Organizational Structures and Manipulable Aggregate Information

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ABSTRACT

This paper considers an organization with the top management (the principal) and multiple subunits (agents), where each agent has private information about his efficiency. Under centralization, inducing the agents' truthful behavior may lead to the principal's incentive to manipulate the aggregate information from the agents—this tension between the principal's and the agents' incentives results in a pooling outcome when the agents are likely to be efficient. Under delegation, although the agent with delegated authority gets more rent, a separating outcome is restored. We show that, delegation (centralization) is optimal when the likelihood that an agent is efficient (inefficient) is high.

JEL Classification: D82, D86

Key words: Agency, Aggregate Information, Organization Design

1 Introduction

Organizational structures, as pointed out by Simon (1973), are "authority mechanisms" that are constructed to coordinate and streamline organizational information. In some organizations, their communication channels are heavily centralized and the top management have a strong grip on processing information, while in other organizations, such channels are delegated to one or a group of subunits and information is processed through chains of command. In any case, designing an organizational structure requires careful examinations of the advantages and disadvantages of potential structures.

Using an agency model, this study compares centralization and delegation of processing collective information within an organization, and provide a novel economic rationale for when and why one structure prevails over the other. In doing so, our analysis identifies new incentive problems and resulting distortions in the optimal outcome.

Our main finding is the following. When the top management centralizes communication channels of the organization, inducing truthful behavior of the organization's subunits may lead to the top management's own misrepresenting behavior—in particular, the top management may have an incentive to misrepresent the aggregate organizational information collected from the subunits. As a result, under centralization, reconciling the tension between the top management's and the subunits' incentives may require some pooling outcome in the optimal contracts. When the top management delegates collecting information to a subunit, then that particular subunit commands more information rent compared to centralization, but a fully separating outcome is restored in the optimal contracts.

We model an internal organization with a principal (the top management) and two agents (the subunits). We postulate that an unlimited communication to perfectly process information is prohibitively costly—it is not feasible for an agent to communicate with all other parties,[1] and the principal can only process the aggregate information. This captures, for example, situations in a large company or a multinational where each subunit cannot process all the other subunits' reports, and the top management's opportunity cost limits it to process only the aggregate report or executive summary. In fact, practitioners frequently point out these limits. For instance, in an interview with Harvard Business Review, Percy Barnevik, then CEO of ABB Group, reports that one of the largest obstacles his organization faces is communicating with its tens of thousand of subunits.[2]

[1] In the extension section, we relax this assumption to show that the principal may want to choose such a restrictive communication technology.

[2] Interview by Tayler (1991). See also Azziz (2013) for a similar point.

Under centralization, there is no communication channel between the agents. Each agent reports his efficiency to the principal only, and the principal receives only the aggregate report (the aggregate efficiency to implement the project). An agent can reap information rent by misrepresenting his efficiency. As in the standard screening model, the principal distorts the project size downward to induce the agents' truthful behavior, and makes the distortion larger as the aggregate efficiency decreases. This, while mitigating the agents' misrepresenting incentive, can lead to the principal's own manipulating incentive. To be specific, when the aggregate efficiency is bad (both agents are inefficient), the principal may have an incentive to misrepresent the aggregate efficiency as medium (one is efficient but the other is inefficient). That is, the principal may gain ex post by manipulating the aggregate information so that each agent is perceived as efficient by the other agent when both agents are inefficient. We show that reconciling the agents' and the principal's incentives may require a pooling between the ex post project sizes in the optimal contracts.

Under delegation, one agent becomes the "superior (the middle-agent)" of the other agent (the bottom-agent). The bottom-agent reports his efficiency to the middle-agent, who in turn reports the aggregate efficiency to the principal. Under this structure, the authority to process the aggregate information is shifted from the principal to the middle-agent, and as a result, the principal faces a loss of control. Namely, since the middle-agent has more information when making his report, the principal must increase rent provision to this agent for a truthful report. In order to extract the middle-agent's larger information rent, the optimal contracts are accompanied by additional distortion in the project size. There is a gain, however, from the loss of control—a fully separating outcome is implemented.

Comparing the two structures, for a small probability that an agent is efficient, the principal prefers centralization. Since only an efficient agent receives rent, when the chance that an agent is efficient is small, the project size is distorted downward but only by a small amount. As mentioned above, the principal's manipulating incentive under centralization stems from the downward distortion in the project size. When the distortion is small enough, the principal's manipulating incentive does not arise, and thus the optimal contracts under centralization implement a fully separating outcome. As a result, for a small probability that an agent is efficient, centralization dominates delegation—under delegation, the principal simply provides more rent compared to centralization.

The rank, however, is reversed as the probability that an agent is efficient becomes larger. Under such parameters, the project size when both agents are inefficient gets significantly distorted downward, which raises the principal's incentive to manipulate the aggregate information from the agents. When it is likely enough that an agent is efficient, the optimal incentive contracts under centralization includes a pooling outcome. Under delegation, although the optimal contracts must provide more rent due to a loss of control, a fully separating outcome is restored. In other words, delegation enables the principal to utilize the organizational information more effectively than centralization. We show that, for a large probability that an agent is efficient, delegation prevails over centralization.

The rest of the paper proceeds as follows. In Section 2, we review the related studies. The model is presented in Section 3. In Section 4, we discuss our benchmark to show that, when the principal cannot manipulate the aggregate information, centralization always dominates delegation. In Section 5, we compare centralization and delegation when the principal can manipulate the aggregate information from the agents. Extension and robustness are discussed in Section 6. We conclude in Section 7. All proofs are in Appendix.

2 Review of Related Studies

Our paper belongs to the literature that links incentive issues and organizational structures.[3] While earlier studies advocate centralization by identifying loss of control under delegation,[4] there have been a number of papers identifying situations where delegation outperforms centralization. Distinguishing organizational structures on the basis of differences in monitoring feasibilities rather than information flows, Baron and Besanko (1992) and Melumad et al. (1995) identify necessary conditions with which the vertical hierarchy achieves the same outcome under the horizontal hierarchy. In their paper, the vertical hierarchy does not dominate the horizontal hierarchy. To be specific, these studies demonstrate that if the top management can monitor transaction between the subunits, then the optimal outcome is independent of the organizational structure.

More closely related to ours are the following studies. Melumad et al. (1997) show that, when contracts are complex, delegating a contracting authority to an agent brings the organization more flexibility. Laffont and Martimort (1998) show that such a delegation enables the organization under limited communication to effectively discriminate transfers among different agents, thus mitigating the agents' side-contracting incentives under centralization. Delegation in their model is a contractual delegation, where the principal contracts only with the middle-agent, and the middle-agent contracts with the bottom-agent, whereas in

[3] Rosen (1982), Harris and Raviv (2002), and Hart and Moore (2005) study coordination issues in different organizational structures.

[4] See Williamson (1967) for example. For later studies, see Qian (1994) and McAfee and McMillan (1995).

our model, the principal under delegation directly offer contracts to both agents, and only an authority of communication is delegated to the middle agent. Friebel and Raith (2004) models a "chain of command" similar to delegation in our model. The authors show that exclusive communication lines to the top management induces middle managers to make a sincere effort for recruiting and training subordinates. None of these studies consider the principal's manipulating incentive under centralization.

The following studies demonstrate the optimality of delegation in incomplete contracting. Beaudry and Poitevin (1995) and Olsen (1996) point out that delegation can make it harder to achieve a successful renegotiation. Aghion and Tirole (1997) demonstrate that delegation induces acquisition of useful information for the organization. Olsen and Torsvik (2000) show that a firm's ability to learn about the difficulty of the tasks workers engage in will induce the firm to give workers more discretion over tasks and weaker incentives. Studies such as Dessein (2002) and Alonso et al. (2008) show that organizations can benefit from delegation because it makes better use of private information. Shin and Strausz (2014) show that delegation can ease a tension between different dynamic incentives of the agent. Unlike these studies, we employ a complete contracting approach in this paper.

