The Value of Transparency in Multidivisional Firms*

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Abstract

We study internal incentives, transparency and firm performance in multidivisional organizations. Two independent divisions of the same firm design internal incentives, and decide whether to publicly disclose their performances. In each division a risk-neutral principal deals with a risk-averse (exclusive) agent under moral hazard. Each agent exerts an unverifiable effort that creates a spillover on the effort cost of the other agent. We first study the determinants of the optimal principal-agent contract with and without performance transparency. Then, we show how effort spillovers affect the equilibrium communication behavior of each division. Both principals commit to disclose the performance of their agents in equilibrium when efforts are complements, while no communication is the only equilibrium outcome when efforts are substitutes.

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1 Introduction

Many large firms are heavily decentralized and delegate important tasks to independent divisions, whose objectives are not always aligned — see, e.g., Groves and Loeb (1979) and Wettstein (1994) among others. Lining up divisions' incentives often requires accurate information, whose costs may depend on the strategic interaction between the divisions' staff. For example, using information about one division to improve the performance of another may be difficult when divisions compete for the same budget, operate in the same or related markets, or one supplies the other with goods or services.

This paper examines the link between incentives, transparency and performance in multidivisional firms. Knowledge sharing mechanisms are traditionally believed to enhance efficiency: because they stimulate learning and imitation — see, e.g., Griffin and Hauser (1992) — or because, by improving firms' internal transparency, they enhance stakeholders' ability to access capital markets — see, e.g., Milgrom (1981) and Roberts (1992). However, these mechanisms may also affect firms' organization and contractual choices. What is the effect of transparency on the trade-off between risk and incentives in multidivisional firms? What are the costs and benefits of information sharing when divisions impose externalities one on the other?

To address these issues we study a firm composed of two independent divisions, each ruled by a principal (top manager) dealing with an exclusive agent (mid-level manager or worker). Top managers simultaneously and independently design incentive contracts for their workers and decide whether or not to publicly disclose their division's performance — i.e., they choose whether to be transparent or not.[1] Agents' effort is unverifiable and produces cross-division spillovers (externalities): an agent's marginal cost of effort depends on the effort exerted by the other agent, either negatively (complementary efforts) or positively (substitute efforts). Divisions are heterogeneous with respect to the volatility of their profits, and contracts can only be based on observed performances, which are an imperfect measure of agents' efforts and are correlated across divisions.

We start by analyzing how each principal conditions his own agent's wage to the performance of the other division (when he can do so), and study the determinants of equilibrium contracts with and without communication (transparency). This allows us to highlight the specificity of our contracting game relative to the benchmark in which there is only one principal-agent pair.

As expected, under secret contracts, incentives equal those of the benchmark when principals do not communicate. Instead, principals enforce steeper own-performance bonuses when both choose to be transparent. The wedge between incentives with and without multiple divisions widens as divisions become more connected: the more correlated are their performances, the steeper the incentives that principals offer in equilibrium.

The cross-performance bonus is determined by the need to diversify risk and its sign depends on

[1] A transparent division commits to publicly disclose its performance. This allows the principal of the other division to condition the payment pledged to his own agent not only on his performance (own-performance bonus), but also on the performance of the other agent (cross-performance bonus). The latter is, in fact, a form of relative performance evaluation.

the correlation between divisions' performances. When the divisions' performances are positively correlated, each principal rewards his agent if the other division under-performs, because a bad performance by the other division is a signal that his own agent may under-perform too. In this case the cross-performance bonus is negative. By contrast, when the correlation between divisions' performances is negative, each principal rewards his agent if the other division performs well to optimally diversify risk. Hence, the cross-performance bonus is positive. As intuition suggests, this bonus decreases in the volatility of the other division's performance: if performance becomes noisier, the value of information received by that division decreases.

Equilibrium efforts are unambiguously higher than in the case of a single principal-agent pair if effort externalities are positive, while the comparison yields ambiguous predictions when efforts are substitutes. In this case, two contrasting effects are at play. On the one hand, both principals offer steeper incentives than in the benchmark, thus boosting the agents' efforts. However, since efforts are strategic substitutes, the increase of one agent's effort implies a reduction of the other agent's effort. It turns out that the first effect dominates when the performance of the division from which a principal receives information is sufficiently noisy — i.e., receiving information from a transparent division mitigates moral hazard and enhances effort even if agents impose negative externalities one on the other.

Next, we characterize the equilibria of the communication game. Principals first decide whether to communicate or not, and then offer contracts to their agents. It turns out that, in equilibrium, the communication behavior of each principal depends on the nature of effort spillovers. When efforts are complements there is a unique equilibrium in which both divisions choose to be transparent, while no communication is the unique equilibrium when efforts are substitutes. Even though divisions are heterogeneous as to profits' volatility, asymmetric equilibria in which only one principal shares information do not exist.

Two main effects shape the incentives to share information in our setting. First, a principal's decision to share information generates an indirect strategic effect on his agent's effort. Indeed, the information disclosed to the other division is used to increase the effort of that division's agent, which indirectly affects the effort of the agent working for the principal who discloses his division's performance. Second, when a principal commits to disclose the performance of his division, he is also directly affecting his own agent's effort. This is because a principal's disclosure decision affects the effort of the agent working in the other division, which in turn determines the agency costs that the principal has to pay to control his own agent. Hence, any change in the effort of the other division modifies the fixed component of the wage that each principal pays to his own agent.

Taken together, these results offer novel predictions both on the type of vertical contracts that shape the internal organization of multidivisional firms, and on the process of communication among their independent profit centers. The model provides testable implications for: the determinants of divisions' incentives to share information; the link between the power of incentives and cross-division externalities; the impact of monitoring and contractual power on their internal structure; the limits to decentralization.

The rest of the paper is organized as follows. Section 2 relates our work to the received literature. Section 3 outlines the model. Section 4 characterizes the agents' effort choices and discusses some important features of the equilibrium contracts. Section 5 presents the equilibrium contracts in the subgames following the first-stage transparency decisions. In Section 6, we characterize the equilibrium disclosure choices. Section 7 concludes. Proofs are in the Appendix.

2 Related literature

Our findings contribute to the literature on multidivisional firms. Stemming from Hirshleifer (1957), this literature has examined the resource allocation problem of the headquarter of a divisionalized firm, whose objective is to harmonize incentives among different, and possibly competing, divisions. An efficient allocation of resources is achieved either directly, through a centralized design of incentives — see, e.g., Faulí-Oller and Giralt (1995) and Groves and Loeb (1979) among others — or, indirectly, through transfer prices between units — see, e.g., Baldenius and Reichelstein (2006) and Harris, Kriebel, and Raviv (1982). In our model, units' contracting decisions are fully decentralized — i.e., they cannot be set by the headquarter. This seems reasonable when contracts can be secretly renegotiated.

Another strand of related literature examines firms' optimal organization form as a response to information asymmetries within firms — see, e.g., Aghion and Tirole (1995), Berkovitch, Israel, and Spiegel (2010), Besanko, Régibeau, and Rockett (2005), Maskin, Qian, and Xu (2000), Qian, Roland, and Xu (2006) and Rotemberg (1999) among many others. All these papers develop theories in which firms' organizational structure is endogenous, and is determined by the trade-offs between the costs and the benefits of divisionalization. In our model the firm structure is exogenous: our objective is to analyze the potential conflicts between units and determine how asymmetries between them determine their decisions on contracts and transparency.

