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Vertical Relationships with Hidden Interactions

Jaesoo Kim [1] and Dongsoo Shin [2,*]

[1] Department of Economics, Indiana University-Purdue University Indianapolis, Indianapolis, IN 46202, USA; jaeskim@iupui.edu
[2] Department of Economics, Leavey School of Business, Santa Clara University, Santa Clara, CA 95053, USA
* Correspondence: dshin@scu.edu

Abstract: In an agency model with adverse selection, we study how hidden interactions between agents affect the optimal contract. The principal employs two agents who learn their task environments through their involvement. The principal cannot observe the task environments. It is important to note that hidden interactions, such as acts of sabotage or help between the agents, have the potential to alter each other's task environments. Our analysis encompasses two distinct organizational structures: competition and cooperation. Without hidden interactions, the competitive structure is optimal because the cooperative structure only provides the agents with more flexibility to collusively misrepresent their task environments. With hidden interactions, however, the cooperative structure induces the agents to help each other to improve the task environments while removing sabotaging incentives at no cost once collusion is deterred. As a result, the cooperative structure can be optimal in such a case. We discuss the link between production technology and organizational structure, finding that complementarity in production favors cooperative structures.

Keywords: agency; collusion; help; sabotage; organizational structure

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1. Introduction

Consider a pharmaceutical company conducting clinical trials for a new drug. The company hires two contract research organizations (CROs) to carry out the trials independently. In this case, a competitive structure ensures that each CRO operates autonomously, without any collaboration or communication. The company maintains control over the process and can monitor the progress of each CRO individually. Alternatively, a cooperative structure involves the CROs working together, sharing data and resources, while potentially creating challenges for the company to maintain control over the process.

The choice between a competitive and cooperative organizational structure has been a long-standing debate. A competitive structure encourages individual subdivisions and members to outperform each other through increased efficiency or lower costs. Organizations with competitive structures believe that this approach better serves their objectives. Conversely, a cooperative structure promotes knowledge sharing and cooperation among subdivisions and members. Organizations with cooperative structures argue that individual members in competitive structures prioritize their own objectives over those of the organization, resulting in gains for one member at the expense of another.

This paper aims to investigate why and under what circumstances a competitive or cooperative structure better serves an organization's objectives. Our preliminary findings suggest that when members within an organization cannot influence each other's task environments, a competitive structure is optimal. However, when members can affect each other's task environments, a cooperative structure can become more efficient in achieving the organization's objectives.

We employ a simple principal–agent framework in which two agents are hired for production. Upon participation, the agents learn their task environments, which the principal cannot directly observe. At the beginning, the principal can choose between a competitive and a cooperative structure. In the competitive structure, no coordination between the agents is possible. While the agents cannot collude to misrepresent their task environments, they cannot improve each other's task environments either. In the cooperative structure, the agents can collusively misrepresent their task environments to increase their information rents, and can alternatively enhance each other's task environments through knowledge transfer. Regardless of the organizational structure, an agent can always sabotage the other agent's task environment.

We first examine traditional settings where agents cannot influence each other's task environments, where we find that the principal is better off with a competitive structure. As established in the previous literature, the cooperative structure mainly provides agents with flexibility in obtaining information rents. Agents can collude to misrepresent their task environments, thereby maximizing their combined gains.

We then analyze cases where agents can affect each other's task environment. As mentioned above, we allow an agent to be able to "sabotage" or "help" the other agent. Sabotage can deteriorate an agent's task environment; if it takes place, a good task environment becomes bad with a strictly positive probability. By contrast, help, such as knowledge transfer, can improve an agent's task environment; through help, a bad task environment becomes good with a strictly positive probability. Our results indicate that preventing sabotage is costly for the principal in a competitive structure. However, in a cooperative structure where collusive misrepresentation is deterred, neither preventing sabotage nor inducing help imposes additional costs on the principal. Therefore, in scenarios involving sabotage/help possibilities, the cooperative structure can outperform the competitive structure.

Our analysis uncovers an interesting relationship between contractual efficiency and hidden interactions. In the absence of hidden interactions, the cooperative structure introduces greater output distortion due to the potential for collusion between the agents to extract more informational rent. This outcome appears to corroborate the commonly held belief that internal competition cultivates increased efficiency within organizations. However, when hidden interactions come into play, we observe that output experiences greater distortion when sabotage is prohibited compared to when it is permitted in the competitive structure. Furthermore, output distortion is amplified when help is encouraged in the cooperative structure. This underscores that surface-level managerial efficiency does not unequivocally signify exemplary performance, just as managerial inefficiency does not invariably indicate subpar performance.

Finally, our discussion extends to the link between production technology and organizational structure. Our analysis demonstrates that the cooperative structure is favored in the presence of complementarity in production. Specifically, we show that with complementary production technology, the principal can deter sabotage and induce help without incurring costs while simultaneously eliminating the incentive for collusive misrepresentation.

The remainder of this paper is structured as follows. Section 2 encompasses the literature review and outlines our unique contributions. Section 3 introduces the model that forms the foundation of our analysis. Moving forward, Section 4 analyzes cases in which the potential for sabotage or help is absent, followed by Section 5, which delves into scenarios in which these interactions are incorporated. In Section 6, we broaden our analysis to investigate the relationship between production technology and organizational structure. Section 7 provides a discussion, and Section 8 serves as the conclusion. The Appendix A contains all accompanying proofs.

2. Literature Review

Our paper is related to studies on hidden interactions in organizations, such as help and sabotage. These dynamics have been predominantly analyzed through two primary frameworks. The first is tournament models. Chen (2003) [1] incorporated sabotage activities in a tournament model and showed a diminished likelihood of promotion for higher-ability agents. In a similar vein, Kräkel (2005) [2] allowed agents to choose help, sabotage, or inaction prior to expending effort. Their central finding demonstrated a diverse array of equilibria, including asymmetrical scenarios in which one player lends aid while the other resorts to sabotage.

Second, various studies have explored the effects of hidden interactions within moral hazard models. Itoh (1991) [3] centered the analysis on cooperation within a multi-agent moral hazard problem in which each agent simultaneously determines their own effort level and level of helping effort to assist others. The paper characterized the optimal compensation scheme for the principal, namely, one that incentivizes agents to extend support to their peers. In contrast, works by Bose, Pal, and Sappington (2010) [4] and Kräkel and Müller (2012) [5] studied the issue of sabotage within a moral hazard setting. The former paper contended that compressing transfers nullifies sabotage incentives among agents, while the latter illustrated that an agent's sabotage may furnish teammates with an additional impetus to put forth higher efforts. Ramakrishnan and Thakor (1991) [6] developed a moral hazard model wherein the principal can choose to structure tasks competitively or cooperatively, although without explicitly incorporating sabotage or help. The principal's optimal choice in this case hinges on the correlation between each agent's output.

Diverging from these analyses, our exploration of hidden interactions pivots on the framework of adverse selection. We demonstrate how these hidden interactions intersect with the principal's optimal contract design, which involves the distortion of output. Consequently, our analysis sheds light on how the potential for help and sabotage influences the optimal organizational structure.

Another strand of the literature pertinent to our work centers on collusion within multi-agent models. Itoh (1993) [7] considered a situation in which agents can coordinate their effort choice in a moral hazard model, showing that the prospect of collusion among subunits can enhance the organization's overall welfare. Che (1995) [8] studied potential collusion between a regulator and a regulated firm, demonstrating that collusion may serve the interests of the government. Similarly, Olsen and Torsvik (1998) [9] argued that corruption in the form of collusion between a supervisor and an agent can be beneficial to a principal in cases with an intertemporal commitment problem.[1]

While akin to these studies in outlining the potential advantages of collusion, our work posits a distinct rationale. In our model, collusion among agents acts as an incentive for preventing sabotage activity and providing mutual assistance, presenting a novel dimension of this phenomenon.

3. Model

A risk-neutral principal hires two risk-neutral agents for production of output $Q \in \mathbb{R}_+$.

3.1. Information

Each agent's task environment (type), respectively denoted as θ_i and θ_j, can be either *Good* (θ_G) or *Bad* (θ_B), where $\triangle\theta \equiv \theta_G - \theta_B > 0$ and $\theta_G < 1$. We assume that θ_i and θ_j are identically and independently distributed with $\Pr(\theta_G) = \mu_G$ and $\Pr(\theta_B) = \mu_B = 1 - \mu_G$. Each agent learns their own task environment (θ_i and the other agent's task environment θ_j) after participation; the principal cannot directly observe these environments. The probability distributions are publicly known.

3.2. Organizational Structure

The principal chooses an organizational structure, denoted by $C \in \{C^m$ (competitive), C^c (cooperative)$\}$. Regardless of $C \in \{C^m, C^c\}$, each agent can sabotage the other agent's task environment. If sabotage takes place, then a *Good* agent (an agent in a *Good* task environment) becomes Bad with probability ϕ_B or remains Good with probability $\phi_G = 1 - \phi_B$.

- In the competitive structure $(C = C^m)$, the agents can only play non-cooperatively, and collusion between them is impossible. Therefore, the agents cannot coordinate on reporting their types to the principal to jointly maximize their information rents.
- In the cooperative structure $(C = C^c)$, the agents can engage in collusion; side-contracting between the agents is possible, and they can coordinate on reporting their types.[2] In the cooperative structure, however, a Good agent can choose to help a Bad agent through knowledge transfer; with a Good agent's help, a Bad agent becomes Good with probability ψ_G and remains Bad with probability $\psi_B = 1 - \psi_G$.