Finally, our paper is related to the studies on the principal's manipulating incentives when contracting with multiple agents. In McAfee and Schwartz (1994), the principal under limited commitment may have an incentive to renegotiate with an agent at another agent's expense. Dequiedt and Martimort (2015) show that there arises the principal's manipulating incentive similar to that under centralization in our paper. In their paper, however, the agents' types are correlated—unlike in ours, the second-best outcome is still achieved if the agents' types are independent to each other.[5] Akbarpoury and Liz (2018) study optimal auctions under the auctioneer's manipulating incentive, when the bidders cannot observe each other's bid. None of these papers consider organizational structures.

3 Model of Internal Organization

We model an organization with a principal who uses two agents α and β for a project. The project of size $q \geq 0$ yields the principal a value $v(q)$, and imposes a cost $\theta^k q$ on agent $k \in \{\alpha, \beta\}$. The project size q is publicly verifiable. Agent k's cost parameter $\theta^k \in \{\theta_g, \theta_b\}$ is his private information, where $\Delta\theta \equiv \theta_b - \theta_g > 0$. We refer to θ^k as agent k's "type." The

[5] Also in their paper, as in Crémer and Mclean (1985, 1988), the agents' correlated types allows the principal to fully extract the agents rent in the absence of the principal's manipulating incentive.

agents' types are drawn independently from identical distributions—$\theta^k = \theta_g$ with $\varphi \in (0, 1)$, and thus $\theta^k = \theta_b$ with $1 - \varphi$. The probability distribution is public knowledge.

We denote by $\Theta \equiv \theta^\alpha + \theta^\beta$ "the aggregate type," which is the project's overall marginal cost. Since $\theta^\alpha, \theta^\beta \in \{\theta_g, \theta_b\}$, there are three possibilities for the aggregate type:

$$\Theta_G \equiv 2\theta_g, \quad \Theta_M \equiv \theta_g + \theta_b, \quad \Theta_B \equiv 2\theta_b.$$

We assume that $v(\cdot)$ satisfies the Inada conditions to ensure interior solutions. The project's efficient size, denoted by q^*, is characterized by:

$$v'(q^*_\gamma) = \Theta_\gamma,\ \gamma \in \{G, M, B\}.$$

In order to compensate the agents for their costs, the principal pays each agent a transfer, denoted by t^k, $k \in \{\alpha, \beta\}$. Given transfers, the principal's and the agent's payoff from the project of size q are respectively:

$$\pi \equiv v(q) - \sum_{k \in \{\alpha,\beta\}} t^k \quad \text{and} \quad u^k \equiv t^k - \theta^k q.$$

We assume that each agent can quit the organization at any time and will do so if his payoff is less than his reservation level of zero.

Our main interest is to compare two organizational structures, centralization versus delegation, each expressing different communication flows. For the main body of the paper, we make the following assumptions regarding information structures. First, we postulate that it is not feasible for an agent to communicate with all other parties. Uder centralization, therefore, each agent reports his type directly only to the principal. Under delegation, one agent (agent β) makes a report to the other agent (agent α), who in turn makes a report to the principal. We will discuss more on this issue as an extension and robustness in Section 6. Second, the principal can processes only the aggregate information from the agents, and thus she conditions the contract only on Θ_γ, the aggregate information from the agents.[6] While our main reason for imposing these assumptions are to reduce the complexity of the problem, we point out that this assumption is consistent with the findings in varies organization studies—unlimited communication to fully process the entire information in detail, due to time constraints, is given up in many organizations.[7]

[6] See Laffont and Martimort (1997, 1998) for a similar assumption. In our companion paper, Celik et al. (2018), centralization when the contract is conditioned on $\{\theta^\alpha, \theta^\beta\}$, instead of Θ_γ, is analyzed.

[7] See Weick (1995) for example.

By the revelation principle, we can restrict attention to contracts that condition the project size, q, and transfers, (t^α, t^β), on the aggregate information possessed by the principal. Hence, we express the contract as a combination:

$$\Phi \equiv \left(q_\gamma, t_\gamma^\alpha, t_\gamma^\beta\right), \ \gamma \in \{G, M, B\}.$$

Figure 1 illustrates organizational structures and information flows under each structure.

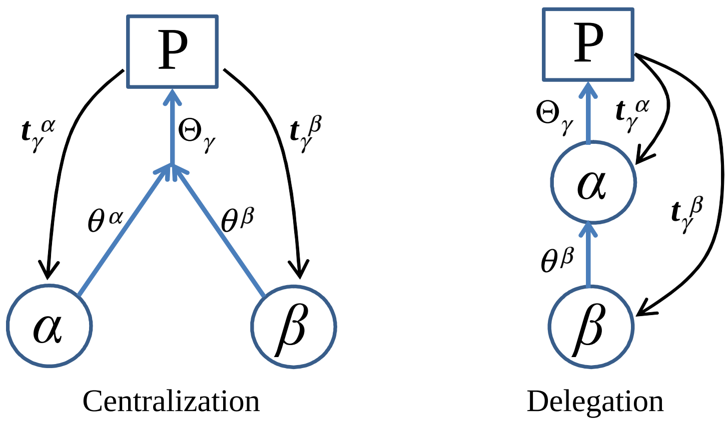

Fig 1. Organizational Structures and Information Flows.

The timings under centralization and delegation are summarized below.

Centralization Under centralization, each agent reports his type directly only to the principal. Once the reports are made, the principal makes an announcement on $\gamma \in \{G, M, B\}$.

1. The principal offers the contract $\Phi \equiv \left(q_\gamma, t_\gamma^\alpha, t_\gamma^\beta\right)$, $\gamma \in \{G, M, B\}$.
2. Each agent makes a report on his type, $\theta^k \in \{\theta_g, \theta_b\}$, to the principal.
3. The principal receives reports and makes a public announcement on $\gamma \in \{G, M, B\}$.
4. The project is implemented and transfers are paid according to Φ.

Delegation Under delegation, the principal receives a report on $\gamma \in \{G, M, B\}$ from agent α, who first receives a report from agent β.

1. The principal offers the contract $\Phi \equiv \left(q_\gamma, t_\gamma^\alpha, t_\gamma^\beta\right)$, $\gamma \in \{G, M, B\}$.

2. Agent β makes a report on his type θ^β to agent α, who in turn, makes a report on $\gamma \in \{G, M, B\}$ to the principal.

3. The principal makes a public announcement on $\gamma \in \{G, M, B\}$.

4. The project is implemented and transfers are paid according to Φ.

As mentioned above, the agents' liabilities are limited in that one can quit at any point in the time line if a strictly negative payoff is expected. For presentational simplicity, we will assume that, one agent's quitting does not require the other agent's quitting—i.e., if the other agent can still choose to work and gets paid according to the contract, although the project yields no value to the principal in such a case.[8] Alternatively, we can assume that if an agent quits, the game ends at that point—our result does not change.

In the following two sections, we compare the principal's maximum payoffs under centralization and delegation. First, we will assume that the principal cannot manipulate the aggregate information. That is, under either organizational structure, the principal truthfully announces $\gamma \in \{G, M, B\}$, consistent with the agents' reports to her. We show that, in the absence of the principal's manipulating incentive, centralization always dominates delegation for the principal.

When the principal can manipulate the aggregate information, however, the result may be reversed. We identify that inducing truthful reports from the agents under centralization may lead to the principal's incentive to manipulate the aggregate information from the agents. In such a case, the optimal contract under centralization may require a pooling outcome to ease the tension between the agents' and the principal's incentives. We show that, in the presence of the principal's manipulating incentive, delegation dominates centralization when it is likely enough that the agnets are efficient.

4 When the Principal Cannot Manipulate Information

4.1 Centralization

Under centralization, the agents report directly and simultaneously to the principal and are symmetric. As a consequence, an optimal contract exhibits the symmetric structure, $t_\gamma^\alpha = t_\gamma^\beta = t_\gamma$, so that we can restrict attention to contracts of the form (q_γ, t_γ), $\gamma \in \{G, M, B\}$, under centralization.