In this respect, our model is closer in spirit to the growing literature linking the issue of optimal contract design to that of communication between principals. Calzolari and Pavan (2006) devise a sequential game in which principals dealing with the same (privately informed) agent learn through costly contracting and then share with the rival the elicited information. More recently, Piccolo and Pagnozzi (2013) have extended this idea to the case of vertical hierarchies. In these models, players acquire private information by contracting with common parties, and create new private information by taking decisions that affect both rivals and contractual counterparts. The approach taken in this literature is different from the one employed in oligopoly models — e.g., Novshek and Sonnenschein (1982), Clarke (1983), Vives (1984), Gal-Or (1985) — where the information shared by competitors is exogenous. In these models there are no incentive issues within firms and communication may simply help to overcome coordination problems, thereby facilitating implicit collusion.[2]

[2]The standard industrial organization approach to information sharing has been applied in the management literature studying information sharing within supply chains. In these models a manufacturer deals with competing retailers and the information sharing decision depends on the contract type and the form of competition (see, e.g., Ha

On the moral hazard side, Maier and Ottaviani (2009) study the costs and benefits of transparency in a common agency game in which principals commit to share information about the common agent's performance. We study the case of exclusive deals. In contrast to Maier and Ottaviani (2009), we find that with exclusive deals the type of externalities that divisions impose one on the other is crucial to determine the equilibrium degree of transparency. This difference arises because in our model the agents' efforts are imperfect complements and can even be substitutes, while in their framework the effort of the common agent affects the profits of both principals. In a nutshell, while in Maier and Ottaviani (2009) the main issue is free-riding — i.e., each principal would like the other to pay for the agent's effort — in our model this problem disappears when efforts are substitutes.

Finally, our paper also contributes to the literature on relative performance evaluation. The possibility of linking an agent's compensation to the performance of another agent *de facto* allows principals to enforce relative performance evaluations. While the existing literature has mainly focused on the problem of a single principal dealing with several agents that free-ride one on the other — see, e.g., (Bolton and Dewatripont, 2005, Ch. 8) — in our context information sharing provides a natural tool to enforce the relative performance evaluation of agents that serve principals with (possibly) conflicting objectives. To the best of our knowledge, only Bertoletti and Poletti (1996) analyze a similar idea in a context with adverse selection and risk neutral agents. Lottery contracts in their setting allow to implement the first-best outcome.

3 The model

Players and environment. Consider a firm consisting of two independent divisions (departments or profit centers). Division i ($i = 1, 2$) is modeled as a principal-agent pair, composed by a principal (manager) P_i, and an exclusive agent (mid-level manager, or employee) A_i. Each division carries over a project that yields a gross profit y_i, which is linear in A_i's unverifiable effort, a_i, and in an additive random component, ε_i. That is,

$$y_i = a_i + \varepsilon_i, \tag{1}$$

where $\varepsilon_i \sim N(0, \sigma_i^2)$ for every i. We allow ε_1 and ε_2 to be correlated, with $\text{Cov}(\varepsilon_1, \varepsilon_2) = \rho\sigma_1\sigma_2$. The parameter $\rho \in [-1, 1]$ denotes the correlation index between the divisions' (gross) profits y_1 and y_2.

Preferences. Principals are risk neutral and offer contracts (wages) to their exclusive agents. P_i maximizes his expected (gross) profit net of the wage paid to A_i. Thus, P_i's objective function is

$$\mathbb{E}[y_i - w_i(\cdot)], \tag{2}$$

and Tong (2008); Li and Zhang (2008), among many others). We contribute to this literature by studying the impact of divisions internal incentives on cross-divisions communication strategies. In a sense, our approach innovates upon this literature by opening the black-box of divisions.

where $w_i(\cdot)$ denotes A_i's wage, whose structure depends on the transparency choice of each division and will be introduced shortly.

Agents are risk-averse with CARA preferences and additively separable effort cost — i.e., A_i's certainty utility is

$$u_i(w_i, a_i, a_j) = 1 - e^{-r(w_i - \psi_i(a_i, a_j))}.$$

The function $\psi_i(a_i, a_j)$ measures A_i's cost of exerting effort a_i, which depends also on A_j's effort. The parameter $r > 0$ indicates the absolute risk-aversion index, which (for simplicity) is common to both agents. Following Faulí-Oller and Giralt (1995) and Berkovitch, Israel, and Spiegel (2010), we assume that

$$\psi_i(a_i, a_j) = \frac{a_i^2}{2} - \delta a_i a_j.$$

This specification for the effort cost includes a standard quadratic component ($a_i^2/2$) and an interaction term ($\delta a_i a_j$), which reflects potential externalities that agents may exert on each other. The parameter $\delta \in (-1, 1)$ is key to our analysis: it measures the type of (strategic) interaction between agents' efforts.[3] Agents' efforts are strategic substitute when $\delta < 0$, as they create negative spillovers across business units — e.g., when these units compete for the same budget, or when they operate on the same or related markets. When $\delta > 0$, instead, agents' efforts are strategic complements. This case captures, for example, the positive externalities generated by investments in basic R&D and informative advertising campaigns that benefit not only the unit enacting them, but also the other units of an organization. Alternatively, positive spillovers may emerge when business units jointly invest in essential facilities, such as distributional networks, that allow them to market their products more effectively and reduce operating costs.

Communication, contracts and timing. A transparent division discloses its performance to the other division. Principals choose their disclosure rule (all or nothing) independently. Further, we assume that this choice is publicly observable and there is full commitment to it. This gives rise to three scenarios: one in which both principals choose to be transparent *(full communication)*, one in which none does *(no communication)*, and one in which only one does *(partial or one-sided communication)*.

The timing of the game is as follows:

- ($T = 0$) Principals decide whether to disclose their agents' performance.
- ($T = 1$) The chosen transparency regime is observed by all players. Principals offer contracts.
- ($T = 2$) Agents choose efforts, the projects' returns realize and principals disclose information (if they committed to do so). Payments are made.

[3] Note that this interaction is on the intensive margin only. We rule out externalities on the extensive margin which play no role under secret contracts.

Contracts are secret and, hence, have no strategic value.[4] We restrict the analysis to the class of linear contracts — i.e., each principal offers a wage

$$w_i(y_i, y_j) = \alpha_i + \beta_i y_i + \mathbb{I}_j \gamma_i y_j \quad \forall i, j = 1, 2, \tag{3}$$

where the indicator function $\mathbb{I}_j \in \{0, 1\}$ takes value 1 if P_j adopts a transparent regime and shares with P_i the information regarding A_j's performance, and equals 0 otherwise. Hence, α_i is the fixed wage component, β_i measures the responsiveness of A_i's pay to his own performance (the standard bonus in this literature), while γ_i measures how A_i's wage reacts to A_j's performance (the cross-performance component of the wage).

The reason why we focus on linear contracts is twofold. First, this restriction is standard in the CARA-normal setting — see, e.g., (Bolton and Dewatripont, 2005, Ch. 5). This approach hinges on Hölmstrom and Milgrom (1987), which shows that linear contracts are optimal in a dynamic CARA-normal model if effort is chosen in continuous time by the agent and (at each stage) the principal rewards him based on the overall history of past performances.[5] The same type of argument justifies the use of linear contracts in our setting, because secret contracts imply that managerial compensations have no strategic value. Second, we consider linear contracts to compare our results with those of Maier and Ottaviani (2009), who impose the same restriction in a setting with common agency.

The possibility of conditioning the wage of one agent on the performance of the other *de facto* introduces a simple form of relative performance evaluation. To avoid the possibility that agents (collectively) undo the effect of these contracts we rule out side transfers across divisions. Each player's outside option is normalized to zero.

Equilibrium concept. The equilibrium concept is *Perfect Bayesian Equilibrium* (PBE). Since contracts are private, we have to make an assumption on each agent's off-equilibrium beliefs about behavior in the other division. Following most of the literature on private contracts (e.g., Caillaud, Jullien, and Picard (1995) and Martimort (1996)), we assume that agents have *passive beliefs*: regardless of the contract offered by his principal, an agent always believes that the other principal offers the equilibrium contract and the other agent exerts the equilibrium effort. This assumption captures the idea that, since principals are independent and act simultaneously, a principal cannot signal to his agent information that he does not possess about the other principal's contract — i.e., the *no signal what you do not know* requirement introduced by Fudenberg and Tirole (1991).