The occurrence of sabotage in both competitive and cooperative contexts (as opposed to help, which is limited to cooperative scenarios) highlights the inherent possibility of disrupting or hindering the task environment of the other agent. On the other hand, the act of knowledge transfer necessitates a coordinated effort with the other agent.

3.3. Report and Production

Before production takes place, each agent reports their task environment (type) to the principal.[3] We follow Martimort (1997) [16] in assuming that, while the agents learn each other's types, an agent only reports their own type; this assumption is justified in that true θ_i is "soft information," i.e., no verifiable evidence on an agent's type can be obtained, and a court cannot assess it.[4]). Each agent produces the individual output that corresponds to their report and sends it to the principal. The output levels are monitored perfectly, i.e., the principal receives each individual output separately. We denote by q_{ij} the individual output level assigned to an agent reporting their type as θ_i $(i = G, B)$ paired with the agent reporting θ_j $(j = G, B)$. The total output is

$$Q_{ij} = q_{ij} + q_{ji} \quad \text{(by symmetry, } Q_{ij} = Q_{ji}\text{)}.$$

3.4. Payoffs

We assume that the types of the agents represent both efficiency and quality, and as such having common values. The principal values Q_{ij} by a value function $v(Q_{ij}, \Theta_k)$ that is strictly increasing and concave in Q satisfies the Inada conditions $v(0, \Theta_k) = 0$, $v'(0, \Theta_k) = \infty$, and $v'(\infty, \Theta_k) = 0$,[5] where Θ_k $(\equiv \theta_i + \theta_j) \in \{\Theta_G, \Theta_M, \Theta_B\}$ and consequently

$$\Theta_G \equiv 2\theta_G > \Theta_M \equiv \theta_G + \theta_B > \Theta_B \equiv 2\theta_B.$$

These conditions ensure that the principal has no incentive to exclude any state. The value function satisfies the following conditions:

$$\Delta v \equiv v(Q_{ij}, \Theta_{\overline{k}}) - v(Q_{ij}, \Theta_{\underline{k}}) > 0 \quad \text{and} \quad \Delta v' \equiv v'(Q_{ij}, \Theta_{\overline{k}}) - v'(Q_{ij}, \Theta_{\underline{k}}) > 0,$$

where if $\Theta_{\overline{k}} = \Theta_G$, then $\Theta_{\underline{k}} = \Theta_M$, while if $\Theta_{\overline{k}} = \Theta_M$, then $\Theta_{\underline{k}} = \Theta_B$.

The principal's ex post payoff is

$$\pi_{ij} = v(Q_{ij}, \Theta_k) - (t_{ij} + t_{ji}),$$

where t_{ij} (t_{ji}) is the transfer to the agent reporting their type as θ_i (θ_j) paired with the agent reporting θ_j (θ_i). The cost of producing q_{ij} to an agent is provided by $(1 - \theta_i)q_{ij}$. Therefore, each agent's ex post payoff is

$$u_{ij} = t_{ij} - (1 - \theta_i)q_{ij}.$$

An agent's liability is limited in that the reservation payoff, normalized to zero, must be guaranteed ex post as long as the agent abides by the contract.

To simplify the notation, we let $Q_G \equiv Q_{GG}$, $Q_M \equiv Q_{GB}$, and $Q_B \equiv Q_{BB}$. In this way, each agent's individual output can be expressed in terms of the total output. When the reported types are the same, both agents produce the same amount in equilibrium; hence,

$$q_{GG} = Q_G/2 \quad \text{and} \quad q_{BB} = Q_B/2.$$ [6]

When the reported types are different,

$$q_{GB} = \gamma Q_M \quad \text{and} \quad q_{BG} = (1-\gamma)Q_M \quad \text{with} 1 \geq \gamma \geq 0,$$

that is, when the types of the agents are different, the Good agent produces the proportion γ of Q_M and the Bad agent produces $1-\gamma$ of Q_M.

The notations are summarized below in Table 1.

Table 1. Summary of Notations.

Notations	Descriptions
$\theta_i, \theta_j \in \{\theta_G, \theta_B\}$	the agent's type
μ_G, μ_B	the distribution of each type
ϕ_B	The probabilty that a *Good* agent becomes *Bad* due to sabotage
ψ_B	The probabilty that a *Bad* agent becomes *Good* due to help
q_{ij}	individual output level
$Q_{ij} = q_{ij} + q_{ji}$	total output level
Q_G, Q_M, Q_B	$Q_G \equiv Q_{GG}, Q_M \equiv Q_{GB}$, and $Q_B \equiv Q_{BB}$
$v(Q_{ij}, \Theta_k)$	value function
$\Theta_k \in \{\Theta_G, \Theta_M, \Theta_B\}$	$\Theta_G \equiv 2\theta_G, \quad \Theta_M \equiv \theta_G + \theta_B, \quad \Theta_B \equiv 2\theta_B$
π_{ij}	The principal's *ex post* payoff
t_{ij}	monetary transfer
γ	the proportion of Q_M produced by the *Good* agent

3.5. Timing of the Game

Below, we summarize the timing of the game according to each organizational structure.

3.5.1. Competitive Structure ($C = C^m$)

- The principal offers $\{Q_k, t_{ij}, \gamma\}_{k \in \{G,M,B\}}^{i,j \in \{G,B\}}$ to the agents.
- If the offers are accepted, the agents learn their types.
- Each agent decides whether or not to sabotage the other agent.
- Depending on sabotage, each agent's type is revised.
- Reports are made to the principal and the contracts are executed.

3.5.2. Cooperative Structure ($C = C^c$)

- The principal offers $\{Q_k, t_{ij}, \gamma\}_{k \in \{G,M,B\}}^{i,j \in \{G,B\}}$ to the agents.
- If the offers are accepted, the agents learn their types.
- Each agent decides whether or not to sabotage/help the other agent.
- Depending on sabotage/help, each agent's type is revised.
- The agents decide whether or not to collude.[7]
- Reports are made to the principal and the contracts are executed.

3.6. The First-Best Outcome

Before moving on to the next section, we look at the optimal outcome under full information (i.e., the types of the agents and their interactions are publicly observed) as the benchmark. The first-best outcome is characterized by

$$v'(Q_G^*, \Theta_G) = 1 - \theta_G, \quad v'(Q_M^*, \Theta_M) = 1 - \theta_G \text{ with } \gamma = 1, \quad v'(Q_B^*, \Theta_B) = 1 - \theta_B.$$

From the output schedule characterized above, we have $Q_G^* > Q_M^* > Q_B^*$.[8] Notice that when the types of the agents are different, the efficient allocation is that the *G*ood agent produces the entire output due to the constant marginal costs.[9] Each agent receives zero rent in any task environment.

In the following section, we proceed to the cases where the agents' types (task environments) are their private information.

4. Without Hidden Interactions

We first discuss those cases in which the types of the agents are private information and the agents cannot affect each other's task environment. The optimal outcomes for the principal in each organizational structure are derived and discussed, followed by comparison of the two outcomes.

4.1. Optimal Outcome in the Competitive Structure (C^m)

To set out the principal's maximization problem, we first present the constraints that the optimal contract offer to the agents must satisfy.

As the revelation principle applies in our model, the principal's optimal offer to each agent must be incentive-compatible. To induce a truthful report from each agent, the optimal contract must satisfy the following incentive constraints:

$$t_{GG} - (1-\theta_G)Q_G/2 \geq t_{BG} - (1-\theta_G)(1-\gamma)Q_M, \tag{IC_{GG}}$$

$$t_{GB} - (1-\theta_G)\gamma Q_M \geq t_{BB} - (1-\theta_G)Q_B/2, \tag{IC_{GB}}$$

$$t_{BG} - (1-\theta_B)(1-\gamma)Q_M \geq t_{GG} - (1-\theta_B)Q_G/2, \tag{IC_{BG}}$$

$$t_{BB} - (1-\theta_B)Q_B/2 \geq t_{GB} - (1-\theta_B)\gamma Q_M. \tag{IC_{BB}}$$

The LHS and RHS of (IC_{ij}), $i,j \in \{G,B\}$ are respectively a type-i agent's payoff with a truthful report and the same agent's payoff with a misreport when paired with a type-j agent. These constraints assure that an agent's payoff is higher with a truthful report.

An agent's liability is limited; hence, the optimal outcome must satisfy the following ex post participation constraints for each agent:

$$t_{GG} - (1-\theta_G)Q_G/2 \geq 0, \tag{PC_{GG}}$$

$$t_{GB} - (1-\theta_G)\gamma Q_M \geq 0, \tag{PC_{GB}}$$

$$t_{BG} - (1-\theta_B)(1-\gamma)Q_M \geq 0, \tag{PC_{BG}}$$

$$t_{BB} - (1-\theta_B)Q_B/2 \geq 0. \tag{PC_{BB}}$$

Without the possibility of sabotage/help, the principal's problem in the competitive structure is to maximize their expected payoff

$$\textstyle\sum_i \sum_j \mu_i \mu_j \left[v(Q_k, \Theta_k) - t_{ij} - t_{ji}\right] \tag{P}$$

subject to $(IC_{GG}) \sim (IC_{BB})$ and $(PC_{GG}) \sim (PC_{BB})$.