[8] Incentive constraitns under delegation enter in simpler forms with this assumption.

In our model, the principal wants a strictly positive size of the project regardless of the agents' types. Since each agent can quit anytime he wants, in order to ensure the agent's ex post participation, the principal's offer, (q_γ, t_γ), must provide a non-negative rent to ewach agent regardless of $\gamma \in \{G, M, B\}$. For a type-g agent, the following participation constraints must be satisfied:

$$t_G - \theta_g q_G \geq 0 \text{ and} \tag{PC_G}$$

$$t_M - \theta_g q_M \geq 0, \tag{$\overline{PC}_M$}$$

while the following constraints must be satisfied for a type-b agent's participation:

$$t_M - \theta_b q_M \geq 0 \text{ and} \tag{$\underline{PC}_M$}$$

$$t_B - \theta_b q_B \geq 0. \tag{PC_B}$$

The Left-Hand-Sides (LHS) of the participation constraints above are an agent's ex post payoffs with his truthful report to the principal. To induce each agent's truthful report, the following Bayesian incentive compatibility conditions must be satisfied in the optimal contracts:

$$\varphi\left[t_G - \theta_g q_G\right] + (1-\varphi)\left[t_M - \theta_g q_M\right] \geq \varphi\left[t_M - \theta_g q_M\right] + (1-\varphi)\left[t_B - \theta_g q_B\right], \tag{IC_g}$$

$$\varphi\left[t_M - \theta_b q_M\right] + (1-\varphi)\left[t_B - \theta_b q_B\right] \geq \varphi\left[\max\{t_G - \theta_b q_G, 0\}\right] + (1-\varphi)\left[t_M - \theta_b q_M\right]. \tag{IC_b}$$

When making a report to the principal, an agent does not know the other agent's type. Therefore, an agent's incentive compatibility constraints is conditional only on his own private information. The Right-Hand Sides (RHS) of the constraints are an agent's expected payoff if he decides to misreport his type. Notice that, an agent, after misreporting his type, may choose to quit. The participation constraints (PC_M^g) and (PC_B^b), however, imply that a type-g agent will not quit in the case of misrepresenting himself as type-b, regardless of the other agent's type. A type-b agent, however, may choose to quit if he decides to misrepresent himself type-g, depending on the other agent's type. Although (PC_M^b) implies that a type-b agent will remain in the organization after misreporting if the principal announces that $\gamma = M$, he may quit if $\gamma = G$ is announced—this is captured by the expression $\max\{t_G - \theta_b q_G, 0\}$ in the RHS of (IC_b).

The principal under centralization chooses $\Phi = \{q_\gamma,\ t_\gamma\}$, $\gamma \in \{G, M, B\}$, to solve the following problem, if she cannot manipulate the aggregate information:

$$\mathcal{P}^c\text{: } \max_{\Phi}\ \pi(\Phi) = \varphi^2\left[v(q_G) - 2t_G\right] + 2\varphi(1-\varphi)\left[v(q_M) - 2t_M\right] + (1-\varphi)^2\left[v(q_B) - 2t_B\right],$$

subject to $(PC_G) \sim (IC_b)$. The following proposition presents the optimal outcome in $\mathcal{P}^c$.

Proposition 1 *Suppose the principal cannot manipulate the aggregate information. Under centralization, there exists $\widetilde{\varphi} < 1/2$, such that the optimal contract, Φ^c, entails the following:*

- *For $\varphi \geq \widetilde{\varphi}$,*

$$v'(q_G^c) = \Theta_G, \quad v'(q_M^c) = \Theta_M + \frac{\varphi}{1-\varphi}\Delta\theta, \quad v'(q_B^c) = \Theta_B + \frac{2\varphi}{1-\varphi}\Delta\theta.$$

  A type-g agent receives strictly positive rents, while a type-b agent receives no rent.

- *For $\varphi < \widetilde{\varphi}$,*

$$v'(q_G^c) = \Theta_G, \quad 2\varphi v'(q_M^c) + (1-2\varphi)v'(q_B^c) = \Theta_B, \text{ where } q_B^c = \frac{1-2\varphi}{1-\varphi}q_M^c.$$

  A type-g agent receives strictly positive rent only when $\gamma = M$, and a type-b agent receives no rent.

As usual in the standard screening model, the optimal project size is distorted except that it exhibits "the efficiency at the top"—a type-g agent has an incentive to exaggerate the cost of implementation to reap information rent, and to reduce information rent while inducing truthful reports from the agents, the principal distort the project sizes in the optimal contracts except when both agents are type-g.

When φ is large enough ($\varphi \geq \widetilde{\varphi}$), a type-$g$ agent receives strictly positive information rent regardless of the other agent's type. When φ is small ($\varphi < \widetilde{\varphi}$), however, a type-$g$ agent receives rent only when he is paired with a type-b agent. Since the agents of different types receive the same amount of transfer when $\gamma = M$, the type-g agent's rent in that case is guaranteed regardless of φ. Because of this, the principal's rent provision when $\gamma = G$ is relatively smaller, and she decreases the amount of this rent as it becomes less likely that an agent is type-g. As a result, for φ small enough, although a type-g agent's expected rent is strictly positive, he receives zero rent when the other agent is also type-g.

4.2 Delegation

Under delegation, agent β makes a report on his type, $\theta^\beta \in \{\theta_g, \theta_b\}$, to agent α who, in turn, makes a report on the aggregate type, $\Theta \in \{\Theta_G, \Theta_M, \Theta_B\}$, to the principal. Each agent's participation constraints are:

$$t_G^k - \theta_g q_G \geq 0 \text{ and} \tag{PC_G^k}$$

$$t_M^k - \theta_g q_M \geq 0, \; k \in \{\alpha, \beta\}, \tag{$\overline{PC}_M^k$}$$

for a type-g agent, and

$$t^k_M - \theta_b q_M \geq 0 \text{ and} \tag{$\underline{PC}^k_M$}$$

$$t^k_B - \theta_b q_B \geq 0,\ k \in \{\alpha, \beta\}, \tag{PC^k_B}$$

for a type-b agent. Notice that, unlike under centralization, the transfers to the agents cannnot be treated symmetrically under delegation.

Since agent β does not know agent α's type when reporting his own type, his incentive constraints coincide with the incentive constraints under centralization:

$$\varphi\left[t^\beta_G - \theta_g q_G\right] + (1-\varphi)\left[t^\beta_M - \theta_g q_M\right] \geq \varphi\left[t^\beta_M - \theta_g q_M\right] + (1-\varphi)\left[t^\beta_B - \theta_g q_B\right], \tag{IC^β_g}$$

$$\varphi\left[t^\beta_M - \theta_b q_M\right] + (1-\varphi)\left[t^\beta_B - \theta_b q_B\right] \geq \varphi\left[\max\{t^\beta_G - \theta_b q_G, 0\}\right] + (1-\varphi)\left[t^\beta_M - \theta_b q_M\right]. \tag{IC^β_b}$$

The clear difference from centralization is that, under delegation, agent α has more information when making a report to the principal due to the chain of communication channels. Since reports are made sequentially under delegation, the Bayesian incentive conditions above imply that agent α, when he makes a report to the principal, knows agent β's type. Inducing agent α's truthful report, therefore, requires that the following incentive compatibility conditions be satisfied in the optimal contract:

$$t^\alpha_G - \theta_g q_G \geq t^\alpha_\gamma - \theta_g q_\gamma,\ \gamma \in \{M, B\}, \tag{$IC^\alpha_{G-\gamma}$}$$

$$t^\alpha_M - \theta_g q_M \geq t^\alpha_\gamma - \theta_g q_\gamma,\ \gamma \in \{G, B\}, \tag{$\overline{IC}^\alpha_{M-\gamma}$}$$

$$t^\alpha_M - \theta_b q_M \geq t^\alpha_\gamma - \theta_b q_\gamma,\ \gamma \in \{G, B\}, \tag{$\underline{IC}^\alpha_{M-\gamma}$}$$

$$t^\alpha_B - \theta_b q_B \geq t^\alpha_\gamma - \theta_b q_\gamma,\ \gamma \in \{G, M\}. \tag{$IC^\alpha_{B-\gamma}$}$$

Under delegation, agent α has more flexibility to manipulate information since he knows agent β's type when making his report to the principal. As a result, the incentive constraints for agent α, unlike the constraints for agent β, do not enter in expected terms. That is, the principal must impose stronger incentive constraints in the optimal contract for agent α to induce his truthful report.