We solve the model under two natural assumptions that must hold in every possible scenario. The first prescribes that an agent is willing to exert positive effort at equilibrium — i.e., $a_i > 0$. The

[4] The commitment value of observable contracts has been extensively analyzed in the traditional industrial organization literature. We will abstract from this issue by assuming secrecy, which is natural when public contracts can be secretly renegotiated, or when division principals can overturn the contractual rules chosen by the firm's headquarter — see, e.g., Katz (1991).

[5] Although standard in the applied contract theory literature, it must be noted that the restriction to linear contracts is not without loss of generality. Mirrlees (1999) argues that (already in a single principal-agent model) discontinuous contracts are nearly first-best.

second is that an agent's effort cost and its derivative cannot be negative — i.e., $\psi_i(a_i, a_j) \geq 0$ and $\frac{\partial}{\partial a_i}\psi_i(a_i, a_j) \geq 0$ for every admissible pair (a_i, a_j). The latter, in turn, implies that the marginal cost of effort is positive. In the Appendix we provide a formal statement of these assumptions.

The single principal-agent pair benchmark. Before turning to the equilibrium analysis, recall that without cross-division spillovers ($\delta = 0$), the agent's effort choice satisfies the first-order condition $a_i = \beta_i$, and the optimal contract entails

$$\beta_i^* = a_i^* = \frac{1}{1 + r\sigma_i^2}.$$

Hence, both a higher volatility (σ_i^2) and a higher risk aversion index (r) induce P_i to offer a low-powered incentive scheme. This is because more uncertainty makes the realized profit y_i a worse indicator of A_i's effort and greater risk-aversion commands a larger risk-premium for the agent — see, e.g., (Bolton and Dewatripont, 2005, Ch. 4) and (Laffont and Martimort, 2002, Ch. 4). Throughout the paper we study how the introduction of the correlation term ρ and the effort interaction parameter δ shapes equilibrium contracts and transparency.

4 Contract design: preliminary insights

In this section we characterize how the contract offered by one principal is affected by the choice on transparency made by the other principal. To this purpose, we first study the effort game between agents and then turn to analyze the principals' contract choices.

Optimal effort. Suppose that A_j chooses effort a_j in equilibrium. Using the wage function in (3) together with the performance structure in (1) yields

$$w_i(y_i, y_j) = \alpha_i + \beta_i \underbrace{(a_i + \varepsilon_i)}_{y_i} + \mathbb{I}_j \gamma_i \underbrace{(a_j + \varepsilon_j)}_{y_j}. \tag{4}$$

Hence, agent A_i's certainty equivalent is[6]

$$CE_i(a_i, a_j) \equiv \alpha_i + \beta_i a_i + \mathbb{I}_j \gamma_i a_j - \frac{r}{2}[\sigma_i^2 \beta_i^2 + \mathbb{I}_j(\sigma_j^2 \gamma_i^2 + 2\beta_i \gamma_i \sigma_i \sigma_j \rho)] - \frac{a_i^2}{2} + \delta a_i a_j. \tag{5}$$

[6]Due to the noise in the performance measures, agents receive an uncertain wage for any pair of efforts they choose. When this noise is normally distributed and the gents' utility has the CARA form, it is convenient to carry out the analysis in terms of the certainty equivalent each agent obtains upon choosing a given level of effort, holding fixed the effort of the other agent. By definition, the certainty equivalent is the certain payment that gives an agent the same expected utility obtained with the original gamble:

$$1 - e^{-rCE_i(\cdot)} = 1 - \mathbb{E}\left[e^{-r\left[\alpha_i + \beta_i a_i + \mathbb{I}_j \gamma_i a_j + \beta_i \varepsilon_i + \mathbb{I}_j \gamma_i \varepsilon_j - \frac{a_i^2}{2} + \delta a_i a_j\right]}\right].$$

It follows that the effort level that maximizes A_i's expected utility is

$$a_i(a_j) \equiv \beta_i + \delta a_j, \tag{6}$$

which defines A_i's best reaction to A_j's effort. This function depends in a direct way only on the sensitivity of A_i's wage to own performance y_i — i.e., β_i — but not on the cross-performance bonus γ_i: in fact, P_j's decision on the transparency regime has no direct impact on A_i's optimal effort. This is because the performance of each agent depends exclusively on his own effort and not on that of the other agent.[7] Nevertheless, A_i's reaction function depends on A_j's effort, so the choice of P_j on the transparency regime indirectly affects A_i's effort insofar as it affects A_j's effort, as will be explained shortly.

Using the expressions in (6), it is then easy to prove the following lemma.

Lemma 1 *Regardless of the transparency regime, if principals are expected to offer β_i and β_j in equilibrium, the agents' equilibrium effort choices are*

$$a_i(\beta_i, \beta_j) \equiv \frac{\beta_i + \delta\beta_j}{1-\delta^2} \quad \forall i, j = 1, 2, \tag{7}$$

with $\frac{\partial a_i(\beta_i,\beta_j)}{\partial \beta_i} > 0$, and $\frac{\partial a_i(\beta_i,\beta_j)}{\partial \beta_j} \geq 0$ if, and only if, $\delta \geq 0$.

The positive sign of the impact of β_i on a_i is intuitive. Moreover, note that the impact of β_j on a_i depends on the sign of δ. A higher value of β_j induces A_i to work more if efforts generate positive spillovers ($\delta > 0$): with complementarity, a higher effort by A_j reduces A_i's marginal cost of effort. Hence, an increase in β_j raises a_j and translates into a higher effort's value by agent A_i. The opposite holds true when efforts are substitutes and generate negative spillovers ($\delta < 0$).

Optimal (linear) contracts. Suppose that A_j is expected to exert effort a_j in equilibrium. Regardless of the first-stage P_i's decision on transparency, A_i's (ex ante) participation constraint binds in equilibrium — i.e., (5) is equal to zero — so that

$$\alpha_i + \beta_i a_i(a_j) + \mathbb{I}_j\gamma_i a_j \equiv \frac{r}{2}[\sigma_i^2\beta_i^2 + \mathbb{I}_j(\sigma_j^2\gamma_i^2 + 2\beta_i\gamma_i\sigma_i\sigma_j\rho)] + \frac{a_i(a_j)^2}{2} - \delta a_i(a_j)a_j. \tag{8}$$

Using the linear performance in (1) together with the wage structure in (4), P_i's objective function is

$$\mathbb{E}[a_i(a_j) + \varepsilon_i - (\alpha_i + \beta_i a_i(a_j) + \mathbb{I}_j\gamma_i a_j + \beta_i\varepsilon_i + \mathbb{I}_j\gamma_i\varepsilon_j)] = a_i(a_j) - [\alpha_i + \beta_i a_i(a_j) + \mathbb{I}_j\gamma_i a_j].$$

[7] See a previous version of the paper for a model in which each agent's effort affects not only his own performance, but also the other agent's performance.

Hence, (8) implies that P_i's maximization problem writes as

$$\max_{(\beta_i,\gamma_i)} \left\{ a_i\left(a_j\right) - \frac{r}{2}\left[\sigma_i^2\beta_i^2 + \mathbb{I}_j(\sigma_j^2\gamma_i^2 + 2\beta_i\gamma_i\sigma_i\sigma_j\rho)\right] - \frac{a_i\left(a_j\right)^2}{2} + \delta a_i\left(a_j\right)a_j \right\}, \tag{9}$$

where $a_i(a_j)$ is given by (6).