The optimal output schedule in the competitive structure is presented in the following lemma.

Lemma 1. *Without the possibility of sabotage/help, the optimal outcome in the competitive structure is as follows:*

- $Q_G^m = Q_G^*$; $Q_M^m = Q_M^*$ *with* $\gamma = 1$; $Q_B^m < Q_B^*$.
- $t_{GG}^m = (1-\theta_G)Q_G^*/2$; $t_{GB}^m = (1-\theta_G)Q_M^* + \Delta\theta Q_B^m/2$; $t_{BG}^m = 0$; $t_{BB}^m = (1-\theta_B)Q_B^m/2$.

- $u^m_{GG} = 0$; $u^m_{GB} = \Delta\theta Q^m_B/2$; $u^m_{BG} = u^m_{BB} = 0$.

As usual, only a *G*ood agent has an incentive to misrepresent their type, and the output schedule is distorted at the bottom (when both agents are of the *B*ad type). When the agents cannot interact with each other, the optimal allocation of production is efficient, i.e., when the types of the agents are different, the *G*ood agent produces the entire output ($\gamma = 1$). Note that when both agents are *G*ood, they receive zero rent ($u^m_{GG} = 0$). To explain the intuition, we rewrite the binding (IC_{GG}) and (IC_{GB}) respectively as follows:

$$t_{GG} - (1-\theta_G)Q_G/2 = \Delta\theta(1-\gamma)Q_M, \tag{1}$$

$$t_{GB} - (1-\theta_G)\gamma Q_M = \Delta\theta Q_B/2. \tag{2}$$

As can be seen from (1), when both agents are of the *G*ood type, the efficient allocation of production ($\gamma = 1$) allows the principal to extract their information rent without distorting Q_M. As shown in (2), however, when a *G*ood agent is paired with a *B*ad agent, the only way to extract the *G*ood agent's rent is to decrease Q_B, resulting in downward distortion.

4.2. Optimal Outcome in the Cooperative Structure (C^c)

In the cooperative structure, the agents can engage in collusion to jointly misreporting their types if this can increase their total rent. Because the agents have extra room for misrepresentation under collusion, (IC_{ij}) may fail to induce truth-telling. In order to ensure truthful reports, the following coalition incentive constraints must be satisfied:

$$t_{GB} + t_{BG} - [(1-\theta_G)r + (1-\theta_B)(1-r)]Q_M \geq 2t_{BB} - (2-\Theta_M)Q_B/2, \tag{$CIC_{GB,BB}$}$$

$$2t_{GG} - (1-\theta_G)Q_G \geq t_{GB} + t_{BG} - (1-\theta_G)Q_M, \tag{$CIC_{GG,GB}$}$$

$$2t_{GG} - (1-\theta_G)Q_G \geq 2t_{BB} - (1-\theta_G)Q_B \tag{$CIC_{GG,BB}$}$$

$$t_{GB} + t_{BG} - [(1-\theta_G)r + (1-\theta_B)(1-r)]Q_M \geq 2t_{GG} - (2-\Theta_M)Q_G/2, \tag{$CIC_{GB,GG}$}$$

$$2t_{BB} - (1-\theta_B)Q_B \geq t_{GB} + t_{BG} - (1-\theta_B)Q_M, \tag{$CIC_{BB,GB}$}$$

$$2t_{BB} - (1-\theta_B)Q_B \geq 2t_{GG} - (1-\theta_B)Q_G \tag{$CIC_{BB,GG}$}$$

The RHS of $(CIC_{ij,i'j'})$, $i, j, i', j' \in \{G, B\}$ is the joint payoff of the agents when one or both misreport their type(s) through side-contracting. Note that this situation is equivalent to the case in which one agent (whose type can be GG, GB, or BB, that is, $(CIC_{ij,i'j'})$) can prevent all combinations of misreporting, thereby encompassing (IC_{ij}).

Without the possibility of sabotage/help, the principal's problem in the cooperative structure is to maximize their expected payoff in (P) subject to $(CIC_{GB,BB}) \sim (CIC_{BB,GG})$, $(IC_{GG}) \sim (IC_{BB})$, and $(PC_{GG}) \sim (PC_{BB})$. The optimal output schedule in the cooperative structure is presented in the following lemma.

Lemma 2. *Without the possibility of sabotage/help, the optimal outcome in the cooperative structure is as follows:*

- $Q^c_G = Q^*_G$; $Q^c_M = Q^*_M$ *with* $\gamma = 1$; $Q^c_B < Q^m_B$ $(< Q^*_B)$.
- $t^c_{GG} = (1-\theta_G)Q^*_G/2 + \Delta\theta Q^c_B/2$; $t^c_{GB} = (1-\theta_G)Q^*_M + \Delta\theta Q^c_B/2$; $t^c_{BG} = 0$; $t^c_{BB} = (1-\theta_B)Q^c_B/2$.
- $u^c_{GG} = u^c_{GB} = \Delta\theta Q^c_B/2$; $u^c_{BG} = u^c_{BB} = 0$.

Compared to the output schedule in the competitive structure, the optimal level of Q_B in the cooperative structure is distorted further. As mentioned above, the agents in the cooperative structure have more room to manipulate their information. Recall that in the competitive structure the agents cannot obtain information rents if their task environments are both *G*ood; as shown in (1), the optimal allocation $\gamma = 1$, allows the principal to extract a *G*ood agent's information rent in the competitive structure when the agent is paired with another *G*ood agent ($u^m_{GG} = 0$).

Under collusion, however, such information extraction can no longer be implemented, as the agents can do better by coordinating their reports. In particular, by jointly misreporting that both of their types are *B*ad, *G*ood agents can reap strictly positive rents, as expressed by the equation below:

$$2t_{GG} - (1 - \theta_G)Q_G = \Delta\theta Q_B. \tag{3}$$

Equation (3) is implied by binding $(CIC_{GG,BB})$. Preventing collusive misreports requires that the principal provide a strictly positive rent of $\Delta\theta Q_B/2$ to each agent when both agents are of the *G*ood type. As a result, in order to reduce the rent, in the cooperative structure Q_B is distorted further downwards from its optimal level in the competitive structure.

We now compare the optimal outcomes in C^m and C^c. The following proposition presents the optimal choice of organizational structure when an agent cannot sabotage or help the other agent.

Proposition 1. *Without the possibility of sabotage/help between the agents, C^m is optimal.*

The result presented above is well known in the literature. As in the standard adverse selection models, when the agents cannot affect each other's types, the cooperative structure only provides the agents with collusion opportunity. Consequently, the principal is better off in the competitive organizational structure.

In the following section, we analyze the optimal outcome in each organizational structure when an agent's task environment can be affected by the other agent.

5. With Hidden Interactions

In this section, we analyze the optimal outcomes in each organizational structure when an agent's task environment can be affected by the other agent. As shown here, new incentives emerge depending on the organizational structure, and as a result the competitive structure can be dominated.

5.1. Optimal Outcome in the Competitive Structure (C^m)

Recall that ϕ_B denotes the probability of an agent's attempt to sabotage the other agent succeeding. Comparing the RHS in (1) and (2) with the outcome in Lemma 1, we have

$$\Delta\theta(1 - \gamma)Q^m_M < \phi_B \Delta\theta Q^m_B/2,$$

where $\Delta\theta(1 - \gamma)Q^m_M = 0$. Again, it is clear from the expressions in (1) and (2) that with the optimal output and transfer schedule in Lemma 1 a *G*ood agent receives a strictly positive rent only when paired with a *B*ad agent. Therefore, in the competitive structure in which the agents cannot collude, the above inequality leads to the following claim.

Claim 1. *For the output schedule in Lemma 1, an agent has an incentive to sabotage the other agent when both agents are of the Good type.*

When the agents can affect each other's task environment, the outcome associated with the *G*ood aggregate environment ($\Theta_k = \Theta_G$) cannot be implemented with the same probability under the output schedule presented in Lemma 1. If sabotage is allowed, the

Good aggregate environment Θ_G is realized only with probability $\mu_G^2\phi_G^2$, that is, only when both Good agents fail to sabotage the other agent.

The principal's expected payoff is then written as follows:

$$\mu_G^2 \sum_i \sum_j \phi_i\phi_j\left[v(Q_k,\Theta_k) - t_{ij} - t_{ji}\right] + \sum_i \sum_j \mu_i\mu_j\,\widehat{\eta}\left[v(Q_k,\Theta_k) - t_{ij} - t_{ji}\right], \qquad (\widehat{P})$$

$$\text{where } \widehat{\eta} = \begin{cases} 0 & \text{if } i = j = G, \\ 1 & \text{if otherwise.} \end{cases}$$

The first term of $(\widehat{P})$ is the principal's expected payoff for the case in which both agents are Good at the outset, while the second term of $(\widehat{P})$ applies to all other cases.

If the principal allows the agents to sabotage each other's task environment, the principal maximizes $(\widehat{P})$ subject to $(IC_{GG}) \sim (IC_{BB})$ and $(PC_{GG}) \sim (PC_{BB})$. The lemma below presents the optimal outcome in such a case.