The principal, under delegation, chooses $\Phi = \{q_\gamma, t^\alpha_\gamma, t^\beta_\gamma\}$ to solve the following problem:

$$\mathcal{P}^d\text{: } \max_{\Phi}\ \pi(\Phi) = \varphi^2\left[v(q_G) - \sum_k t^k_G\right] + 2\varphi(1-\varphi)\left[v(q_M) - \sum_k t^k_M\right] + (1-\varphi)^2\left[v(q_B) - \sum_k t^k_B\right],$$

subject to $(PC^k_G) \sim (IC^\alpha_{B-\gamma})$.

The following proposition presents the optimal outcome in $\mathcal{P}^d$.

Proposition 2 *Suppose the principal cannot manipulate the aggregate information. Under delegation, there exists $\widehat{\varphi} < 1/2$, such that the optimal outcome, Φ^d, entails the following:*

- *For $\varphi \geq \widehat{\varphi}$,*

$$v'(q_G^d) = \Theta_G, \quad v'(q_M^c) = \Theta_B + \frac{3\varphi - 1}{1-\varphi}\Delta\theta, \quad v'(q_B^c) = \Theta_B + \frac{\varphi}{1-\varphi}\Delta\theta.$$

  A type-g agent receives strictly positive rent, while a type-b agent receives zero rent.

- *For $\varphi < \widehat{\varphi}$, $q_B^d = \frac{1-2\varphi}{1-\varphi} q_M^d$. Also, there exists $\widehat{\rho} > 1$ such that:*

$$\begin{aligned} &\text{if } \theta_b/\theta_g \geq \widehat{\rho}, \text{ then } v'(q_G^d) = \Theta_G,\ 2\varphi v'(q_M^d) + (1-2\varphi)v'(q_B^d) = \Theta_B + \Delta\theta\varphi^2, \text{ and} \\ &\text{if } \theta_b/\theta_g < \widehat{\rho}, \text{ then } \varphi(2-\varphi)v'(q_M^d) + (1-\varphi)(1-2\varphi)v'(q_B^d) = \Theta_B, \text{ where } q_M^d = q_G^d. \end{aligned}$$

  Agent α of type-g receives strictly positive rent regardless of agent β's type, whereas agent β of type-g receives strictly positive rent only when $\gamma = M$. A type-b agent receives zero rent.

While the reasoning behind distortions in the optimal project size is similar to centralization, agent α's information rent is larger under delegation. By delegating the communicational authority, the principal is relinquishing part of her control to agent α. Since agent α ends up possessing more information and makes a report to the principal on behalf of both agents, he has more flexibility to manipulate information, which is the source of larger information rent under delegation. Recall that, for example, when φ is small, a type-g agent under centralization receives rent only when the other agent is type-b. The same is true for agent β under delegation since he does not know agent α's type when making his report. In contrast, the principal, regardless of agent β's type, cannot fully extract the agent α's information rent, because under delegation the agent α knows agent β's type when he makes a report to the principal.

4.3 Comparison

A direct comparison of the two propositions shows that different contracts are optimal under the different organizational structures. It is relatively easy to see that the principal does better under centralization. The intuition, as mentioned above, delegation of the communicational authority transfers the principal's control over agent β to agent α, without bringing any benefit to the principal. A somewhat more technical perspective provides a deeper insight concerning the optimality of centralization, leading to a straightforward formal proof. Under delegation, the incentive constraints for the agent α induces a truthful report regardless of the other agent's reporting strategy, whereas under centralization the incentive constraint induces a truthful report given the other agent's reporting strategy. Hence, delegation leads to a dominant strategy incentive compatibility constraint for truthtelling, while under centralization truthtelling leads a Bayesian incentive compatible for the α agent. Because Bayesian incentive compatibility constraints are weaker than the incentive constraints in dominant strategies, the principal's problem is less restricted under centralization. As a result, the allocation which the optimal contract under delegation, Φ^d, implements is also feasible under centralization, whereas the allocation which optimal contract under centralization, Φ^c, implements is not feasible under delegation. This observation leads directly to the following corollary.

Corollary 1 *Suppose the principal cannot manipulate the aggregate information. Then, centralization dominates delegation.*

5 When the Principal Can Manipulate Information

In the previous section, we derived the optimal contracts under the implicit assumption that, after receiving the agents' reports, the principal truthfully announces the aggregate information from the agents. As will be shown below, this assumption is not innocuous since the principal's manipulating incentive arises given Φ^c, the optimal contract under centralization. In particular, the principal, after learning that true $\gamma = B$ (both agents are type-b), benefits from misannouncing the aggregate type as $\gamma = M$ (so that a type-b agent perceives the other agent as type-g).

In order to see why the principal's manipulating incentive arises, recall that the optimal contract under centralization, Φ^c, provides zero rent to a type-b agent, i.e., $t^c_M = \theta_b q^c_M$ and $t^c_B = \theta_b q^c_B$. Hence, the principal's ex post payoffs when $\gamma = M$ and $\gamma = B$ are respectively:

$$v(q^c_M) - \Theta_B q^c_M \quad \text{and} \quad v(q^c_B) - \Theta_B q^c_B,$$

imlying that the maximizer of the *ex post* payoffs for both $\gamma = M$ and $\gamma = B$ is q^*_B. Also, from the optimal project sizes characterzed in Proposition 1, we observe that:

$$q^c_M = q^*_B \text{ for } \varphi = 1/2,$$

which in turn indicates that:

$$v(q^c_M) - \Theta_B q^c_M > v(q^c_B) - \Theta_B q^c_B \text{ for } \varphi = 1/2.$$

The discussion above implies the following lemma.

Lemma 1 *Suppose the principal can manipulate the aggregate information. Under centralization, Φ^c provides the principal with an incentive to misannounce $\gamma = B$ as $\gamma = M$ at $\varphi = 1/2$.*

Intuitively, the principal has an incentive to underreport the overall cost to implement the project, because the agents then, in line with the contract, have to complete the bigger project q_M^c rather than the smaller project q_B^c. Notice that the principal cannot misannounce $\gamma = B$ as $\gamma = G$ since the agents will know the principal's misannouncement in that case. Likewise, when true $\gamma = M$, the aggregate type cannot be misannounced as $\gamma = B$ or $\gamma = G$ by the principal—if $\gamma = B$ is announced, then the type-g agent will know the principal's misannouncement, and if $\gamma = G$ is announced, then the type-b agent will know. When true $\gamma = G$, the principal can misannounce the aggregate type as $\gamma = M$, but she has no incentive to do so.

In what follows, we take the principal's incentive to manipulate the aggregate information into account for our analyses.

5.1 Centralization

Within a centralized organization, the top management's superior position provides it with better access to the organization's big picture.[9] Our identification of the principal's misrepresenting incentive is in line with reports from various management studies—an organization's top management may abuse its position for private gains.[10] For the principal's truthful behavior, the following incentive constraint must be satisfied, in addition to the participation and incentive constraints for the agents:

$$v(q_B) - \Theta_B q_B \geq v(q_M) - \Theta_B q_M.^{11} \qquad (PIC)$$

When the principal can manipulate the aggregate information, her problem under centralization is:

$$\widetilde{\mathcal{P}}^c\text{:} \max_{\Phi} \ \pi(\Phi) = \varphi^2 \left[v(q_G) - 2t_G\right] + 2\varphi(1-\varphi)\left[v(q_M) - 2t_M\right] + (1-\varphi)^2 \left[v(q_B) - 2t_B\right],$$

subject to (PIC) and the constraints in $\mathcal{P}^c$.