The first-order conditions with respect to β_i and γ_i are, respectively

$$\frac{\partial a_i\left(a_j\right)}{\partial \beta_i} = r\left[\sigma_i^2\beta_i + \mathbb{I}_j\gamma_i\sigma_i\sigma_j\rho\right] + \frac{\partial a_i\left(a_j\right)}{\partial \beta_i}\left[a_i\left(a_j\right) - \delta a_j\right], \tag{10}$$

$$-r\mathbb{I}_j(\sigma_j^2\gamma_i + \beta_i\sigma_i\sigma_j\rho) = 0, \tag{11}$$

where $\frac{\partial a_i(a_j)}{\partial \beta_i} = 1$ by equation (6). Indeed, because contracts are secret, any (out of equilibrium) change in β_i affects A_i's effort only through its direct effect on (6) — i.e., holding A_j's effort fixed at the (conjectured) equilibrium level.

These first-order conditions highlight how the basic trade-off between risk and incentives changes in a multidivisional firm in which, due to transparency, the principal of each division may tailor his agent's compensation to the performance of the agents working for other divisions. The first-order condition with respect to β_i in equation (10) has a simple interpretation. Its left-hand side is standard and represents the marginal benefit associated with an increase in the own performance bonus. The two terms on the right-hand side capture the impact of a higher bonus on A_i's risk premium and effort cost. First, a higher bonus β_i makes A_i more responsive to his own performance. Hence, it increases the agent's risk exposure and calls for higher insurance: a standard cost of providing high-powered incentives. Other things being equal, this extra cost depends not only on A_i's risk aversion (r) and the volatility of division-i's profit (σ_i), but also on whether principal P_j commits to disclose information. If he does, agent A_i's insurance will also depend on the sensitivity of his wage to A_j's performance (γ_i), the correlation index (ρ) and the volatility of division-j's profit (σ_j). The second term on the right-hand side of (10) shows that, by increasing agent A_i's effort, a higher own-performance bonus makes it more costly for the agent to exert effort. Also, it illustrates the effect of the interaction term δa_j on P_i's optimal contract. When δ is negative, so that efforts are strategic substitutes, principal P_i is less willing to offer a high-powered incentive if agent A_j is expected to exert high effort in equilibrium. The opposite holds when efforts are complements ($\delta > 0$).

The first-order condition with respect to γ_i in (11) represents the main novelty of introducing the choice on transparency in a setting with multiple divisions. Clearly, this condition matters only if P_j discloses A_j's performance to P_i — i.e., if $\mathbb{I}_j = 1$. Two effects determine the cross-performance bonus γ_i. First, by making A_i's compensation more responsive to A_j's performance, P_i induces A_i to take a higher risk, for which he needs to be compensated. Second, there is a risk-diversification effect: when A_i's wage is tailored to his opponent's performance, increasing γ_i spurs P_i's expected profits as long as the agents' performances are negatively correlated ($\rho < 0$), whereas it decreases P_i's expected profits if the agents' performances are positively correlated ($\rho > 0$). The strength of this risk-diversification effect clearly depends on the magnitude of the own-performance bonus β_i.[8] If β_i is equal to zero then there is no need for risk-diversification because A_i's wage does not depend on A_j's performance. By contrast, when β_i is positive, A_i's wage positively depends on his own performance. Hence, to diversify A_i's risk exposure, P_i chooses a positive cross-performance bonus γ_i when ε_1 and ε_2 are negatively correlated, and a negative one when they are positively correlated.

5 Equilibrium analysis

We now characterize the equilibrium efforts and contracts chosen in every subgame following the principals' (first-stage) communication decisions.

5.1 No communication

Consider the subgame in which none of the divisions commits to disclose its performance — i.e., $\mathbb{I}_i = \mathbb{I}_j = 0$ — and let $\alpha_i^n + \beta_i^n y_i$ be the wage offered by P_i.

Proposition 1 *In the regime without communication*

$$\beta_i^n \equiv \frac{1}{1 + r\sigma_i^2} = \beta_i^* \quad \forall i = 1, 2.$$

At equilibrium, agent A_i exerts effort

$$a_i^n \equiv \frac{1 + r\sigma_j^2 + \delta(1 + r\sigma_i^2)}{\left(1 - \delta^2\right)\left(1 + r\sigma_i^2\right)\left(1 + r\sigma_j^2\right)} \geq 0 \quad \forall i = 1, 2.$$

Moreover, $a_i^n \geq a_j^n$ if, and only if, $\sigma_i^2 \leq \sigma_j^2$, a_i^n decreases with σ_i^2, and it increases with σ_j^2 if, and only if, $\delta < 0$.

Because we assumed unobservable contracts and passive beliefs, principals offer the same bonus as in the standard principal-agent problem (which obtains when $\delta = 0$) — i.e. $\beta_i^n = \beta_i^*$. This is because the effort of agent A_i reacts to a change in its own bonus β_i only via its direct impact on a_i — see equation (6).

Finally, using the equilibrium condition (7) and the expression for the equilibrium bonus β_i^n, we compare the agents' efforts to that exerted in the single principal-agent model.

Corollary 1 *If there are positive effort spillovers, $\delta \geq 0$, then $a_i^n \geq a_i^*$. By contrast, if there are negative spillovers, $\delta < 0$, then $a_i^n \geq a_i^*$ if σ_j^2 is large enough.*

Both agents exert more effort than in the single principal-agent model when spillovers are positive. That is, $a_i^n > a_i^*$ when $\delta > 0$, with $a_i^n = a_i^*$ if $\delta = 0$. The reason is that principals

[8] For the sake of exposition, we assume here that β_i is positive. We later verify that in equilibrium $\beta_i > 0$.

can exploit the synergies between their agents to implement higher efforts at lower costs. When, instead, efforts are substitutes the result is non-obvious because of the strategic effect linking the agents' effort choices. The result shows that, in the regime without communication, a_i^n exceeds a_i^* when σ_j^2 is large enough. This is because, since A_j's effort is decreasing in σ_j^2, as σ_j^2 increases the division-j's monitoring power weakens and the externality that A_j imposes on P_i becomes negligible.

5.2 Full transparency

Consider the subgame in which both divisions disclose their performance — i.e., $\mathbb{I}_i = \mathbb{I}_j = 1$ — and let $\alpha_i^t + \beta_i^t y_i + \gamma_i^t y_j$ be P_i's wage offer.

Proposition 2 *Assume that both principals choose to be transparent, then*

$$\beta_i^t \equiv \frac{1}{1 + r\sigma_i^2 (1-\rho^2)} \quad \forall i = 1,2, \tag{12}$$

$$\gamma_i^t \equiv -\frac{\sigma_i}{\sigma_j} \frac{\rho}{1 + r\sigma_i^2 (1-\rho^2)} \quad \forall i,j = 1,2. \tag{13}$$

Hence, $\beta_i^t \geq \beta_i^n = \beta_i^*$ *and* $\gamma_i^t \geq 0$ *if, and only if,* $\rho \leq 0$*. Moreover,*

$$a_i^t \equiv \frac{1 + \delta + r(1-\rho^2)(\sigma_j^2 + \delta\sigma_i^2)}{(1-\delta^2)(1 + r\sigma_i^2 (1-\rho^2))(1 + r\sigma_j^2 (1-\rho^2))} \geq 0 \quad \forall i,j = 1,2,$$

with $a_i^t \geq a_j^t$ *if, and only if,* $\sigma_j \geq \sigma_i$*. Effort* a_i^t *decreases with* σ_i^2*, while it increases with* σ_j^2 *if, and only if,* $\delta < 0$*.*

As for the case without communication (Proposition 1), and for the same reasons discussed above, the equilibrium contracts offered by P_i and P_j do not depend on the interaction parameter δ. However, the equilibrium contracts under full transparency differ from those obtained in the no communication regime along two fundamental dimensions. First, since the divisions' performances are correlated, with full transparency principals can optimally diversify the risk taken by their agents, thereby reducing agency costs and implementing steeper incentive schemes — i.e., $\beta_i^t \geq \beta_i^n = \beta_i^*$. Moreover, one can easily verify that

$$\frac{\partial \beta_i^t}{\partial \rho} = \frac{2r\rho\sigma_i^2}{\left(1 + r\sigma_i^2 (1-\rho^2)\right)^2} \geq 0 \quad \Leftrightarrow \quad \rho \geq 0.$$

A U-shaped relationship arises between the own-performance coefficient β_i^t and the correlation index ρ: when the divisions' performances are strongly correlated (either positively or negatively) principals exploit more heavily risk-diversification to reduce agency costs. This, in turn, allows them to provide steeper incentives.