Lemma 3. *With the possibility of sabotage/help, the optimal outcome in the competitive structure if sabotage is allowed is as follows:*

- $Q_G^{\widehat{m}} = Q_G^*$; $Q_M^{\widehat{m}} = Q_M^*$ *with* $\gamma = 1$; $Q_B^{\widehat{m}} < Q_B^*$.
- $t_{GG}^{\widehat{m}} = (1-\theta_G)Q_G^*/2$; $t_{GB}^{\widehat{m}} = (1-\theta_G)Q_M^* + \Delta\theta Q_B^{\widehat{m}}/2$; $t_{BG}^{\widehat{m}} = 0$; $t_{BB}^{\widehat{m}} = (1-\theta_B)Q_B^{\widehat{m}}/2$.
- $u_{GG}^{\widehat{m}} = 0$; $u_{GB}^{\widehat{m}} = \Delta\theta Q_B^{\widehat{m}}/2$; $u_{BG}^{\widehat{m}} = u_{BB}^{\widehat{m}} = 0$.

The reason behind the distortion in Q_B is the same as in the case where the agents cannot affect each other's task environment. Note, however, that the aggregate task environment is less likely to be Good (Θ_G) when sabotage is allowed.

We now discuss the case in which sabotage is deterred. If the principal wants to keep a Good agent from sabotaging the other agent when both agents are Good, the following constraint must be satisfied in addition to the incentive and participation constraints:

$$t_{GG} - (1-\theta_G)Q_G/2 \geq \phi_B[t_{GB} - (1-\theta_G)\gamma Q_M] + \phi_G[t_{GG} - (1-\theta_G)Q_G/2]. \qquad (SC)$$

The LHS is a Good agent's payoff without sabotaging the other agent, and the RHS is the same agent's payoff when engaging in sabotage. The principal's problem that prevents sabotage between the agents maximizes the expected payoff in (P) subject to $(IC_{GG}) \sim (IC_{BB})$, $(PC_{GG}) \sim (PC_{BB})$, and (SC).

Lemma 4. *With the possibility of sabotage/help, the optimal outcome in the competitive structure if sabotage is deterred is as follows:*

- $Q_G^{\widetilde{m}} = Q_G^*$; $Q_M^{\widetilde{m}} = Q_M^*$ *with* $\gamma = 1$; $Q_B^{\widetilde{m}} < Q_B^{\widehat{m}}$ $(< Q_B^*)$.
- $t_{GG}^{\widetilde{m}} = (1-\theta_G)Q_G^*/2$; $t_{GB}^{\widetilde{m}} = (1-\theta_G)Q_M^* + \Delta\theta Q_B^{\widetilde{m}}/2$; $t_{BG}^{\widetilde{m}} = 0$; $t_{BB}^{\widetilde{m}} = (1-\theta_B)Q_B^{\widetilde{m}}/2$.
- $u_{GG}^{\widetilde{m}} = u_{GB}^{\widetilde{m}} = \Delta\theta Q_B^{\widetilde{m}}/2$; $u_{BG}^{\widetilde{m}} = u_{BB}^{\widetilde{m}} = 0$.

Compared to the output schedule when sabotage is allowed, the optimal level of Q_B is distorted further here. In addition to inducing truthful reports from the agents, the principal must prevent sabotage between Good agents, as the sabotage constraint (SC) is binding in the optimal contract. This implies that the following expression must be satisfied in the optimal contract:

$$t_{GG} - (1-\theta_G)Q_G/2 = t_{GB} - (1-\theta_G)\gamma Q_M \ (= \Delta\theta Q_B/2). \qquad (4)$$

Recall that when sabotage is allowed a Good agent's rent when paired with another Good agent is $t_{GG}^{\widehat{m}} - (1-\theta_G)Q_G^{\widehat{m}}/2 = 0$. As shown in (4), preventing sabotage requires that the principal provide a strictly positive rent of $\Delta\theta Q_B/2$ to each agent when both agents are of the Good type. To reduce this rent, the level of Q_B is distorted further downwards in the optimal contract.

As presented in the lemma below, there is a trade-off between allowing and deterring sabotage.

Lemma 5. *In the competitive structure, sabotage is allowed if ϕ_B is small enough and deterred otherwise.*

If sabotage is allowed, the aggregate task environment has a small chance of being *Good* (Θ_G), while the optimal output schedule is distorted by a smaller amount. As a result, when sabotage is likely to be successful, the principal deters it in the optimal contract; however, when it is likely to fail, the principal allows it.

Sabotage is a widely recognized problem when members of an organization are rewarded based on their relative performance. In particular, when a worker's payoff decreases due to another worker's performance, mutual sabotage, as in Claim 1, can be a natural incentive arising in competitive structures. This is clearly exemplified by our model's outcomes, where sabotage occurs when $u^{\widehat{m}}_{GB} > u^{\widehat{m}}_{GG}$ and is deterred when $u^{\widetilde{m}}_{GG} = u^{\widetilde{m}}_{GB}$. As shown, it is costly to mitigate sabotage incentives in a competitive structure; the outcomes in Lemma 2 in the previous section and Lemma 4 here can be compared to see that, in our model, removing sabotage incentives in the competitive structure is as costly as preventing collusion in the cooperative structure.

We now proceed to the case in which the agents can be cooperative with each other under the possibility of sabotage/help.

5.2. Optimal Outcome in the Cooperative Structure (C^c)

Again, the agent in the cooperative structure can engage in collusion to maximize their joint payoff. As before, the principal's maximization problem must satisfy the coalition incentive constraints $(CIC_{GB,BB}) \sim (CIC_{BB,GG})$ presented in the previous section.

Suppose that the principal wants a *Good* agent to help a *Bad* agent when they are paired with each other. Again, with probability ψ_G, the good agent's help succeeds, while it fails with probability ψ_B. In order for help to take place, the following condition must be satisfied for the *Good* agent facing the *Bad* agent:

$$\psi_G[t_{GG} - (1-\theta_G)Q_G/2] + \psi_B[t_{GB} - (1-\theta_G)\gamma Q_M] \geq t_{GB} - (1-\theta_G)\gamma Q_M. \qquad (HC)$$

The LHS of (HC) is the *Good* agent's expected payoff from helping the *Bad* agent's task environment, and the RHS is the former's rent without helping the latter. After simple rearrangements, both (SC) and (HC) reduce to the same inequality:

$$t_{GG} - (1-\theta_G)Q_G/2 \geq t_{GB} - (1-\theta_G)\gamma Q_M.$$

Claim 2. *In the cooperative structure, both (SC) and (HC) are automatically satisfied.*

In the organizational structure in which the agents can collude, inducing truthful reports automatically induces help between the agents while preventing sabotage. Note that sabotage deterrence and help inducement are implemented regardless of the principal's willingness to deter and/or induce such interactions. The claim above is consistent with empirical findings in the management context (e.g., Wageman 1995) [17] that cooperative behaviors in organizations often manifest in members' willingness to work with others, even when organizations reward the members for individual performance without formally demanding cooperative behavior.

In the cooperative structure, the principal's objective function becomes

$$\textstyle\sum_i \mu_i^2[v(Q_k,\Theta_k) - 2t_{ii}] + \mu_G\mu_B \sum_i \sum_j \widetilde{\psi}[v(Q_k,\Theta_k) - t_{ij} - t_{ji}], \qquad (\widetilde{P})$$

$$\text{where } \widetilde{\psi} = \begin{cases} \psi_G & \text{if } i = j = G, \\ \psi_B & \text{if } i \neq j, \\ 0 & \text{if } i = j = B. \end{cases}$$

The second term in $(\widetilde{P})$ reflects the principal's higher chance of having $\Theta = G$ due to the agents' helping incentives when their task environments are different. The principal maximizes $(\widetilde{P})$ subject to $(CIC_{GB,BB}) \sim (CIC_{BB,GG})$ and $(PC_{GG}) \sim (PC_{BB})$. As claimed above, (SC) and (HC) are automatically satisfied in the cooperative structure.

The following lemma presents the optimal outcome in the cooperative structure with the possibility of sabotage/help.

Lemma 6. *With the possibility of sabotage/help, the optimal outcome in the cooperative structure entails*

- $Q_G^{\widetilde{c}} = Q_G^*$; $Q_M^{\widetilde{c}} = Q_M^*$ *with* $\gamma = 1$; $Q_B^{\widetilde{c}} < Q_B^{\widetilde{m}} < Q_B^{\widehat{m}}$ $(< Q_B^*)$.
- $t_{GG}^{\widetilde{c}} = (1-\theta_G)Q_G^*/2 + \Delta\theta Q_B^{\widetilde{c}}/2$; $t_{GB}^{\widetilde{c}} = (1-\theta_G)Q_M^* + \Delta\theta Q_B^{\widetilde{c}}/2$; $t_{BG}^{\widetilde{c}} = 0$; $t_{BB}^{\widetilde{c}} = (1-\theta_B)Q_B^{\widetilde{c}}/2$.
- $u_{GG}^{\widetilde{c}} = u_{GB}^{\widetilde{c}} = \Delta\theta Q_B^{\widetilde{c}}/2$; $u_{BG}^{\widetilde{c}} = u_{BB}^{\widetilde{c}} = 0$.

As in the previous section, in the cooperative structure the optimal output $Q_B^{\widetilde{c}}$ associated with Bad task environments is more distorted compared to the optimal output $Q_B^{\widetilde{m}}$ in the competitive structure. The reason behind it, however, is different here. Recall that preventing sabotage in the competitive structure requires providing strictly positive rents to Good agents paired with each other; the distortion in $Q_B^{\widetilde{m}}$ is to reduce the amount of rents. In the cooperative structure, the optimal contract must prevent collusion between the agents; to this end, the principal must provide the agents with positive rents when they are both of the Good type. In the cooperative structure, however, when collusion is deterred, a Good agent has an incentive to improve a Bad agent's task environment. Therefore, the chance of both agents working in Good environments is higher, which means that the chance of agents receiving rents is higher in the cooperative structure. As a result, the principal reduces the distortion in Q_B even further to reduce the rents to the agents.