[9] See Mintzberg (1973, 1983) for example.

[10] See Bartolome (1989) for example.

[11] As mentioned above, when true $\gamma = G$, the principal can misannounce the aggregate type as $\gamma = M$, but she has no incentive to do so. It can be easily verified that the principal's incentive constraint for $\gamma = G$, $v(q_G) - \Theta_G q_G \geq v(q_M) - \Theta_G q_M$, is automatically satisfied by our solution.

Lemma 2 *Suppose the principal can manipulate the aggregate information. Under centralization with Φ^c, there exist $\varphi^- \in (0, 1/2)$ and $\varphi^+ \in (\varphi^-, 1/2)$, such that:*

- *For $\varphi \leq \varphi^-$, the principal's manipulating incentive is not an issue, i.e., (PIC) is non-binding.*
- *For $\varphi \geq \varphi^+$, the principal's manipulating incentive is an issue, i.e., (PIC) is binding.*

The intuition behind Lemma 2 is as follows. The distortions in the project sizes to extract type-g agents' rents depend on the probability distribution of an agent's type. If the likelihood that an agent is type-g is small, the principal must provide a rent only with a small probability. In such a case, distortions in the project linked to with a type-b agent are small. For φ small enough, ($\varphi < \varphi^-$), distortion for $\gamma = B$ is smaller than distortion for $\gamma = M$ with respect to q_B^*, the fist-best level for $\gamma = B$. As a result, the principal has no incentive to manipulate the aggregate information when learning that $\gamma = B$.

If the likelihood that an agent is type-g is larger, however, extracting a type-g agent's information rent requires large distortions in project sizes associated with a type-b agent. In such a case, the optimal project size when both agents are type-b is distorted more than when only one of them is type-b. For φ large enough ($\varphi > \varphi^+$), distortion for $\gamma = B$ is larger than distortion for $\gamma = M$ with respect to q_B^*. As a result, there arises the principal's incentive to misrepresent the aggregate information as $\gamma = M$ when the true $\gamma = B$.

The following proposition presents the optimal outcome in $\widetilde{\mathcal{P}}^c$ when an agent is more likely to be type-g.

Proposition 3 *Suppose the principal can manipulate the aggregate information. Under centralization, the optimal outcome, $\Phi^{\widetilde{c}}$, entails:*

$$v'(\widetilde{q}_G^c) = \Theta_G, \quad v'(\widetilde{q}_M^c) = v'(\widetilde{q}_B^c) = \Theta_B + \frac{2\varphi^2}{1-\varphi^2}\Delta\theta \;\; \textit{for } \varphi \geq 1/2, \textit{ and}$$

a type-g agent receives strictly positive rent, whereas a type-b agent receives zero rent.

As shown above, under centralization, the principal's incentive to manipulate the aggregate information arises when it is likely enough that an agent is type-g, and in such a case, the optimal contracts must discourage the principal from misrepresentation. In coping with her own manipulating incentive, the principal makes contract offers that involve pooling outcome for $\gamma = M$ and $\gamma = B$. The intuition behind this pooling result is that, even though the principal can still offer a separating contract that does not induce her to manipulate aggregate information, such a contract requires the principal to concede large information rents when both agents are of type-g. As a result, it becomes too costly for the principal to offer a separating contract, when the likelihood that an agent is type-g is large. In such a case, it is optimal to mitigate the principal's misrepresenting incentives by pooling the project sizes q_M and q_B.

5.2 Delegation and Comparison

Under delegation, the principal receives the aggregate information directly from agent α. Any manipulation of the information by the principal is therefore directly detectable by agent α, which prevents the principal from misannouncing the aggregate information. Thus, the same optimal outcome as in $\mathcal{P}^d$ is achieved. Recall from the previous section that, in the absence of the principal's manipulating incentive, delegation is always dominated by centralization—under delegation, the principal simply needs to provide more rent to one of the agents who is granted the authority to collect information. In the presence of the principal's manipulating incentive, however, a trade-off betwen these structures arises.

Our main result is presented in the following proposition.

Proposition 4 *Suppose the principal cannot manipulate the aggregate information. Then, there exists $\varphi^c > \varphi^-$ and $\varphi^d > \varphi^+$ for the following result:*

- *For $\varphi \leq \varphi^c$, centralization dominates delegation.*
- *For $\varphi \geq \varphi^d$, delegation dominates centralization.*

As shown in Lemma 2, the principal's misrepresenting incentive arises only when the likelihood that an agent is type-g is large enough. Therefore, for φ small enough, centralization is the prevailing structure for the same reason as the previous section. As φ becomes larger, however, the principal's incentive becomes an issue under centralization, and a trade-off between the two structures starts to emerge. Although, the principal must provide more rent under delegation due to a loss of control, a separating outcome is implemented in the optimal contracts. In other words, delegation allows the principal to more effectively utilize useful information within the orgainzation. For φ large enough, the trade-off between the structures leans toward delegation, making it the prevailing structure.

6 Extension and Robustness

In this section, we discuss robustness of the main result by extending our analysis to the following two directions. First, we assumed that, due to costly communication, each agent is restricted to make his report to only one party. We relax this assumption to discuss circumstances under which the principal may want to impose such restriction if she can choose restrictiveness of communication within the organization. Second, we discuss a case where the principal allows part of the operation to be conducted externally.

6.1 Unlimited Communication between the Agent

If communication between the agent is unlimited, then the principal cannot manipulate the aggregate information under centralization. As a result, centralization achieves the optimal outcome in Proposition 1, and hence always optimal. This, however, is based on an implicit assumption that there is no prospect of collusion between the agents when they can engage in two-way communication. As stressed in organization studies, group behaviors are frequently observed in organizations where communication among their members are less restricted.[12] Studies in organizational economics also point out the possibility of unwanted communication and collusion among agents.[13]

In fact, when two-way communication between the agents is possible, although there is no prospect of manipulation by the principal, the agents may agree upon a collusive reporting strategy, $S \equiv \{\widehat{\theta}^{\alpha}, \widehat{\theta}^{\beta}\}$, where $\widehat{\theta}^{\alpha}, \widehat{\theta}^{\beta} \in \{\theta_g, \theta_b\}$, to maximize their payoffs. That is, the agents communicate with each other, and commit to their reports to the principal.

When the agents can engage in side-contracting, centralization and delegation will give the same outcome. For truthful reports, the following incentive constraints for each agent must be satisfied:

$$t_G - \theta_g q_G \geq \max\ \{t_M - \theta_g q_M,\ t_B - \theta_g q_B\}, \qquad (IC^g_{G-\gamma})$$

$$t_M - \theta_g q_M \geq \max\ \{t_G - \theta_g q_G,\ t_B - \theta_g q_B\}, \qquad (IC^g_{M-\gamma})$$

$$t_M - \theta_b q_M \geq \max\ \{t_G - \theta_b q_G,\ t_B - \theta_b q_B\}, \qquad (IC^b_{M-\gamma})$$

$$t_B - \theta_b q_B \geq \max\ \{t_G - \theta_b q_G,\ t_M - \theta_b q_M\}, \qquad (IC^b_{B-\gamma})$$

When unlimited communication between the agents provides them with a side-contracting opportunity, the principal's optimal contracts must be incentive compatible for each agent

[12] See Gouldner (1954), Dalton (1959) and Mintzberg (1979) for example.
[13] See Laffont and Rochet (1997) among others.

regardless of the other agent's reporting strategy. Notice that these constraints encompass all incentive constraints for individual agents discussed in previous sections.