Equation (13) establishes the link between A_i's equilibrium wage and A_j's performance. The sign of this coefficient depends on the correlation index ρ and again hinges on the risk-diversification logic discussed above. When performances are positively correlated ($\rho > 0$) a bad performance by A_j likely causes A_i to underperform. Hence, principal P_i rewards his agent when division j underperforms ($y_j < 0$). Thus, $\gamma_i^t < 0$ in this case. By the same token, when performances are negatively correlated ($\rho < 0$) risk-diversification induces P_i to reward A_i when the other division performs well — i.e., $\gamma_i^t > 0$. Finally, notice that γ_i^t is decreasing in σ_j^2: receiving information from a division whose performance is noisy has little value. As a consequence, the incentive scheme is optimally less responsive to such information.

Differentiating with respect to ρ and σ_i, one can also verify that

$$\begin{aligned} \frac{\partial \gamma_i^t}{\partial \rho} &= -\frac{\sigma_i}{\sigma_j} \frac{1+\sigma_i^2 r\left(1+\rho^2\right)}{\left(1+r\sigma_i^2\left(1-\rho^2\right)\right)^2} < 0, \\ \frac{\partial \gamma_i^t}{\partial \sigma_i} &= -\frac{\rho\left(1-r\sigma_i^2\left(1-\rho^2\right)\right)}{\sigma_j\left(1+r\sigma_i^2\left(1-\rho^2\right)\right)^2} \geq 0 \quad \Leftrightarrow \quad -\rho\left[2-\frac{1}{\beta_i^t}\right] \geq 0. \end{aligned} \tag{14}$$

The derivative in (14) measures the impact of the correlation index ρ on the cross-performance bonus γ_i^t. As ρ grows larger in absolute value, the divisions' profits become more correlated. Thus, to diversify risk, principal P_i responds with a reduction of the (absolute) value of γ_i^t if performances are positively correlated, and with an increase in γ_i^t otherwise.

The impact of σ_i on γ_i^t is shaped by two contrasting effects. First, holding β_i fixed, a larger σ_i implies more need for risk-diversification because agent A_i takes more risk. Hence, γ_i must increase in absolute value: a direct risk-diversification effect. Second, a larger σ_i implies a lower β_i because division-i's performance is noisier. This induces a lower γ_i because agent A_i takes less risk: an indirect risk-shifting effect. The tension between these two effects depends on the sign of ρ and the magnitude of the own-performance bonus β_i^t. Assume first that $\rho > 0$, so that $\gamma_i^t < 0$. Then, a larger σ_i tends to increase γ_i^t in absolute value when $\beta_i^t < \frac{1}{2}$, because the direct risk-diversification effect dominates the indirect risk-shifting effect. Next, assume $\rho < 0$, so that $\gamma_i^t > 0$. In this case, a larger σ_i tends to increase γ_i^t when $\beta_i^t < \frac{1}{2}$, because the direct risk-diversification effect dominates the indirect risk-shifting effect.

Finally, combining condition (7) with the equilibrium bonus β_i^t, Corollary 2 below compares agents' efforts in the full transparency regime to the equilibrium effort in the benchmark model.

Corollary 2 *If there are positive effort spillovers, $\delta \geq 0$, then $a_i^t \geq a_i^*$. By contrast, if there are negative spillovers, $\delta < 0$, then $a_i^t \geq a_i^*$ if, and only if, σ_j^2 is large enough.*

The economic intuition behind these results is the same as that offered for Corollary 1.

5.3 Partial (one-sided) communication

Finally, consider the subgame in which only one principal (P_1, say) chooses to be transparent. Principal P_2 has a competitive advantage: he can use the additional information provided by P_1 to control A_2's effort, whereas P_1 can only condition A_1's wage on his own performance. Let $\alpha_1^{t,n} + \beta_1^{t,n} y_1$ be P_1's wage offer and $\alpha_2^{n,t} + \beta_2^{n,t} y_2 + \gamma_2^{n,t} y_1$ be P_2's wage offer in equilibrium.

Proposition 3 *When only P_1 is transparent $\beta_1^{t,n} = \beta_1^n$, $\beta_2^{n,t} = \beta_2^t$ and $\gamma_2^{n,t} = \gamma_2^t$. Agent A_i's effort decreases with σ_i^2. Moreover, it increases with σ_j^2 if, and only if, $\delta < 0$.*

If only one principal commits to be transparent, the equilibrium contracts are the same as those in Propositions 1 and 2 above. However, the principal that receives information copes more effectively with the moral hazard problem he has with his own agent, as compared to the other principal who draws inference about his agent's effort based on his own performance only.

Finally, using the equilibrium condition (7), it can be easily shown that

$$a_1^{t,n} \equiv \frac{\beta_1^n + \delta\beta_2^t}{1-\delta^2} = \frac{1+\delta+r\delta\sigma_1^2+r\sigma_2^2(1-\rho^2)}{\left(1-\delta^2\right)\left(1+r\sigma_1^2\right)\left(1+r\sigma_2^2\left(1-\rho^2\right)\right)},$$

$$a_2^{n,t} \equiv \frac{\beta_2^t + \delta\beta_1^n}{1-\delta^2} = \frac{1+\delta+r\sigma_1^2+r\sigma_2^2\delta(1-\rho^2)}{\left(1-\delta^2\right)\left(1+r\sigma_1^2\right)\left(1+r\sigma_2^2\left(1-\rho^2\right)\right)},$$

implying that

$$a_i^{t,n} - a_i^t = \frac{1}{1-\delta^2}\left[\beta_i^n - \beta_i^t\right] \leq 0,$$

and

$$a_i^{n,t} - a_i^n = \frac{1}{1-\delta^2}\left[\beta_i^t - \beta_i^n\right] \geq 0.$$

Hence, agent A_i's effort is higher when principal P_j commits to be transparent, regardless of principal P_i's disclosure decision.

6 Communication at equilibrium

Solving the model backward, in this section we characterize the equilibrium of the whole game. We first study how the transparency choice of one principal affects his agent's effort, holding fixed the transparency choice of the other principal. The insights offered by this simple exercise are useful to understand the forces that drive the equilibrium outcome of the game.

Proposition 4 *Effort choices satisfy the following properties:*

(i) $a_i^t \geq a_i^{n,t}$ *for every* $i = 1, 2$ *if, and only if,* $\delta \geq 0$*;*

(ii) $a_i^n \geq a_i^{t,n}$ *for every* $i = 1, 2$ *if, and only if,* $\delta \leq 0$*.*

Holding fixed P_j's (first-stage) behavior, P_i's decision to be transparent increases A_i's effort if and only if agents exert positive externalities one on the other ($\delta \geq 0$). In fact, the information that P_i discloses to P_j is used to increase A_j's effort, which in turn boosts A_i's effort due to complementarity. The opposite is true when efforts are strategic substitutes ($\delta \leq 0$).

Building on this result, we can now characterize the equilibrium of the game. Principals' expected profits when they choose to disclose information (t) or not (n) are illustrated in Figure 1.

		P_2	
		t	n
P_1	t	π_1^t, π_2^t	$\pi_1^{t,n}, \pi_2^{n,t}$
	n	$\pi_1^{n,t}, \pi_2^{t,n}$	π_1^n, π_2^n

Figure 1: Communication Game.