The remaining task in this section is to compare the optimal outcomes in C^m and C^c when an agent can affect the other agent's task environment. The following proposition presents the optimal choice of organizational structure depending on Δv.

Proposition 2. *With the possibility of sabotage/help between the agents, the optimal organizational structure is as follows:*

- *When Δv is small, C^m is optimal.*
- *When Δv is intermediate,* $\begin{cases} C^m \text{ is optimal} & \text{if } \phi_B \text{ and/or } \psi_G \text{ is small.} \\ C^c \text{ is optimal} & \text{if } \phi_B \text{ and } \psi_G \text{ are large.} \end{cases}$
- *When Δv is large, C^c is optimal.*

The fact that the cooperative structure confers a higher chance of the Good aggregate task environment at the cost of larger distortion in the output schedule leads to the result above. When the principal's valuation of the project environment is low, helping between the agents to improve the aggregate task environment is not worth a larger distortion in the output schedule. As a result, the principal prefers the competitive structure. In contrast when the principal's valuation of the project environment is high, the trade-off shifts in the other direction. In such a case, the principal chooses the cooperative structure, thereby sacrificing efficiency in the output schedule for improvement in the aggregate task environment.

When the principal's valuation of the task environment is intermediate, the optimal structure of the organization depends on how likely an agent's attempt to affect the other agent's task environment is to succeed. If both sabotaging and helping the other agent are likely to succeed, then the cooperative structure is the principal's optimal choice. Otherwise, the competitive structure prevails.

In standard models, in which the agents cannot engage in sabotage or helping, the principal is worse off in the cooperative structure where the agents can collusively misrepresent their types. Provided that an agent cannot affect another agent's task environments, our result is in line with the conventional result that it is optimal for the organization to build a competitive structure. When the agents can affect each other's types, however, our result suggests that the principal's preference can be reversed; in this case, a cooperative structure can help the organization to achieve its objective more efficiently.

Proposition 2, coupled with the shifts in the optimal output outlined in Lemma 6 (where $Q_B^{\widetilde{c}} < Q_B^{\overline{m}} < Q_B^{\widehat{m}}$), yields a significant implication. The output experiences the least distortion when sabotage is permissible in the competitive structure, while it is most distorted when help is encouraged in the cooperative structure. It appears that competition generally leads to improved efficiency in output, whereas cooperation tends to have the opposite effect. Nevertheless, it is important to note that output efficiency alone does not necessarily ensure optimal organizational performance.

6. Production Technology and Organizational Structure

Thus far, we have looked at the cases where the outputs produced by the agents are substitutes. In practice, organizations often employ complementary production technology. A clear benefit of complementarity in operation consists of gains from specialization. As demonstrated below, complementary production is more friendly to the cooperative structure than substitutive production. In our model, when production is complementary, the principal is able to deter sabotage and induce helping without cost while removing incentives for collusive misrepresentation, again at no cost.

With complementary technology, each agent's contribution in equilibrium is

$$q_{ij} = q_{ji} = q_k,$$

where $i, j \in \{G, B\}$ and $k \in \{G, M, B\}$.

The first-best output schedule under full information is characterized by

$$v'(q_k^*, \Theta_k) = 2 - \Theta_k, \quad k \in \{G, M, B\}.$$

Suppose that the agents cannot affect each other's task environment, i.e., there is no possibility of sabotage or help. In the cooperative structure in which the agents can jointly misrepresent their types, the principal's problem is to maximize

$$\sum_i \sum_j \mu_i \mu_j \left[v(q_k, \Theta_k) - t_{ij} - t_{ji} \right]$$

subject to

$$t_{ij} + t_{ji} - (2 - \Theta_k) q_k \geq t_{i'j'} + t_{j'i'} - (2 - \Theta_k) q_{k'}, \qquad (\overline{CIC}_{ij,i'j'})$$

$$t_{ij} - (1 - \theta_i) q_k \geq t_{i'j'} - (1 - \theta_i) q_{k'}, \qquad (\overline{IC}_{ij})$$

$$t_{ij} - (1 - \theta_i) q_k \geq 0, \quad i, j \in \{G, B\}, \qquad (\overline{PC}_{ij})$$

where $i, j, i', j' \in \{G, B\}$ and $k, k' \in \{G, M, B\}$.

The following lemma presents the optimal outcome in the principal's problem above.

Lemma 7. *Suppose contributions from the agents are complements. Without the possibility of sabotage or help, the optimal outcome in the competitive structure entails the following:*

- $q_G^{\overline{m}} = q_G^*$; $q_M^{\overline{m}} < q_M^*$; $q_B^{\overline{m}} < q_B^*$.
- $t_{GG}^{\overline{m}} = (1 - \theta_G) q_G^* / 2 + \Delta\theta q_M^m$; $t_{GB}^{\overline{m}} = (1 - \theta_G) q_M^* + \Delta\theta q_B^{\overline{m}}$; $t_{BG}^{\overline{m}} = t_{BB}^{\overline{m}} = (1 - \theta_B) q_B^{\overline{m}} / 2$.
- $u_{GG}^{\overline{m}} = \Delta\theta q_M^m$; $u_{GB}^{\overline{m}} = \Delta\theta q_B^{\overline{m}}$; $u_{BG}^{\overline{m}} = u_{BB}^{\overline{m}} = 0$.

According to the optimal outcome in Lemma 5, an agent's ex post rents are ranked as follows:

$$u^{\overline{m}}_{GG} > u^{\overline{m}}_{GB} > u^{\overline{m}}_{BG} = u^{\overline{m}}_{BB}. \tag{5}$$

The ranking exhibited in (5) implies that if the agents can affect each other's task environment, then the optimal outcome in Lemma 5 is both sabotage-proof and help-inducing. Furthermore, as the following claim formally states, the optimal outcome prevents collusion between the agents at no cost.

Claim 3. *The optimal outcome without* $(\overline{CIC}_{ij,i'j'})$ *is the same as the one in Lemma 7.*

Recall from the previous sections that when the contributions from the agents are substitutive, the competitive structure dominates the cooperative structure without the possibility of sabotage/help; the cooperative structure is costlier to the principal, as they have to prevent the agents from collectively manipulating their private information. When the contributions from the agents are complementary to each other, the competitive structure cannot dominate the cooperative structure, as collusion between the agents is not impactful. Our exploration of complementarity vividly elucidates our decision to base our main model on substitutability. This particular scenario presents the most formidable task in illustrating the advantages of the cooperative structure. Our discussion in this section is summarized in the following Proposition.

Proposition 3. *Complementarity in operation favors the cooperative structure.*

The above proposition suggests that complementarity in cooperative structures makes it easier for organizations to induce help among their individual members. As Brynjolfsson and Milgrom (2013) [18] reported, a united and cooperative organizational structure is especially important to companies that engage in frequent acquisitions, such as Cisco Systems. In the case of Cisco Systems, the company employs complementarity in its operations by implementing an explicit process for changing all acquired firms' operational processes to match Cisco's. In addition, the company has employed a director of structure who issues "structure badges" to all employees in recognition of the complementarity of structure to the functioning of the rest of their systems. Our result in the proposition above supports such organizational behaviors. A number of early studies, such as Alchian and Demsetz (1972) [19] and Marschak and Radner (1972) [20], emphasized complementarity in team production for cooperative behaviors.[10] In these papers, the authors have argued that complementarity is a fundamental feature determining cooperation among team members in an organization. Our finding in this section echoes these arguments.

7. Discussion

We make a couple of remarks here on robustness. First, as mentioned earlier, we employed a constant marginal cost for each agent's production for expositional purposes. Suppose instead that each agent's marginal cost is increasing in the output, e.g., a cost function is provided by $\alpha(q_{ij}, \theta_i)$ with $\alpha_q(q_{ij}, \theta_i) > 0$, $\alpha_{qq}(q_{ij}, \theta_i) > 0$, $\alpha_\theta(q_{ij}, \theta_i) < 0$ and $\alpha_{q\theta}(q_{ij}, \theta_i) < 0$. Then, the common value is not needed in the model, as in such a case the principal's value function can be provided by $v(Q_{ij})$ instead of $v(Q_{ij}, \Theta_k)$. The assumption of constant marginal costs in our paper requires a common value of the agents' task environments, i.e., θ_i and θ_j directly enter the principal's value function along with each agent's cost function. This is because it is necessary to break the tie between the optimal outcomes for Θ_G and Θ_M when the marginal costs are constant.

Second, our qualitative result are not altered when the agents' types are correlated unless their types are perfectly correlated. Under perfect correlation (positive or negative), however, there are no hidden interactions between the agents, i.e., the principal can directly enforce an interaction between them. For example, if the agents' types are perfectly positively correlated, when one agent's type is *Good*, the other agent's type must be *Good* as well. Thus, whenever the agent's types are different, the principal knows that the *B*ad agent has been sabotaged. Likewise, if the types are perfectly negatively correlated, the principal can directly enforce help by requiring that both types be *G*ood.

