
(i)	(45), (47), (48)	$s^{HL} = c\left(\frac{1}{p_1-p_0} - \frac{g_1}{(g_1-g_0)} + 1\right)$ $s^{HH} = c\left(\frac{1}{p_1-p_0} - \frac{g_1}{(g_1-g_0)} + 1\right) + \frac{c}{g_1-g_0}$	$c\left[\frac{p_1}{(p_1-p_0)} + p_1\right]$
(ii)	(45)	$s^{HH} = \frac{c}{g_1-g_0}$	$c\frac{p_1 g_1}{(g_1-g_0)}$

If $EC_{IPE[(12)]} - EC_{FPE[(45),(47),(48)]} = 0$ holds only for $g_0 < 0$, the threshold $\dot{g_0}^{(I)}$ does not exist in the relevant range $0 < g_0 < g_1$, and set $\dot{g_0}^{(I)} = 0$. It implies that in this case no threshold $g_0[(11),(12)]$ exists for transition from the binding constraint (11) to (12), because $\dot{g_0}^{(I)} > g_0[(11),(12)]$. Therefore (12) binds for $g_0 \to 0$. (This corresponds to parameter settings in the lower left corner in Fig. 4.) Non-existence of a threshold $\dot{g_0}^{(I)} > 0$ implies that either $EC_{IPE[(12)]} > EC_{FPE[(45),(47),(48)]}$ or $EC_{IPE[(12)]} < EC_{FPE[(45),(47),(48)]}$ holds for all g_0 if (12) is singly binding. At $g_0[(12),(13)]$, where the transition from (12) binding to (13) binding occurs, $EC_{IPE[(12)]} = EC_{IPE[(13)]} > EC_{FPE[(45)]}$ holds, which will be proven in (iii). Hence, $(EC_{IPE[(12)]} - EC_{FPE[(45),(47),(48)]}) > 0$ holds if constraint (12) binds implying (again) $\dot{g_0}^{(I)} = 0$.

(iii) If constraint (13) binds in IPE, then:

$$EC_{IPE[(13)]} - EC_{FPE[(45)]} = c\frac{g_1}{(g_1-g_0)} - c\frac{p_1 g_1}{(g_1-g_0)} > 0, \tag{56}$$

and

$$EC_{IPE[(13)]} - EC_{FPE[(45),(47),(48)]} = c\frac{g_1}{(g_1-g_0)} - c\left[\frac{p_1}{(p_1-p_0)} + p_1\right] > 0. \tag{57}$$

(56) is obvious. To prove (57), note that for constraint (13) to be singly binding instead of (12), $s_{[(13)],2H} \geq s_{[(12)],2H}$ holds, which implies $\frac{c}{p_1 g_1 - p_1 g_0} \geq \frac{2c}{p_1 g_1 - p_0 g_0} \Leftrightarrow p_1 \geq \frac{p_0 g_0}{2g_0 - g_1}$. (If the latter condition is fulfilled, it is readily verified that $s_{[(13)],2H} \geq s_{[(11)],2H}$ also holds.) Plugging $\tilde{p_1} = \frac{p_0 g_0}{2g_0 - g_1}$ into (57) gives, after rearranging,

$$\left[\frac{g_1}{g_1-g_0} - \frac{g_0}{g_1-g_0}\right] - \frac{p_0 g_0}{2g_0 - g_1} > 0. \tag{58}$$

The term in brackets in (58) equals 1; the term $\frac{p_0 g_0}{2g_0 - g_1}$ is smaller than 1 because it equals the threshold level $\tilde{p_1}$ for constraint (13) to be singly binding, and it must hold $\tilde{p_1} \leq 1$. Therefore, the relation in (57) holds.

(iv) If both constraints (13) and (11) bind in IPE, (45) singly binds in FPE. From condition (18) so that (45) singly binds in FPE it follows that conditions for both $s^{2H}_{(13)} \geq s^{2H}_{(12)}$ and $s^{2H}_{(13)} \geq s^{2H}_{(11)}$ are met. Thus, neither constraint (11) nor (12) can be singly binding in this case. Only (13) can be singly binding (and this case has been considered in (iii)), or constraints (13) and (11) bind jointly. From (iii) it follows that at $g_0[(13);(11),(13)]$, $EC_{IPE[(13)]} = EC_{IPE[(11),(13)]} > EC_{FPE[(45)]}$. Note that $\lim_{g_0 \to g_1} EC_{FPE[(23)]} = \infty$ while $\lim_{g_0 \to g_1} EC_{IPE[(11),(13)]} = \frac{p_1 c}{p_1 - p_0} + \frac{b_1 c}{(1-p_1)(b_1-b_0)}$. Given Lemma 1, $EC_{IPE[(13,11)]}$ is monotone in g_0, and, by inspection, $EC_{FPE[(45)]}$ is increasing in g_0. Hence, there exists a unique threshold $\ddot{g_0}$—keeping all other parameters constant—such that $EC_{IPE[(11),(13)]} \gtrless EC_{FPE[(23)]}$ if $g_0 \lessgtr \ddot{g_0}$.