Observe first that transparency does not affect principals' expected profits when there are no effort externalities ($\delta = 0$) or when divisions' performances are uncorrelated ($\rho = 0$). If there is no strategic interaction between the agents, communication only allows principals to enforce welfare enhancing relative performance evaluations. Hence, it is easy to verify that principals coordinate on the equilibrium with full transparency, which clearly maximizes their joint profits. Similarly, if division performances are uncorrelated, disclosing information about own performance to the other division has no impact on the effort choice of that division's agent. Hence, for $\rho = 0$ principals are indifferent between being transparent or not. By contrast, when δ and ρ are different from zero strategic considerations shape the divisions' equilibrium behavior. We now discuss them and find the conditions under which communication occurs at equilibrium.

Consider first an outcome in which both principals choose to be transparent. This is an equilibrium if, and only if, the following holds

$$\pi_i^t \geq \pi_i^{n,t} \quad \forall i = 1, 2.$$

Using the objective function (9), the above condition can be split in two parts

$$\pi_i^t - \pi_i^{n,t} \equiv \underbrace{a_i^t - \psi(a_i^t, a_j^t) - \left[a_i^{n,t} - \psi(a_i^{n,t}, a_j^t)\right]}_{\text{Strategic Effect}} \underbrace{+\delta a_i^{n,t}\left[a_j^t - a_j^{t,n}\right]}_{\text{Fixed-fee Effect}} \geq 0. \tag{15}$$

First, principal P_i's decision to be transparent has an indirect effect on agent A_i's effort: the information disclosed to P_j is used to increase A_j's effort, which indirectly affects A_i's effort. *De facto*, the disclosure of a division's performance can be interpreted as a commitment device to rise the rival's effort. This gives rise to a strategic effect that is captured by the first term in equation (15). Specifically, the difference in the first term measures P_i's gain from disclosing information holding A_j's effort equal to its (candidate) equilibrium level a_j^t. Moreover, when P_i commits to be transparent he is also directly affecting A_i's expected utility. This is because the information he discloses impacts on A_j's effort, which in turn determines A_i's effort cost. Hence, holding A_i's effort equal to its deviation level $a_i^{n,t}$, any change in a_j induced by P_i's first-stage decision modifies the fixed component of A_i's wage, which impacts on division i's expected profit.

Next, consider an outcome of the game in which both principals refrain from being transparent. This is an equilibrium if, and only if, the following holds

$$\pi_i^n \geq \pi_i^{t,n} \quad \forall i = 1, 2.$$

Using the objective function stated in equation (9) the above condition can be rewritten as

$$\pi_i^n - \pi_i^{t,n} \equiv \underbrace{a_i^n - \psi(a_i^n, a_j^n) - \left[a_i^{t,n} - \psi(a_i^{t,n}, a_j^n)\right]}_{\text{Strategic Effect}} - \underbrace{\delta a_i^{t,n}\left[a_j^{n,t} - a_j^n\right]}_{\text{Fixed-fee Effect}} \geq 0. \tag{16}$$

Again, principal P_i's incentive not to disclose information can be split into two components, reflecting the role of the strategic and the fixed-fee effects discussed above. First, when principal P_i refuses to be transparent, he gives up the possibility of influencing agent A_j's effort choice through P_j's contract. Thus, depending on whether efforts are strategic complements or substitutes, by refusing to communicate P_i decreases or increases A_i's performance. Second, holding fixed A_i's effort, when principal P_i decides not to disclose information he shifts agent A_j's effort downward, which has an impact on A_i's effort cost thereby affecting the fixed component of the wage that P_i must pay to A_i.

It turns out that the direction of the effects just described and the signs of (15) and (16) uniquely depend on the sign of δ.

Proposition 5 *For any admissible value of δ, the equilibrium exists and is unique. It features full communication if $\delta \geq 0$, and no communication if $\delta < 0$.*

To understand the result, consider first a fully transparent equilibrium — i.e., equation (15). The proposition shows that both effects discussed above are positive when efforts are strategic complements. In fact, P_i's decision to share information increases A_j's equilibrium effort, which, because $\delta > 0$, leads A_i to choose a higher effort, and, at the same time, allows P_i to reduce the fixed component of A_i's wage. Thus, when efforts are strategic complements, principals will communicate at equilibrium.

What happens if efforts are strategic substitutes? Note that, even in this case, P_i's decision to disclose information spurs A_j's effort because performances are correlated and the risk-diversification effect discussed above allows P_j to lower agency costs and increase his agent's effort. This means that the sign of the fixed-fee effect is negative when $\delta < 0$, because $a_j^t > a_j^{t,n}$ from Proposition 4. Instead, the sign of the strategic effect is ambiguous: even if the choice of not disclosing information allows P_i to increase A_i's effort — i.e., $a_i^t < a_i^{n,t}$ for $\delta < 0$ — this does not increase P_i's profits. In fact, when efforts are strategic substitutes and A_j exerts high effort, it is in P_i's best interest to keep A_i's effort low and take advantage of the performances' correlation. Indeed, Proposition 5 establishes that the negative effects of transparency prevail on the positive ones for both principals when efforts are substitutes, thereby excluding the full transparency regime from the possible equilibrium outcomes when $\delta < 0$.

Consider now an equilibrium without communication — i.e., equation (16). If efforts are strategic substitutes, the strategic effect and the fixed-fee effect are both positive. By disclosing information principal P_i indirectly spurs A_j's effort, which increases A_i's (marginal) cost of effort because $\delta < 0$. This reduces A_i's effort, meaning that the strategic effect is positive. At the same time, it increases the fixed component of the wage paid to A_i, implying that also the fixed-fee effect is positive. As a consequence, if efforts are substitutes equation (16) holds true and principals do not communicate at equilibrium.

What happens when efforts are strategic complements? Again, although the sign of the fixed-fee effect is negative,[9] that of the strategic effect is ambiguous. In fact, when efforts are strategic complements, other things being equal, principal P_i would like to disclose information in order to increase agent A_i's effort and exploit complementarity. Proposition 5 establishes that the net effect is negative for both principals, so that no communication is not an equilibrium when efforts are complements ($\delta > 0$).

Finally, it is clear from the above discussion that asymmetric equilibria with unilateral information sharing cannot exist.

7 Concluding remarks

The analysis developed in this paper has offered novel insights about: the determinants of divisions' incentives to share information about their performances; the link between the power of incentives, efforts and cross-division externalities; the impact of monitoring and contractual power on their internal structure. The results have been derived under a few simplifying assumptions that are worth discussing. First, we assumed that contracts are linear. It is well known that discontinuous contracts (wages) might perform better. Given the hypothesis of secret contracts, we believe that this property is likely to remain valid also in our framework. Second, we have assumed that principals commit to disclose information at the outset of the game. More generally, it would be interesting to know how these incentives change if principals lack this commitment power. Our conjecture is that, without commitment, each principal may strategically select the states of nature to be disclosed ex-post, so as to influence the effort of the other agent to his own advantage. Third, in our model agents are ex-ante identical and divisions do not compete to attract them. Clearly, when divisions compete to attract efficient types, information disclosure about past performances may act as a signal device that makes rivals aware of own agents' productivity. Hence, divisions with lower cash flows may be unable to retain efficient agents; this may create an assortative matching that could be worth investigating. Finally, a somewhat natural extension of the model worth exploring is its infinitely repeated version in which contract and information sharing decisions may allow principals to achieve more cooperative outcomes. One question that could be analyzed in that extended framework is whether information disclosure about agents' performances is substitute or complement to information disclosure about contracts. We leave these questions to future research.

[9] That is, the sign of this effect is the opposite of the one we obtain with strategic complementarities, because $a_j^{n,t} > a_j^n$ when $\delta > 0$.

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Appendix

Preliminaries. Before proving the results stated in the main body of the paper, we detail the conditions that guarantee that equilibrium efforts, the cost and the marginal cost of effort are positive in every admissible outcome of the game. These conditions define the region of parameters to which we restrict the analysis.

Using the expressions for the equilibrium efforts, it can be easily verified that they are positive as long as the following assumption holds

$$\textbf{A1:} \qquad 1+\delta+r(\sigma_j^2\left(1-\rho^2\right)+\delta\sigma_i^2)>0 \quad \forall i,j=1,2,$$

which implies that an agent whose principal adopts a regime with transparency, but does not receive information, exerts positive effort.