8. Conclusions

Organizational structure affects how individual members or subdivisions of an organization interact with each other.[11] Such interactions, however, are typically hard to observe and verify. It is often impossible for top management to identify whether or not a worker has helped or sabotaged another worker. In this paper, we have compared a competitive structure and a cooperative structure to show where one structure may serve organizations to achieve their objectives better than the other in the presence of unverifiable interactions.

According to our results, when there is no possibility of hidden interactions, the traditional result in the agency theory literature holds, that is, organizations benefit from a competitive structure because a cooperative structure only provides their individual members with more opportunity to collusively misrepresent their task environments. When individual members can interact to affect each other's task environment, however, a cooperative structure allows organizations to remove incentives towards sabotage while inducing helping incentives at no cost as long as collusive misrepresentations are deterred. As a result, a cooperative structure can be optimal for organizations encountering the prospect of hidden interactions. As an extension, we have demonstrated that complementarity in operation favors cooperative structures.

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Appendix A

Proof of Lemma 1. As the objective function is concave and the constraints are convex sets, the solution of the problem is unique. Therefore, we show that the incentive constraints (IC_{GG}) and (IC_{GB}) associated with a *G*ood agent and the participation constraints (PC_{BG}) and (PC_{BB}) associated with a *B*ad agent are binding in the optimal contract. It is straightforward to show that the remaining constraints are satisfied in our solution without them.

The Lagrangian of the principal's problem is written as follows:

$$\begin{aligned}\mathcal{L} = &\textstyle\sum_i \sum_j \mu_i \mu_j \left[v(Q_k, \Theta_k) - t_{ij} - t_{ji}\right] \\ &+ \lambda_1[t_{GG} - (1-\theta_G)Q_G/2 - t_{BG} + (1-\theta_G)(1-\gamma)Q_M] \\ &+ \lambda_2[t_{GB} - (1-\theta_G)\gamma Q_M - t_{BB} + (1-\theta_G)Q_B/2] \\ &+ \lambda_3[t_{BG} - (1-\theta_B)(1-\gamma)Q_M] \\ &+ \lambda_4[t_{BB} - (1-\theta_B)Q_B/2],\end{aligned}$$

with $\gamma \in [0,1]$. The first-order conditions with respect to the transfers are as follows:

$$\frac{\partial \mathcal{L}}{\partial t_{GG}} = -2\mu_G^2 + \lambda_1 = 0, \quad \text{(A1)}$$

$$\frac{\partial \mathcal{L}}{\partial t_{GB}} = -2\mu_G\mu_B + \lambda_2 = 0, \tag{A2}$$

$$\frac{\partial \mathcal{L}}{\partial t_{BG}} = -2\mu_G\mu_B - \lambda_1 + \lambda_3 = 0, \tag{A3}$$

$$\frac{\partial \mathcal{L}}{\partial t_{BB}} = -2\mu_B^2 - \lambda_2 + \lambda_4 = 0. \tag{A4}$$

From (A1) and (A2), we have $\lambda_1 = 2\mu_G^2 > 0$ and $\lambda_2 = 2\mu_G\mu_B$, respectively; thus, (IC_{GG}) and (IC_{GB}) are binding. With the values of λ_1 and λ_2, (A3) and (A4) respectively provide $\lambda_3 = 2\mu_G > 0$ and $\lambda_4 = 2\mu_B > 0$, implying that (PC_{BG}) and (PC_{BB}) are binding. From the binding constraints, we have

$$\begin{aligned} t_{GG} &= (1-\theta_G)Q_G/2 + \Delta\theta(1-\gamma)Q_M, & t_{GB} &= (1-\theta_G)\gamma Q_M + \Delta\theta Q_B/2, \\ t_{BG} &= (1-\theta_B)(1-\gamma)Q_M, & t_{BB} &= (1-\theta_B)Q_B/2. \end{aligned} \tag{A5}$$

Substituting for the transfers in the objective function and optimizing with respect to γ results in

$$2(\mu_G^2 + \mu_G\mu_B)\Delta\theta Q_M > 0,$$

implying that $\gamma = 1$ in the optimal contract. With $\gamma = 1$, $(A5)$ provides the expressions for an agent's ex post rent in Lemma 1. Replacing the transfers with their values, optimization in the output levels yields:

$$v'(Q_G^m, \Theta_G) = 1 - \theta_G, \quad v'(Q_M^m, \Theta_M) = 1 - \theta_G, \quad v'(Q_B^m, \Theta_B) = 1 - \theta_B + \frac{\mu_G}{\mu_B}\Delta\theta,$$

implying that $Q_G^m = Q_G^*$, $Q_M^m = Q_M^*$ and $Q_B^m < Q_B^*$. □

Proof of Lemma 2. As before, we show that two incentive constraints $(CIC_{GG,BB})$ and (IC_{GB}) associated with a *G*ood agent, and the participation constraints (PC_{BG}) and (PC_{BB}) associated with a *B*ad agent are binding in the optimal contract. Again, it can be easily shown that the other constraints are satisfied in our solution without them.

The Lagrangian of the principal's problem is written as follows:

$$\begin{aligned} \mathcal{L} = \textstyle\sum_i \sum_j \mu_i\mu_j &[v(Q_k, \Theta_k) - t_{ij} - t_{ji}] \\ &+ \lambda_5[2t_{GG} - (1-\theta_G)Q_G - 2t_{BB} + (1-\theta_G)Q_B] \\ &+ \lambda_6[t_{GB} - (1-\theta_G)\gamma Q_M - t_{BB} + (1-\theta_G)Q_B/2] \\ &+ \lambda_7[t_{BG} - (1-\theta_B)(1-\gamma)Q_M] \\ &+ \lambda_8[t_{BB} - (1-\theta_B)Q_B/2], \end{aligned}$$

with $\gamma \in [0,1]$. The first-order conditions with respect to the transfers are as follows:

$$\frac{\partial \mathcal{L}}{\partial t_{GG}} = -2\mu_G^2 + 2\lambda_5 = 0, \tag{A6}$$

$$\frac{\partial \mathcal{L}}{\partial t_{GB}} = -2\mu_G\mu_B + \lambda_6 = 0, \tag{A7}$$

$$\frac{\partial \mathcal{L}}{\partial t_{BG}} = -2\mu_G\mu_B + \lambda_7 = 0, \tag{A8}$$

$$\frac{\partial \mathcal{L}}{\partial t_{BB}} = -2\mu_B^2 - 2\lambda_5 - \lambda_6 + \lambda_8 = 0. \tag{A9}$$

From (A6)–(A8), we have $\lambda_5 > 0$ and $\lambda_6 = \lambda_7 > 0$, respectively; thus, $(CIC_{GG,BB})$, (IC_{GB}) and (PC_{BG}) are binding. With the values of λ_5 and λ_6, (A9) provides $\lambda_8 > 0$, implying that (PC_{BB}) is binding. From the binding constraints, we have

$$\begin{aligned} t_{GG} &= (1-\theta_G)Q_G/2 + \Delta\theta Q_B/2, & t_{GB} &= (1-\theta_G)\gamma Q_M + \Delta\theta Q_B/2, \\ t_{BG} &= (1-\theta_B)(1-\gamma)Q_M, & t_{BB} &= (1-\theta_B)Q_B/2. \end{aligned} \tag{A10}$$

Substituting for the transfers in the objective function and optimizing with respect to γ results in

$$2\mu_G\mu_B\Delta\theta Q_M > 0,$$

implying that $\gamma = 1$ in the optimal contract. With $\gamma = 1$, (A10) provides the expressions for an agent's ex post rent in Lemma 2. Replacing the transfers with their values, optimization in the output levels yields

$$v'(Q_G^c, \Theta_G) = 1-\theta_G, \quad v'(Q_M^c, \Theta_M) = 1-\theta_G, \quad v'(Q_B^c, \Theta_B) = 1-\theta_B + \frac{\mu_G}{\mu_B}\left(1+\frac{\mu_G}{\mu_B}\right)\Delta\theta,$$

implying that $Q_G^c = Q_G^*$, $Q_M^c = Q_M^*$ and $Q_B^c < Q_B^m$ $(< Q_B^*)$. □

Proof of Proposition 1. The proof is direct, as the problem in C^c simply has additional constraints $(CIC_{ij,i'j'})$. □

Proof of Claim 1. Claim 1 directly follows from the discussion. □

Proof of Lemma 3. The only difference from the principal's problem when the agents cannot affect each other's type is that when sabotage is allowed, the probability distribution for $k \in \{G, M, B\}$ is redistributed more in favor of M and B. Therefore, the constraints that are binding remain the same as those in the Proof of Lemma 1, and the binding constraints provide the expressions for the transfers:

$$\begin{aligned} t_{GG} &= (1-\theta_G)Q_G/2 + \Delta\theta(1-\gamma)Q_M, & t_{GB} &= (1-\theta_G)\gamma Q_M + \Delta\theta Q_B/2, \\ t_{BG} &= (1-\theta_B)(1-\gamma)Q_M, & t_{BB} &= (1-\theta_B)Q_B/2. \end{aligned} \tag{A11}$$

Substituting for the transfers in the objective function and optimizing with respect to γ results in

$$2\mu_G(\mu_G\phi_G + \mu_B)\Delta\theta Q_M > 0,$$

implying that $\gamma = 1$ in the optimal contract. With $\gamma = 1$, (A15) provides the expressions for an agent's ex post rent in Lemma 3. Replacing the transfers with their values, optimization in the output levels yields

$$v'(Q_G^{\widehat{m}}, \Theta_G) = 1-\theta_G,\ v'(Q_M^{\widehat{m}}, \Theta_M) = 1-\theta_G,\ v'(Q_B^{\widehat{m}}, \Theta_B) = 1-\theta_B + \frac{\mu_G^2\phi_G\phi_B + \mu_G\mu_B}{\mu_G^2\phi_B^2 + \mu_B^2}\Delta\theta,$$

implying that $Q_G^{\widehat{m}} = Q_G^*$, $Q_M^{\widehat{m}} = Q_M^*$ and $Q_B^{\widehat{m}} < Q_B^*$. □

Proof of Lemma 4. We show that (SC), (IC_{GB}), (PC_{BG}), and (PC_{BB}) are binding in the optimal contract. It is straightforward to show that the other constraints are satisfied in our solution without them.