In addition, since the agents can exchange side-transfers, the following coalition incentive constraints must also be satisfied to induce truthful reports:

$$2t_G - \Theta_G q_G \geq \max\ \{2t_M - \Theta_G q_M,\ 2t_B - \Theta_G q_B\}, \tag{$CIC_{G-\gamma}$}$$

$$2t_M - \Theta_M q_M \geq \max\ \{2t_G - \Theta_M q_G,\ 2t_B - \Theta_M q_B\}, \tag{$CIC_{M-\gamma}$}$$

$$2t_B - \Theta_B q_B \geq \max\ \{2t_G - \Theta_B q_G,\ 2t_M - \Theta_B q_M\}. \tag{$CIC_{B-\gamma}$}$$

When communication between the agents are unlimited, the principal's problem under collusion is:

$$\mathcal{P}^u\text{: } \max_{\Phi}\ \pi(\Phi) = \varphi^2 \left[v(q_G) - 2t_G\right] + 2\varphi(1-\varphi)\left[v(q_M) - 2t_M\right] + (1-\varphi)^2 \left[v(q_B) - 2t_B\right],$$

subject to $(IC^g_{G-\gamma}) \sim (IC^b_\gamma)$, $(CIC_{G-\gamma}) \sim (CIC_{B-\gamma})$, and the participation constraints,

$$t_\gamma - \theta_i q_\gamma \geq 0, \tag{PC_γ}$$

where $\gamma \in \{G, M\}$ for $i = g$, and $\gamma \in \{M, B\}$ for $i = b$.

The following proposition presents the optimal outcome in $\mathcal{P}^u$.

Proposition 5 *Suppose communication between the agents is unlimited. Under collusion, the optimal outcome, Φ^u, entails:*

$$v'(q^u_G) = \Theta_G, \quad v'(q^u_M) = v'(q^u_B) = \Theta_B + \frac{2\varphi^2}{1-\varphi^2}\Delta\theta,\ \textit{and}$$

a type-g agent receives strictly positive rent, whereas a type-b agent receives zero rent.

Comparing the optimal outcome in $\mathcal{P}^u$ with our results in the previous sections, we have the following results.

Corollary 2 *Suppose the principal can choose restrictiveness of communication between the agents. Allowing unlimited communication between the agents, under collusion, is sub-optimal.*

As mentioned above, although unlimited communication between the agents prevents the principal from manipulating information under centralization, it may provide the agents extra flexibility to manipulate their private information. Under delegation with limited communication (discussed in the previous sections), only the middle-agent can have such flexibility for manipulation. With unlimited communication between the agents, collusion allows both agents to manipulate their information in all directions. As a result, if the principal can choose, she prefers to limit on communication between the agent.

6.2 Contractual Delegation

So far, we have focused on cases where all agents are hired by the principal—all agent's are members of the organization. In this section, we extend our analysis to a case where the principal contracts with the middle-agent only, who in turn sub-contract with the bottom-agent.[14] We refer to this structure to as "contractual delegation." Figure 2 illustrats the difference between delegation and contractual delegation.

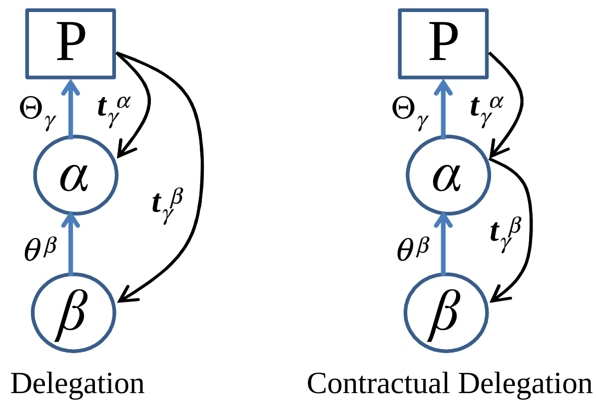

Fig 2. Different Structures of Delegation.

Under delegation, the project is implemented entirely within the organization, whereas under contractual delegation, the project is implemented partly outside the organization (partly outsourced). Under contractual delegation, the principal's offer specifying q and t to the middle-agent, contingent on the report γ from him, is:

$$\Phi_\alpha^d \equiv \{q_\gamma, t_\gamma\},\ \gamma \in \{G, M, B\}.$$

Given Φ_α^d, the middle-agent makes an offer to the sub-agent. The sub-contact consists of γ and t^β, a report that the prime-agent is to send to the principal, and the transfer to the sub-agent. In line with the prime-contract from the principal, Φ_α^d, the report γ fixes the project size and the overall transfer that the middle-agent receives, t_γ, out of which transfer to the bottom-agent t^β is paid. The sub-contract, $\{\gamma, t^\beta\}$, depends on the middle-agent's report on his type to the bottom-agent, $i \in \{g, b\}$, and the bottom-agent's report on his type to the middle-agent, $j \in \{g, b\}$. The middle-agent's offer to the bottom-agent is:

$$\Phi_\beta^s \equiv \{\gamma_{ij}, t_{ij}^\beta\},\ i, j \in \{g, b\},\ \gamma \in \{G, M, B\}.$$

[14] See also Laffont and Martimort (1998) and Mookherjee and Tsumagari (2004) for such settings.

Under contractual delegation, the principal's, the middle-agent's and the bottom-agent's an ex post payoff are respectively:

$$\pi_\gamma = v(q_\gamma) - t_\gamma, \quad u^\alpha_{ij} = t_\gamma - t^\beta_{ij} - \theta^\alpha q_\gamma \quad \text{and} \quad u^\beta_{ij} = t^\beta_{ij} - \theta^\beta q_\gamma.$$

The middle-agent's problem is an informed principal problem with 'private values.' That is, although the middle-agent has private information about his type when making an offer to the sub-agent, this private information does not directly affect the sub-agent's utility. As shown in Maskin and Tirole (1990), this allows us to treat the middle-agent's problem as if the bottom-agent were fully informed of the middle-agent's type. To induce the bottom-agent's truthful report, the middle-agent's offer Φ^s_β must satisfy:

$$t^\beta_{ij} - \theta_j q_{\gamma_{ij}} \geq t^\beta_{ij'} - \theta_j q_{\gamma_{ij'}}, \tag{IC^β}$$

where $i, j, j' \in \{g, b\}$ and $\gamma_{ij} \in \{G, M, B\}$ according to ij and ij'. The participation constraint that induces the bottom-agent not to quit is:

$$t^\beta_{ij} - \theta_j q_{\gamma_{ij}} \geq 0, \tag{PC^β}$$

where $i, j \in \{g, b\}$ and $\gamma_{ij} \in \{G, M, B\}$ according to ij.

From the perspective of the middle-agent of type-i, the optimal offer to the bottom-agent, Φ^s_β, corresponds to the solution of the following problem:

$$\widetilde{\mathcal{A}}^d\!: \max_{\gamma_{ij}, t_{ij}} E_j\left[u^\alpha_{ij}\right] = \varphi\left[t_{\gamma_{ig}} - t^\beta_{ig} - \theta_i q_{\gamma_{ig}}\right] + (1-\varphi)\left[t_{\gamma_{ib}} - t^\beta_{ib} - \theta_i q_{\gamma_{ib}}\right],$$

subject to (IC^β) and (PC^β). As in the standard screening problem, the bottom agent reaps information rent only when he is type-g. The ex post transfers to the bottom agent of type-g and type-b are respectively:

$$t^\beta_{ig} = \theta_g q_{\gamma_{ig}} + \Delta\theta q_{\gamma_{ib}} \text{ and } t^\beta_{ib} = \theta_b q_{\gamma_{ib}}.$$

That is, the bottom agent of type-g receives rent of $\Delta\theta q_{\gamma_{ib}}$ from the middle-agent. Substituting for the transfers, the middle-agent's problem is written as:

$$\max_{\gamma_{ij}, t_{ij}} E_j\left[u^\alpha_{ij}\right] = \varphi\left[t_{\gamma_{ig}} - (\theta_i + \theta_g) q_{\gamma_{ig}}\right] + (1-\varphi)\left[t_{\gamma_{ib}} - \left(\theta_i + \theta_b + \frac{\varphi}{1-\varphi}\Delta\theta\right) q_{\gamma_{ib}}\right].$$