Scenario (II). The threshold $\ddot{g_0}$ is the same as in Scenario (I) above. To see this, note that—with increasing g_0—the jointly binding incentive constraints (11) and (12) or (12) and (13) precede the jointly binding constraints (11) and (13) because, for $g_0 \to g_1$, constraints (11) and (13) are relevant (lemma 1). At $g_0[(11),(12);(11),(13)]$ or $g_0[(12),(13);(11),(13)]$, where the transition to jointly binding constraints (11) and (13) takes place, all three incentive constraints (11)-(13) bind under IPE and this contract has been shown to be equally costly as the contract under FPE given the *unconditional* production schedule. Therefore, if a conditional production schedule is implemented under FPE, $EC_{IPE} > EC_{FPE}$ holds at $g_0[(11),(12);(11),(13)]$ or $g_0[(12),(13);(11),(13)]$, respectively, because the conditional production schedule under FPE is less costly to the principal than the unconditional production schedule. Then, the proof in part (iv) of Scenario (I) above applies accordingly.

The equality $\dot{g_0}^{(II)} = \dot{g_0}^{(I)}$ holds if a single constraint binds under IPE for all $g_0 \leq \dot{g_0}^{(I)}$ as established in Scenario (I). If jointly binding incentive constraints (11) and (12) or (12) and (13) become relevant for $g_0 > \dot{g_0}^{(I)}$, $EC_{IPE} > EC_{FPE}$ will hold for all $g_0 \in (\dot{g_0}^{(I)}, g_0[(11),(12);(11),(13)])$ or $g_0 \in (\dot{g_0}^{(II)}, g_0[(12),(13);(11),(13)]$. To see this note that $EC_{IPE} > EC_{FPE}$ holds for $g_0 > \dot{g_0}^{(I)}$ with a single, binding constraint under IPE and because EC_{IPE} is monotone in g_0 and EC_{FPE}—by inspection - is convex increasing in g_0. Given the existence of $\ddot{g_0}$ and $EC_{IPE} \leq EC_{FPE}$ if $g_0 \leq \ddot{g_0}$, the compensation functions $EC_{IPE}(g_0)$ and $EC_{FPE}(g_0)$ either never intersect or have to intersect three times for $g_0 \in (\dot{g_0}^{(I)}, g_0[(11),(12);(11),(13)]$ or $g_0 \in (\dot{g_0}^{(I)}, g_0[(12),(13);(11),(13)]$. Three intersections are ruled out by monotonicity and convexity, respectively, of expected compensation costs.

The threshold $\dot{g_0}^{(II)}$ applies if constraints (11) and (12) jointly bind for $g_0 < \dot{g_0}^{(I)}$. $\dot{g_0}^{(II)}$ is obtained from simplifying the zero of $EC_{IPE}[(11),(12)] - EC_{FPE}$. For $g_0 > \dot{g_0}^{(II)}$, the previous paragraph applies accordingly. Finally, if (12) and (13) become jointly binding, this will occur for $g_0 \geq g_0[(12),(13)] > \dot{g_0}^{(II)}$. To see this, note that at $\dot{g_0}^{(II)}$ either (12) singly binds (see the previous paragraph) or constraints (11) and (12) jointly bind for $g_0 \leq \dot{g_0}^{(II)}$. In either case, $EC_{IPE[(12),(13)]} > EC_{FPE}$ will apply and the previous paragraph applies accordingly.

Part (ii). The proof of Proposition 1 applies. ■

A.7 Conditional implementation $e_2(H) = 0, e_2(L) = 1$: Derivation of payments in FPE

The principal's program obtains from setting $(e_1^* = e_2^*(L) = 1, e_2^*(H) = 0)$ in (5). The constraints in explicit form are:

Table 9 Conditional effort—binding constraints and optimal contract given FPE

Binding constraint(s)	Nonzero payments	Expected compensation
(61), (63), (64)	$s^{HL} = c\left(\frac{1}{p_1-p_0} - 1 + \frac{b_1}{(b_1-b_0)}\right)$ $s^{LH} = c\left(\frac{1}{b_1-b_0}\right)$ $s^{HH} = s^{HL}$	$c\left[\frac{p_1}{(p_1-p_0)} - p_1 + \frac{b_1}{(b_1-b_0)}\right]$

$$E(S_{1;0,1}) \geq 0 \tag{59}$$

$$E(S_{1;0,1}) \geq E(S_{1;1}) \tag{60}$$

$$E(S_{1;0,1}) \geq E(S_{1;0}) \tag{61}$$

$$E(S_{1;0,1}) \geq E(S_{0;1}) \tag{62}$$

$$E(S_{1;0,1}) \geq E(S_{0;0}) \tag{63}$$

$$E(S_{1;0,1}) \geq E(S_{0;0,1}) \tag{64}$$

$$E(S_{1;0,1}) \geq E(S_{0;1,0}) \tag{65}$$

$$E(S_{1;0,1}) \geq E(S_{1;1,0}) \tag{66}$$

$$s^{ij} \geq 0. \tag{67}$$

Proceeding similarly to Sect. A.6, payments given in Table 9 can be determined. It is readily verified that constraints (61),(63) and (64) bind.

A.8 Proof of Proposition 3

Part (i): **Scenario (I) and (II).** Note that $\frac{\partial EC_{FPE}}{\partial g_0} = 0$ and $\frac{\partial EC_{IPE}}{\partial g_0} \geq 0$ irrespective of the binding constraint(s) in IPE. Since $EC_{IPE[(11)]} - EC_{FPE} < 0$ and:

$$\lim_{g_0 \to g_1} EC_{IPE[(13),(11)]} = c\left[\frac{p_1}{p_1 - p_0} + \frac{b_1}{(1-p_1)(b_1 - b_0)}\right] > c\left[\frac{p_1}{p_1 - p_0} - p_1 + \frac{b_1}{b_1 - b_0}\right] = EC_{FPE}, \tag{68}$$

existence of the unique threshold $\hat{g_0}$ follows.

Part (ii): The proof of Proposition 1 applies. ■

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