The Lagrangian of the principal's problem is written as follows:

$$\begin{aligned} \mathcal{L} = {} & \textstyle\sum_i \sum_j \mu_i\mu_j[v(Q_k, \Theta_k) - t_{ij} - t_{ji}] \\ & + \tau_5[t_{GG} - (1-\theta_G)Q_G/2 - t_{GB} + (1-\theta_G)\gamma Q_M] \\ & + \tau_6[t_{GB} - (1-\theta_G)\gamma Q_M - t_{BB} + (1-\theta_G)Q_B/2] \\ & + \tau_7[t_{BG} - (1-\theta_B)(1-\gamma)Q_M] \\ & + \tau_8[t_{BB} - (1-\theta_B)Q_B/2], \end{aligned}$$

with $\gamma \in [0,1]$. The first-order conditions with respect to the transfers are as follows:

$$\frac{\partial \mathcal{L}}{\partial t_{GG}} = -2\mu_G^2 + \tau_5 = 0, \tag{A12}$$

$$\frac{\partial \mathcal{L}}{\partial t_{GB}} = -2\mu_G\mu_B - \tau_5 + \tau_6 = 0, \tag{A13}$$

$$\frac{\partial \mathcal{L}}{\partial t_{BG}} = -2\mu_G\mu_B + \tau_7 = 0, \tag{A14}$$

$$\frac{\partial \mathcal{L}}{\partial t_{BB}} = -2\mu_B^2 - \tau_6 + \tau_8 = 0. \tag{A15}$$

From (A12), we have $\tau_5 = 2\mu_G^2 > 0$; thus, (SC) is binding. With $\tau_5 = 2\mu_G^2$, (A13) provides $\tau_6 = 2\mu_G > 0$, implying that (IC_{GB}) binds. From (A14), $\tau_7 = 2\mu_G\mu_B > 0$, and from (A15), with $\tau_6 = 2\mu_G$, we have $\tau_8 = 2(\mu_B^2 + \mu_G) > 0$. Thus, (PC_{BG}) and (PC_{BB}) are binding. From the binding constraints, we have

$$\begin{array}{ll} t_{GG} = (1-\theta_G)Q_G/2 + \Delta\theta Q_B/2, & t_{GB} = (1-\theta_G)\gamma Q_M + \Delta\theta Q_B/2, \\ t_{BG} = (1-\theta_B)(1-\gamma)Q_M, & t_{BB} = (1-\theta_B)Q_B/2. \end{array} \tag{A16}$$

Substituting for the transfers in the objective function and optimizing with respect to γ results in

$$2\mu_G\mu_B\Delta\theta Q_M > 0,$$

implying that $\gamma = 1$ in the optimal contract. With $\gamma = 1$, (A16) provides the expressions for an agent's ex post rent in Lemma 4. Replacing the transfers with their values, optimization in the output levels yields

$$v'(Q_G^{\widetilde{m}}, \Theta_G) = 1-\theta_G, \quad v'(Q_M^{\widetilde{m}}, \Theta_M) = 1-\theta_G, \quad v'(Q_B^{\widetilde{m}}, \Theta_B) = 1-\theta_B + \frac{\mu_G}{\mu_B}\left(1+\frac{\mu_G}{\mu_B}\right)\Delta\theta,$$

implying that $Q_G^{\widetilde{m}} = Q_G^*$, $Q_M^{\widetilde{m}} = Q_M^*$ and $Q_B^{\widetilde{m}} < Q_B^m$ $(< Q_B^*)$. □

Proof of Lemma 5. The principal's optimal payoffs when allowing and deterring sabotage are, respectively,

$$\begin{aligned} \pi_{comp}^{allow} = {} & \mu_G^2\phi_G^2\pi_G^* + 2(\mu_G^2\phi_G\phi_B + \mu_G\mu_B)[\pi_M^* - \Delta\theta Q_B^{\widehat{m}}/2] \\ & + (\mu_G^2\phi_B^2 + \mu_B^2)[v(Q_B^{\widehat{m}}, \Theta_G) - (1-\theta_G)Q_B^{\widehat{m}}] \quad \text{and} \end{aligned} \tag{A17}$$

$$\begin{aligned} \pi_{comp}^{deter} = {} & \mu_G^2[\pi_G^* - \Delta\theta Q_B^{\widetilde{m}}] + 2\mu_G\mu_B[\pi_M^* - \Delta\theta Q_B^{\widetilde{m}}/2] \\ & + \mu_B^2[v(Q_B^{\widetilde{m}}, \Theta_G) - (1-\theta_G)Q_B^{\widetilde{m}}], \end{aligned} \tag{A18}$$

where $\pi_G^* \equiv v(Q_G^*, \Theta_G) - (1-\theta_G)Q_G^*$ and $\pi_M^* \equiv v(Q_M^*, \Theta_M) - (1-\theta_G)Q_M^*$. Recall that $v'(Q_B^{\widehat{m}}, \Theta_B) = 1-\theta_B + \frac{\mu_G^2\phi_G\phi_B + \mu_G\mu_B}{\mu_G^2\phi_B^2 + \mu_B^2}\Delta\theta$ from the Proof of Lemma 3. Therefore, as $\phi_B \longrightarrow 0$ (or $\phi_G \longrightarrow 1$), we have $Q_B^{\widehat{m}} \longrightarrow Q_B^m$ and π_{comp}^{allow} in $(A21)$ approaches the payoff resulting from the outcome in Lemma 1. This implies that as ϕ_B decreases, π_{comp}^{allow} becomes more attractive, and that $\pi_{comp}^{allow} > \pi_{comp}^{deter}$ for small enough ϕ_B. As $\phi_B \longrightarrow 1$ (or $\phi_G \longrightarrow 0$), we have

$$\begin{aligned} \pi_{comp}^{allow} \longrightarrow {} & 2\mu_G\mu_B[\pi_M^* - \Delta\theta Q_B^{\widehat{m}}/2] \\ & + (\mu_G^2 + \mu_B^2)[v(Q_B^{\widehat{m}}, \Theta_G) - (1-\theta_G)Q_B^{\widehat{m}}], \end{aligned}$$

implying that if μ_G is not too small, then π^{deter}_{comp} becomes more attractive as ϕ_B increases, and that $\pi^{deter}_{comp} > \pi^{allow}_{comp}$ for large enough ϕ_B. □

Proof of Claim 2 and Lemma 6. Again, we first consider $(CIC_{GG,BB})$, (IC_{GB}), (PC_{BG}), and (PC_{BB}) without the other constraints, as it can be easily shown that the other constraints are satisfied in our solution without them.

The Lagrangian of the principal's problem is written as follows:

$$\begin{aligned}\mathcal{L} = &\textstyle\sum_i \mu_i^2[v(Q_k,\Theta_k) - 2t_{ii}] + \mu_G\mu_B \sum_i \sum_j \widetilde{\psi}[v(Q_k,\Theta_k) - t_{ij} - t_{ji}] \\ &+ \tau_9[2t_{GG} - (1-\theta_G)Q_G - 2t_{BB} + (1-\theta_G)Q_B] \\ &+ \tau_{10}[t_{GB} - (1-\theta_G)\gamma Q_M - t_{BB} + (1-\theta_G)Q_B/2] \\ &+ \tau_{11}[t_{BG} - (1-\theta_B)(1-\gamma)Q_M] \\ &+ \tau_{12}[t_{BB} - (1-\theta_B)Q_B/2],\end{aligned}$$

where $\gamma \in [0,1]$ and $\widetilde{\psi} = \begin{cases} \psi_G & \text{if } i = j = G, \\ \psi_B & \text{if } i \neq j, \\ 0 & \text{if } i = j = B. \end{cases}$

The first-order conditions with respect to the transfers are as follows:

$$\frac{\partial \mathcal{L}}{\partial t_{GG}} = -2\mu_G^2 - 2\mu_G\mu_B\psi_G + \tau_9 = 0, \tag{A19}$$

$$\frac{\partial \mathcal{L}}{\partial t_{GB}} = -2\mu_G\mu_B\psi_B + \tau_{10} = 0, \tag{A20}$$

$$\frac{\partial \mathcal{L}}{\partial t_{BG}} = -2\mu_G\mu_B\psi_B + \tau_{11} = 0, \tag{A21}$$

$$\frac{\partial \mathcal{L}}{\partial t_{BB}} = -2\mu_B^2 - 2\tau_5 - \tau_{10} + \tau_{12} = 0. \tag{A22}$$