The middle-agent's problem above implies that the principal's offer to the middle-agent must satisfy the following constraints:

$$t_{\gamma_{ig}} - (\theta_i + \theta_g) q_{\gamma_{ig}} \geq t_{\gamma_{i'j}} - (\theta_i + \theta_g) q_{\gamma_{i'j}}, \tag{$IC\gamma_{ig-i'j}$}$$

$$t_{\gamma_{ib}} - \left(\theta_i + \theta_b + \frac{\varphi}{1-\varphi}\Delta\theta\right) q_{\gamma_{ib}} \geq t_{\gamma_{i'j}} - \left(\theta_i + \theta_b + \frac{\varphi}{1-\varphi}\Delta\theta\right) q_{\gamma_{i'j}}, \qquad (IC\gamma_{ib-i'j})$$

where $\forall i', j \in \{g, b\}$, $\gamma_{ig} \in \{G, M\}$, $\gamma_{ig} \in \{M, B\}$ and $\gamma_{i'j} \in \{G, M, B\}$ for the middle-agent's truthful report, and

$$t_{\gamma_{ig}} - (\theta_i + \theta_g) q_{\gamma_{ig}} \geq 0, \qquad (PC\gamma_{ig})$$

$$t_{\gamma_{ib}} - \left(\theta_i + \theta_b + \frac{\varphi}{1-\varphi}\Delta\theta\right) q_{\gamma_{ib}} \geq 0, \qquad (PC\gamma_{ib})$$

where $i \in \{g, b\}$, $\gamma_{ig} \in \{G, M\}$ and $\gamma_{ig} \in \{M, B\}$ for his participation. In addition, since the principal can process only the aggregate information, $t_{\gamma_{gb}} = t_{\gamma_{bg}} = t_M$ and $q_{\gamma_{gb}} = q_{\gamma_{bg}} = q_M$.

Notice from (PC_{ib}) that, the middle-agent receives rent even when he is type-b. This is due to "double-marginalization" of rent under contractual delegation, which will be discussed later. The principal chooses $\Phi_{\alpha}^{d} \equiv \{q_\gamma, t_\gamma\}$, where $\gamma \in \{G, M, B\}$, to solve the following problem:

$$\widetilde{\mathcal{P}}^d\!: \max_{\Phi^\alpha} \pi(\Phi^\alpha) = \varphi^2 \left[v(q_G) - t_G\right] + 2\varphi(1-\varphi)\left[v(q_M) - t_M\right] + (1-\varphi)^2\left[v(q_B) - t_B\right],$$

subject to $(IC\gamma_{ig}) \sim (PC\gamma_{ib})$, with $t_{\gamma_{gb}} = t_{\gamma_{bg}} = t_M$ and $q_{\gamma_{gb}} = q_{\gamma_{bg}} = q_M$.

The next proposition presents the optimal outcome in $\widetilde{\mathcal{P}}^d$.

Proposition 6 *Under contractual delegation, the optimal outcome, $\Phi_{\alpha}^{\widetilde{d}}$, entails:*

$$v'(\widetilde{q}_G^d) = \Theta_G, \quad v'(\widetilde{q}_M^d) = \Theta_M + \frac{\varphi(3-2\varphi)}{2(1-\varphi)^2}\Delta\theta, \quad v'(\widetilde{q}_B^d) = \Theta_B + \frac{\varphi(3-2\varphi)}{(1-\varphi)^2}\Delta\theta, \text{ and}$$

the middle-agent receives rent regardless of his type, whereas the bottom-agent receives rent only when he is of type-g.

Contractual delegation allows the principal to implement fully separating outcome in the optimal contract, but the middle-agent always receive rent. As mentioned above, the middle-agent can take advantage of "double-marginalization" of rent. Under contractual delegation, it is the middle-agent who must provide rent to the bottom-agent for a truthful report. The principal, therefore, must provide the middle-agent with enough rent so that the middle agent has an incentive not only to report truthfully to the principal but also to induce the bottom-agent's truthful report. In addition, while the principal always wants the project since she values it intrinsically, the middle-manager who values the project extrinsically may have an incentive to quit, depending on his and the bottom-agent's type.[15] To be specific, by offering a sub-contract that only hires the bottom-agent of type-g (and

[15] See McAfee and McMillan (1995) for a similar issue.

quit subsequently), the middle-agent can fully extract the bottom-agent's information rent. This way, even the middle-agent of type-b can command rent if he faces the bottom-agent of type-g, since he can pocket the bottom-agent's rent passed down from the principal. To prevent this, the principal must provide rent to the middle-agent even for $\gamma = B$. As a chain effect, the middle-agent's rent must increase for $\gamma = M$ and $\gamma = G$ as well.

When the principal can manipulate the aggregate information, comparing centralization and contractual delegation is not an easy task, and does not provide clear and intuitive answers. We can, however, compare the principal's problems under delegation and contractual delegation, $\mathcal{P}^d$ and $\widetilde{\mathcal{P}}^d$, to have the following result.

Proposition 7 *There exists $\widetilde{\varphi}^d < 1/2$, such that for $\varphi \geq \widetilde{\varphi}^d$, delegation dominates contractual delegation.*

Delegation can be optimal as shown in Corollary 2, but the principal prefers keeping the operation within the organization. The result above is in line with Coase (1937) and other related studies—organizations, in particular, firms, are a response to extra "exchange costs" of using markets. In our model, such extra costs are represented by double-marginalization of information rent when one of the agents operates outside the organization. When it is more likely that the agents are rent-receiving type, the principal prefers in-house operation. By keeping all agents within the organization's boundary, and thus making them directly involved in the project, the principal can save such costs.

7 Conclusion

In this paper, we have analyzed the optimal structure of an organization when information can be manipulated, not only by the agents with direct possession of private information, but also by the principal who can have private information indirectly. Under centralization, inducing the agents' truthful behavior raises the principal's manipulating incentive. As a result, reconciliation of the tension between the principal's and the agent's incentives may require a pooling outcome under centralization. Under delegation, although the principal must provide more rent to the agent with the communication authority, a separating outcome is restored in the optimal contracts—the organization's useful information is more effectively utilized. This trade-off determines the optimal structure of the organization in our model. We have shown that centralization is optimal when the likelihood that an agent is efficient is small, but when such a likelihood is large, the optimal structure is delegation.

We have also extended our analysis for robustness of our result. First, if the principal can choose the organization's communication technology, she prefers more restrictive communication as in our paper when the agents can collude. Second, contractual delegation, under which the principal contracts with only one of the agents, who in turn contracts with the other agent has been discussed. According to our result, when an agent is more likely to be efficient, contractual delegation is dominated by communicational delegation—the principal prefers to keep the operation within the organization's boundary.

Appendix

Proof of Proposition 1.

Note first that the principal's objective function is concave and all constraints are convex sets in choice variables, and therefore the solution is unique. Thus, we can employ the standard technique—binding constraints are conjectured to solve the problem, and it will be verified that the solution satisfies the ignored constraints. In particular, we conjecture that the incentive constraint for type-g agents, (IC_g), and the participation constraints for type-b agents, $(\underline{PC}_M)$ and (PC_B), are binding, then verify whether the solution satisfies the other constraints $(\overline{PC}_M)$, (PC_G), and (IC_b). Binding (PC^b_M), (PC^b_B) and (IC_g) give the following expressions for the transfers:

$$t_G = \theta_g q_G + \frac{2\varphi - 1}{\varphi}\Delta\theta q_M + \frac{1-\varphi}{\varphi}\Delta\theta q_B, \quad t_M = \theta_b q_M, \quad t_B = \theta_b q_B. \tag{A1}$$