Moreover, the effort cost, $\psi_i\left(a_i,a_j\right)$, is positive if, and only if, $2\delta<\frac{a_i}{a_j}$, while the marginal cost is positive if, and only if, $\delta<\frac{a_i}{a_j}$, which is implied by the former condition. Using the expression for the equilibrium efforts, a sufficient condition for the effort cost to be (strictly) positive is

$$\textbf{A2:} \qquad 2\delta<\frac{1+\delta+r(\delta\sigma_i^2+(1-\rho^2)\sigma_j^2)}{1+\delta+r(\sigma_i^2+\delta(1-\rho^2)\sigma_j^2)} \quad \forall i,j=1,2,$$

which implies that an agent whose principal does not disclose but receives information incurs in effort costs. More generally, **A2** guarantees that the cost of effort is always positive in equilibrium, even when there are positive externalities between the agent's choices so that the net cost of effort is attenuated. Note that, given assumption **A1**, condition **A2** is compelling only if $\delta>0$.

Proof of Lemma 1. The proof of this result obtains by combining the agents' first-order conditions (6). The comparative statics is immediate. ■

Proof of Proposition 1. Suppose that principals do not communicate. The first-order conditions in (10) rewrite as

$$1-\delta^2=\left(1-\delta^2\right)r\sigma_i^2\beta_i+[\beta_i+\delta\beta_j^n-\delta(\beta_j^n+\delta\beta_i)] \quad \forall i,j=1,2,$$

whose solution yields

$$\beta_i^n=\frac{1}{1+r\sigma_i^2},$$

which implies that $\beta_s^n=\beta_i^*$. Substituting β_i^n and β_j^n into $a_i\left(\beta_i,\beta_j\right)$, we obtain that

$$a_i^n=\frac{1+r\sigma_j^2+\delta(1+r\sigma_i^2)}{\left(1-\delta^2\right)\left(1+r\sigma_i^2\right)\left(1+r\sigma_j^2\right)}.$$

Differentiating with respect to σ_i^2 and σ_j^2, we have that

$$\frac{\partial a_i^n}{\partial\sigma_i^2}=-\frac{r}{(1-\delta^2)(1+r\sigma_i^2)^2}<0,$$

and

$$\frac{\partial a_i^n}{\partial \sigma_j^2} = -\frac{r\delta}{(1-\delta^2)(1+r\sigma_i^2)^2} \geq 0 \quad \Leftrightarrow \quad \delta \leq 0.$$

Direct comparison between a_i^n and a_j^n yields

$$a_i^n - a_j^n = \frac{(\sigma_i + \sigma_j)(\sigma_j - \sigma_i) r}{(1+\delta)\left(1+r\sigma_i^2\right)(1+r\sigma_j^2)} \geq 0 \quad \Leftrightarrow \quad \sigma_i \leq \sigma_j.$$

Finally, it can be easily verified that, under assumptions **A1** and **A2**, $a_i^n > 0$ and $a_i^n - \delta a_j^n > 0$ for each $i, j = 1, 2$, which concludes the proof. ■

Proof of Corollary 1. The result that $a_i^n \geq a_i^*$ when $\delta \geq 0$ follows from the definition of the function $a_i(\beta_i^n, \beta_j^n)$ and the fact that $\beta_i^n = \beta_i^*$. Consider thus the case with $\delta < 0$. Then

$$a_i^n \geq a_i^* \quad \Leftrightarrow \quad a_i^n = \frac{1 + r\sigma_j^2 + \delta(1 + r\sigma_i^2)}{\left(1-\delta^2\right)\left(1+r\sigma_i^2\right)(1+r\sigma_j^2)} \geq \frac{1}{1+r\sigma_i^2}.$$

First, recall that $\frac{\partial a_i^n}{\partial \sigma_j^2} > 0$ for $\delta < 0$ by Proposition 1. Second, observe that

$$\lim_{\sigma_j \to +\infty} (a_i^n - a_i^*) = \frac{\delta^2}{\left(1-\delta^2\right)(1+r\sigma_i^2)} > 0,$$

$$\lim_{\sigma_j \to 0} (a_i^n - a_i^*) = \frac{\delta\left(1+\delta+r\sigma_i^2\right)}{\left(1-\delta^2\right)\left(1+r\sigma_i^2\right)} < 0.$$

Hence, by the mean-value theorem there exists a threshold $\sigma_j^* > 0$ such that $a_i^n \geq a_i^*$ if $\sigma_j \geq \sigma_j^*$. ■

Proof of Proposition 2. Suppose that both principals choose to be transparent. The first-order conditions in (10)-(11) rewrite as

$$\begin{aligned} 1-\delta^2 &= \left(1-\delta^2\right) r(\sigma_i^2\beta_i + \gamma_i\sigma_i\sigma_j\rho) + [\beta_i + \delta\beta_j^t - \delta(\beta_j^t + \delta\beta_i)] \quad \forall i, j = 1, 2, \\ 0 &= \sigma_j^2\gamma_i + \beta_i\sigma_i\sigma_j\rho \quad \forall i, j = 1, 2, \end{aligned}$$

whose solution yields

$$\begin{aligned} \beta_i^t &= \frac{1}{1 + r\sigma_i^2(1-\rho^2)}, \\ \gamma_i^t &= -\frac{\sigma_i}{\sigma_j}\,\frac{\rho}{1+r\sigma_i^2(1-\rho^2)}. \end{aligned}$$

Hence, $\beta_i^t \geq \beta_i^n = \beta_i^*$ for all $\rho \in (-1, 1)$. Moreover, $\gamma_i^t \geq 0$ if, and only if, $\rho \leq 0$. Substituting β_i^t and β_j^t into $a_i(\beta_i, \beta_j)$, we then obtain

$$a_i^t = \frac{1 + \delta + r(1-\rho^2)(\sigma_j^2 + \delta\sigma_i^2)}{\left(1-\delta^2\right)(1 + r\sigma_i^2(1-\rho^2))(1 + r\sigma_j^2(1-\rho^2))}.$$

Differentiating with respect to σ_i^2 and σ_j^2, we find that

$$\begin{aligned}\frac{\partial a_i^t}{\partial \sigma_i^2} &= -\frac{\left(1-\rho^2\right) r}{(1-\delta^2)(1+r\sigma_i^2\left(1-\rho^2\right))^2} < 0,\\ \frac{\partial a_i^t}{\partial \sigma_j^2} &= -\frac{\left(1-\rho^2\right) r\delta}{(1-\delta^2)(1+r\sigma_i^2\left(1-\rho^2\right))^2} \geq 0 \quad \Leftrightarrow \quad \delta \leq 0.\end{aligned}$$

Direct comparison of a_i^t and a_j^t yields

$$a_i^t - a_j^t = \frac{\left(1-\rho^2\right)\left(\sigma_i+\sigma_j\right)\left(\sigma_j-\sigma_i\right) r}{(1+\delta)(1+r\sigma_i^2\left(1-\rho^2\right))(1+r\sigma_j^2\left(1-\rho^2\right))} \geq 0 \quad \Leftrightarrow \quad \sigma_i \leq \sigma_j.$$

Finally, it can be easily verified that under assumptions **A1** and **A2** $a_i^t > 0$ and $a_i^t - \delta a_j^t > 0$ for each $(i,j) = 1,2$, which concludes the proof. ■

Proof of Corollary 2. The proof of this result follows the same logic as that offered to prove Corollary 1. ■

Proof of Proposition 3. The proof of this result follows the same logic as in the proofs of Propositions 1 and 2. ■

Proof of Proposition 4. First, note that

$$\begin{aligned}a_i^t - a_i^{n,t} &\equiv \frac{1}{1-\delta^2}[\beta_i^t + \delta\beta_j^t - (\beta_i^t + \delta\beta_j^n)]\\ &= \frac{\delta}{1-\delta^2}[\beta_j^t - \beta_i^n] \geq 0 \quad \Leftrightarrow \quad \delta \geq 0.\end{aligned}$$

Similarly,

$$\begin{aligned}a_i^n - a_i^{t,n} &\equiv \frac{1}{1-\delta^2}[\beta_i^n + \delta\beta_j^n - (\beta_i^n + \delta\beta_j^t)]\\ &= \frac{\delta}{1-\delta^2}[\beta_j^n - \beta_j^t] \geq 0 \quad \Leftrightarrow \quad \delta \leq 0.\end{aligned}$$

Hence, the result. ■

Proof of Proposition 5. We want to prove that the equilibrium is unique and that it features full transparency when $\delta > 0$ and no communication when $\delta < 0$.