From (A19)–(A21), we have $\tau_9 > 0$ and $\tau_{10} = \tau_{11} > 0$, respectively; thus, $(CIC_{GG,BB})$, (IC_{GB}) and (PC_{BG}) are binding. With the values of τ_9 and τ_{10}, (A22) provides $\tau_{12} > 0$, implying that (PC_{BB}) is binding. From the binding constraints, we have

$$\begin{aligned} &t_{GG} = (1-\theta_G)Q_G/2 + \Delta\theta Q_B/2, \qquad &&t_{GB} = (1-\theta_G)\gamma Q_M + \Delta\theta Q_B/2, \\ &t_{BG} = (1-\theta_B)(1-\gamma)Q_M, &&t_{BB} = (1-\theta_B)Q_B/2. \end{aligned} \tag{A23}$$

Substituting for the transfers in the objective function and optimizing with respect to γ results in

$$2\mu_G\mu_B\psi_B\Delta\theta Q_M > 0,$$

implying that $\gamma = 1$ in the optimal contract. With $\gamma = 1$, (A23) provides the expressions for an agent's ex post rent in Lemma 6. Replacing the transfers with their values, optimization in the output levels yields

$$v'(Q_G^{\tilde{c}},\Theta_G) = 1-\theta_G,\; v'(Q_M^{\tilde{c}},\Theta_M) = 1-\theta_G,\; v'(Q_B^{\tilde{c}},\Theta_B) = 1-\theta_B + \frac{\mu_G}{\mu_B}\left(1+\psi_G+\frac{\mu_G}{\mu_B}\right)\Delta\theta,$$

implying that $Q_G^{\tilde{c}} = Q_G^*$, $Q_M^{\tilde{c}} = Q_M^*$ and $Q_B^{\tilde{c}} < Q_B^{\tilde{m}}$ $(< Q_B^*)$. □

Proof of Proposition 2. The principal's optimal expected payoff in the cooperative structure is

$$\pi_{coop} = (\mu_G^2 + 2\mu_G\mu_B\psi_G)[\pi_G^* - \Delta\theta Q_B^{\tilde{c}}] + 2\mu_G\mu_B\psi_B[\pi_M^* - \Delta\theta Q_B^{\tilde{c}}/2] + \mu_B^2[v(Q_B^{\tilde{c}}, \Theta_G) - (1-\theta_G)Q_B^{\tilde{c}}],$$

where $\pi_G^* \equiv v(Q_G^*, \Theta_G) - (1-\theta_G)Q_G^*$ and $\pi_M^* \equiv v(Q_M^*, \Theta_M) - (1-\theta_G)Q_M^*$. We can compare this with π_{comp}^{allow} in (A18) and π_{comp}^{deter} in $(A18)$. Suppose that Δv is sufficiently small; then, the state G is not much valued by the principal, while the optimal outcome for state B suffers a larger distortion in the cooperative structure than in the competitive structure. Thus, $\pi_{coop} < \min\{\pi_{comp}^{allow}, \pi_{comp}^{deter}\}$ in such cases. Suppose that Δv is sufficiently large; then, because $k = G$ takes place with a higher probability in the cooperative structure than in the competitive structure, $\pi_{coop} > \max\{\pi_{comp}^{allow}, \pi_{comp}^{deter}\}$.

Suppose that v_Θ is neither sufficiently small nor sufficiently large. We define ψ_G^- and ϕ_B^- following equation $\pi_{coop}(\psi_G^-) - \pi_{comp}^{allow}(\phi_B^-) = 0$. It then follows that, for a given ψ_G^-, $\pi_{coop} \gtrless \pi_{comp}^{allow}$ if $\phi_B \gtrless \phi_B^-$. If ϕ_B is sufficiently small, we have $\pi_{comp}^{allow} > \pi_{comp}^{deter}$ from Lemma 5; hence, π_{comp}^{allow} dominates. Likewise, for a given ϕ_B^-, $\pi_{coop} \gtrless \pi_{comp}^{allow}$ if $\psi_G \gtrless \psi_G^-$. We define ψ_G^+ based on $\pi_{coop}(\psi_G^+) - \pi_{comp}^{allow} = 0$. It follows that $\pi_{coop} \gtrless \pi_{comp}^{deter}$ if $\psi_G \gtrless \psi_G^+$. Thus, if ψ_G and ϕ_B are sufficiently large, then C^c dominates C^m for sufficiently large Δv. □

Proof of Lemma 7. We consider $(\overline{IC}_{GG})$, $(\overline{IC}_{GB})$, $(\overline{PC}_{BG})$ and $(\overline{PC}_{BB})$ here, as the remaining constraints can be shown to be satisfied by the solution without them. The Lagrangian of the principal's problem is written as follows:

$$\begin{aligned}\mathcal{L} = &\textstyle\sum_i \sum_j \mu_i\mu_j[v(q_k, \Theta_k) - t_{ij} - t_{ji}] \\ &+ \omega_1[t_{GG} - (1-\theta_G)q_G - t_{BG} + (1-\theta_G)q_M] \\ &+ \omega_2[t_{GB} - (1-\theta_G)q_M - t_{BB} + (1-\theta_G)q_B] \\ &+ \omega_3[t_{BG} - (1-\theta_B)q_M] \\ &+ \omega_4[t_{BB} - (1-\theta_B)q_B],\end{aligned}$$

The first-order conditions with respect to the transfers are as follows:

$$\frac{\partial \mathcal{L}}{\partial t_{GG}} = -2\mu_G^2 + \omega_1 = 0, \quad \text{(A24)}$$

$$\frac{\partial \mathcal{L}}{\partial t_{GB}} = -2\mu_G\mu_B + \omega_2 = 0, \quad \text{(A25)}$$

$$\frac{\partial \mathcal{L}}{\partial t_{BG}} = -2\mu_G\mu_B - \omega_1 + \omega_3 = 0, \quad \text{(A26)}$$

$$\frac{\partial \mathcal{L}}{\partial t_{BB}} = -2\mu_B^2 - \omega_2 + \omega_4 = 0. \quad \text{(A27)}$$

From (A24) and (A25), we have $\omega_1 > 0$ and $\omega_2 > 0$, respectively; thus, $(\overline{IC}_{GG})$ and $(\overline{IC}_{GB})$ are binding. With the values of ω_1 and ω_2, (A26) and (A27) respectively provide $\omega_3 > 0$ and $\omega_4 > 0$, implying that $(\overline{PC}_{BG})$ and $(\overline{PC}_{BB})$ are binding. From the binding constraints, we have an agent's ex post rent in Lemma 7. Substituting for the transfers in the objective function and optimizing with respect to the output levels yields

$$v'(q_G^{\overline{m}}, \Theta_G) = 2 - \Theta_G, \;\; v'(q_M^{\overline{m}}, \Theta_M) = 2 - \Theta_M + \frac{\mu_G}{\mu_B}\Delta\theta, \;\; v'(q_B^{\overline{m}}, \Theta_B) = 2 - \Theta_B + \frac{2\mu_G}{\mu_B}\Delta\theta,$$

implying that $q_G^{\overline{m}} = q_G^*$, $q_M^{\overline{m}} < q_M^*$ and $q_B^{\overline{m}} < q_B^*$. □

Proof of Claim 3. The proof follows directly from the Proof of Lemma 7. □

Proof of Proposition 3. The proof follows directly from the discussion. □

Notes

1 In traditional principal–agent models, the possibility of collusion among agents limits the principal's welfare (e.g., Tirole 1986 [10]; Kofman and Lawarrée 1993 [11]; Laffont and Martimort 1997 [12], 1998 [13]; Khalil and Lawarrée 2006 [14]). The possibility of collusion in the traditional models corresponds to the integrated organizational structure in our model, in which the agents cannot affect each other's task environment.

2 This is a standard assumption; see Tirole (1992) [15] for a discussion of enforceability of side-contracts.

3 In our model, an agent only reports their updated type. If an agent reports both their initial type and the updated type, then there is no hidden interaction. When reporting both the initial and the updated type, it is necessary to impose a random shock in our model (i.e., the agent's task environment can be changed by chance) to generate the prospect of hidden interactions; such a model adds more cases to our current setting without changing the qualitative result.

4 Thus, we assume that an agent has a right to protest the other agent's report in court if an agent's type is reported by the other agent, and that resolution is prohibitively costly. Suppose that an agent can acquire hard evidence on the other agent's type with a strictly positive probability. Then, the principal can achieve the first-best outcome if the penalty applied to a misreporting agent can be unlimited.

5 Due to the Inada conditions, Q_{ij} is strictly positive at the optimum.

6 In the principal's problem, constraints are identical for agents of the same type, which implies that $q_{GG} = Q_G/2$ and $q_{BB} = Q_B/2$.

7 The result will be the same as long as the agents can collude after learning their types and before reporting them.

8 The strictly decreasing schedule, in particular $Q_G^* > Q_M^*$, is due to the fact that Θ_k enters the value function (common value). We discuss the robustness related to this issue later.

9 Constant marginal costs are adopted for expositional purposes; this allows us to exaggerate the intuition. We discuss this issue at greater length in the concluding section.

10 See Winter (2009) [21], who showed that, in a team production context, rewards may affect performance in a nonmonotonic way, i.e., a higher reward in the case of success may reduce agents' incentives to exert effort.

11 See Daft (2009) [22] for an example.

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