Consider first the incentive to stick to an equilibrium with fully transparency. This is given by the sign of $\pi_i^t - \pi_i^{n,t}$. We want to prove that $\pi_i^t - \pi_i^{n,t} < 0$ for at least one principal when $\delta < 0$, while $\pi_i^t - \pi_i^{n,t} > 0$ for both principals when $\delta > 0$. We can rewrite (15) as

$$\pi_i^t - \pi_i^{n,t} = a_i^t - \frac{(a_i^t)^2}{2} + \delta a_i^t a_j^t - \left[a_i^{n,t} - \frac{(a_i^{n,t})^2}{2} + \delta a_i^{n,t} a_j^{t,n}\right],$$

which, substituting the efforts as functions of the contracts — i.e., equation (7) — and simplifying, becomes

$$\pi_i^t - \pi_i^{n,t} = [\beta_j^t - \beta_j^n]\delta \frac{2 + \delta(\beta_j^n + \beta_j^t - 2\delta\left(1 - \beta_i^t\right))}{2\left(1 - \delta^2\right)^2}. \tag{A1}$$

Notice first that (A1) equals 0 when $\delta = 0$, while its sign depends, for given δ, on the sign of the numerator — in fact, $\beta_j^t > \beta_j^n$ by Proposition 2. Define the numerator of (A1) as

$$\xi_i(\delta) \equiv 2 + \delta(\beta_j^n + \beta_j^t - 2\delta\left(1 - \beta_i^t\right)).$$

Consider first $\delta < 0$. Then, we need $\xi(\delta) > 0$ for at least one $i = 1, 2$. Because $\beta_i^t < 1$ by Proposition 2, it is clear that

$$\frac{\partial \xi_i(\delta)}{\partial \delta} = \beta_j^n + \beta_j^t - 4\delta\left(1 - \beta_i^t\right) > 0 \qquad \forall \delta \in (-1, 0).$$

Hence, in the range considered, $\xi_i(\delta)$ is minimized at $\delta \to -1$, taking value $\xi_i(-1) = 2\beta_i^t - \beta_j^t - \beta_i^n$. Let's now assume that $\sigma_j > \sigma_i$. Then, by Proposition 2, $\beta_i^t > \beta_j^t$, implying that $\xi(-1) > 0$ and, *a fortiori*, $\xi_i(\delta) > 0$ for all $\delta < 0$. This implies that (A1) is negative so that principal P_i deviates from the equilibrium with full transparency. If $\sigma_j < \sigma_i$, then the argument applies unchanged to principal P_j who breaks the equilibrium. This proves that there exists no equilibrium with full transparency when $\delta < 0$.

Consider now $\delta > 0$. Then, we want to show that $\xi_i(\delta) > 0$ for all $\delta > 0$ for both principals. Now, $\xi_i(\delta)$ is clearly concave and such that $\xi_i^{'}(0) = \beta_j^n + \beta_j^t > 0$. Hence, the minimum value of $\xi_i(\delta)$ over the range $[0, 1]$ is either at $\delta = 0$ or, if the function has a maximum for some $\delta^{\max} \in (0, 1)$, at $\delta = 1$. Because $\xi_i(0) = 2$ and $\xi_i(1) = \beta_j^n + \beta_j^t + 2\beta_i^t > 0$, we conclude that $\xi_i(\delta) > 0$ for all $\delta > 0$. Hence, (A1) is positive for both principals and full transparency is indeed an equilibrium.

Next, consider the incentive to stick to an equilibrium with no communication. We want to prove that $\pi_i^n - \pi_i^{t,n} < 0$ for at least one principal when $\delta > 0$, while $\pi_i^n - \pi_i^{t,n} > 0$ for both principals when $\delta < 0$. We can rewrite the profit difference as

$$\pi_i^n - \pi_i^{t,n} = a_i^n - \frac{(a_i^n)^2}{2} + \delta a_i^n a_j^n - \left[a_i^{t,n} - \frac{(a_i^{t,n})^2}{2} + \delta a_i^{t,n} a_j^{n,t}\right],$$

which, using (7) and simplifying, becomes

$$\pi_i^n - \pi_i^{t,n} = -[\beta_j^t - \beta_j^n]\delta \frac{2 + \delta(\beta_j^n + \beta_j^t - 2\delta\left(1 - \beta_i^n\right))}{2\left(1 - \delta^2\right)^2}. \tag{A2}$$

Again, (A2) equals 0 when $\delta = 0$, while its sign depends, for given δ, on the sign of the numerator. Define the numerator as

$$\chi_i(\delta) \equiv 2 + \delta(\beta_j^n + \beta_j^t - 2\delta\left(1 - \beta_i^n\right)).$$

Consider first $\delta > 0$. By the same logic used above, it is easy to show that $\chi_i(\delta)$ is a concave function increasing at $\delta = 0$ and such that it has a minimum either at $\delta = 0$ or at $\delta = 1$. Because $\chi_i(0) = 2 > 0$ and $\chi_i(1) = \beta_j^n + \beta_j^t + 2\beta_i^n > 0$, it is clear that, when $\delta > 0$, it holds $\pi_i^n - \pi_i^{t,n} < 0$ for both principals. Together with the arguments made above, this implies that, whenever $\delta > 0$, the unique equilibrium features full transparency.

Consider now $\delta < 0$. We want to show that $\pi_i^n - \pi_i^{t,n} > 0$ for both principals. The profit differential can be rewritten as in equation (16)

$$\pi_i^n - \pi_i^{t,n} = a_i^n - \psi(a_i^n, a_j^n) - [a_i^{t,n} - \psi(a_i^{t,n}, a_j^n)] - \delta a_i^{t,n}[a_j^{n,t} - a_j^n].$$

We know from Section 5.3 that $a_j^{n,t} > a_j^n$ so that the last term above is clearly positive. We still have to show that the sum of the remaining addenda is also positive. We can rewrite it as

$$\pi_i^n - \pi_i^{t,n} + \delta a_i^{t,n}[a_j^{n,t} - a_j^n] = a_i^n \left[1 - \frac{a_i^n}{2} + \delta a_j^n\right] - a_i^{t,n} \left[1 - \frac{a_i^{t,n}}{2} + \delta a_j^n\right],$$

which, using (7), becomes

$$\pi_i^n - \pi_i^{t,n} + \delta a_i^{t,n}[a_j^{n,t} - a_j^n] = -(\beta_j^t - \beta_j^n)\delta \frac{2\left(1-\delta^2\right)(1-\beta_i^n) - \delta(\beta_j^t - \beta_j^n)}{2\left(1-\delta^2\right)^2}. \tag{A3}$$

The sign of (A3) depends, for given δ, on the sign of the numerator. Which is positive when $\delta < 0$ for $i = 1, 2$, as $\beta_i^n < 1$ and $\beta_j^t \geq \beta_j^n$. Hence, $\pi_i^n - \pi_i^{t,n} > 0$ for both principals whenever $\delta < 0$. This, coupled with the arguments above establishes uniqueness of the no communication equilibrium when $\delta < 0$. ■