Substituting for the transfers in the objective function and optimizing with respect to the project sizes gives:

$$v'(q^c_G) = \Theta_G, \quad v'(q^c_M) = \Theta_M + \frac{\varphi}{1-\varphi}\Delta\theta, \quad v'(q^c_B) = \Theta_B + \frac{2\varphi}{1-\varphi}\Delta\theta. \tag{A2}$$

implying that $q^c_G > q^c_M > q^c_B$. We next check whether this solution satisfies the other consrtaints, $(\overline{PC}_M)$, (PC_G) and (IC_b). Notice first that $(\underline{PC}_M)$ implies $(\overline{PC}_M)$. Also, by $(A1)$ the constraint (IC_b) simplifies to:

$$0 \geq \varphi \max\{0,\ t_G - \theta_b q^c_G\},$$

which holds because, by $(A1)$ and $q^c_G > q^c_M > q^c_B$, it follows that:

$$t_G - \theta_b q_G = [(2\varphi - 1)(q^c_M - q^c_G) + (1-\varphi)(q^c_B - q^c_G)]\,\Delta\theta/\varphi < 0.$$

Note, however, that this solution satisfies (PC_G) only if $(2\varphi-1)q_M^c+(1-\varphi)q_B^c \geq 0$. Hence, (A1) and (A2) characterize principal's optimal contract only if

$$\varphi < \widetilde{\varphi} = \left(q_M^c - q_B^c\right) / \left(2q_M^c - q_B^c\right), \text{ where } \widetilde{\varphi} < 1/2.$$

In other words, for $\varphi < \widetilde{\varphi}$, the solution violates (PC_G). The concavity of the maximization problem then implies that for $\varphi < \widetilde{\varphi}$, also (PC_G) must bind at the optimum. When (PC_G) binds, (A1) implies that $(1-\varphi)q_B = (1-2\varphi)q_M$. It follows that, with constraints (IC_g), $(\underline{PC}_M)$, (PC_B), and (PC_G) all binding, we can rewrite the principal's problem as:

$$\varphi^2\left[v(q_G)-\Theta_G q_G\right]+2\varphi(1-\varphi)\left[v(q_M)-\Theta_B q_M\right]+(1-\varphi)^2\left[v(q_B)-\Theta_B q_B(q_M)\right], \quad \text{(A3)}$$

where

$$q_B(q_M) = \frac{1-2\varphi}{1-\varphi} q_M.$$

Substituting out $q_B(q_M)$ in (A3) and optimizing with respect to the project sizes yields:

$$v'(q_G^c) = \Theta_G, \quad 2\varphi v'(q_M^c) + (1-2\varphi)v'(q_B^c) = \Theta_B, \text{ where } q_B^c = \frac{1-2\varphi}{1-\varphi} q_M^c.$$

To check (IC_b), note again that it is satisfied if $t_G - \theta_b q_G^c \leq 0$. Using (A1) and the relationship $(1-\varphi)q_B^c = (1-2\varphi)q_M^c$, we have:

$$t_G - \theta_b q_G^c = -\Delta\theta q_G < 0.$$

Thus, for both $\varphi < \widetilde{\varphi}$ and $\varphi \geq \widetilde{\varphi}$ we have characterized the optimal contract as specified in the proposition. The agents' rents follow from the binding constraints. ■

Proof of Proposition 2.

Similar to the proof of Proposition 1, we make a conjecture about binding constraints and optimize the objective function under this subset of constraints. We then verify whether the solution satisfies the other constraints. In particular, we conjecture that incentive constraints, (IC_g^β) and (IC_{G-M}^α), and the participation constraints, $(\underline{PC}_M^\alpha)$, (PC_B^α), $(\underline{PC}_M^\beta)$ and (PC_B^β). These binding constraints give the following expressions for transfers:

$$\begin{array}{ll} t_G^\alpha = \theta_g q_G + \Delta\theta q_M, & t_G^\beta = \theta_g q_G + \frac{2\varphi-1}{\varphi}\Delta\theta q_M + \frac{1-\varphi}{\varphi}\Delta\theta q_B, \\ t_M^\alpha = \theta_b q_M, & t_M^\beta = \theta_b q_M, \\ t_B^\alpha = \theta_b q_B, & t_B^\beta = \theta_b q_B. \end{array} \quad \text{(A4)}$$

Substituting these transfers out of the objective function, we can rewrite it as:

$$\varphi^2\left[v(q_G)-\Theta_G q_G - \Delta\theta q_M\right]+2\varphi(1-\varphi)\left[v(q_M)-\Theta_B q_M\right]+(1-\varphi)^2\left[v(q_B)-\Theta_B q_B\right]. \quad \text{(A6)}$$

Optimizing (A6) in the project sizes yields:

$$v'(q_G^d) = \Theta_G, \quad v'(q_M^d) = \Theta_B + \frac{3\varphi - 1}{2(1-\varphi)}\Delta\theta, \quad v'(q_B^d) = \Theta_B + \frac{\varphi}{1-\varphi}\Delta\theta, \tag{A7}$$

implying that $q_G^d > q_M^d > q_B^d$. Since $\theta_g < \theta_b$, (A4) implies that (PC_G^α), $(\overline{PC}_M^\alpha)$ and $(\overline{PC}_M^\beta)$ are satisfied. Also, (A4) together with $q_G^d > q_M^d > q_B^d$ implies that (IC_{G-B}^α), $(\underline{IC}_{M-\gamma}^\alpha)$, $(\overline{IC}_{M-\gamma}^\alpha)$, $(IC_{B-\gamma}^\alpha)$ and (IC_b^β) are satisfied. Hence, it remains to check whether the solution also satisfies (PC_G^β). Using (A4), it holds $t_G^\beta - \theta_g q_G \geq 0$ if and only if $\varphi \geq \widehat{\varphi} \equiv \left(q_M^d - q_B^d\right) / \left(2q_M^d - q_B^d\right)$, where $\widehat{\varphi} < 1/2$ (since $q_M^d > q_B^d$). Therefore, (PC_G^β) is satisfied for $\varphi \geq \hat{\varphi}$. Then, it follows that, for $\varphi \geq \hat{\varphi}$, (A4) together with (A7) fully characterizes the optimal contract as presented in Proposition 2.

For $\varphi < \hat{\varphi}$, the solution characterized above violates (PC_G^β), implying that this participation constraint also binds at the optimum. Under (A4) the constraint (PC_G^β) simplifies to:

$$(1-\varphi)q_B = (1-2\varphi)q_M. \tag{A8}$$

Consequently, the problem is to maximize (A6) subject to (A8). That is, the principal maximizes:

$$\varphi^2\left[v(q_G) - \Theta_G q_G - \Delta\theta q_M\right] + 2\varphi(1-\varphi)\left[v(q_M) - \Theta_B q_M\right] + (1-\varphi)^2\left[v(q_B(q_M)) - \Theta_B q_B(q_M)\right],$$

where $q_B(q_M) = (1-2\varphi)q_M/(1-\varphi)$. The first order conditions with respect to q_G and q_M imply that the optimal project sizes are characterized by:

$$v'(q_G^d) = \Theta_G, \quad 2\varphi v'(q_M^d) + (1-2\varphi)v'(q_B^d) = \Theta_B + \varphi^2\Delta\theta \text{ and } (1-\varphi)q_B^d = (1-2\varphi)q_M^d, \tag{A9}$$

implying that $q_M^d > q_B^d$. Unlike centralization where the optimal contract is Bayesian incentive compatible, delegation requires that the optimal contract be incentive compatible in dominant strategy for agent α since he learns agent β's type when he makes a report to the principal. Thus, it is needed that $q_G^d \geq q_M^d \geq q_B^d$ to satisfy all of the ignored constraints. In fact, the solution characterized in (A9) may not satisfy $(\underline{IC}_{M-G}^\alpha)$ and $(\underline{IC}_{B-G}^\alpha)$ if $q_G^d \geq q_M^d$ does not hold, since $(\underline{IC}_{M-G}^\alpha)$ and $(\underline{IC}_{B-G}^\alpha)$ with the transfers for agent α in (A4) require that:

$$0 \geq \Delta\theta(q_M - q_G).$$

We next show that for any $\varphi < \hat{\varphi}$, there exists $\widehat{\rho} > 1$ such that $q_G^d \geq q_M^d$ if and only if $\theta_b/\theta_g \geq \widehat{\rho}$. From (A9), q_G^d is defined by $v'(q_G^d) = \Theta_G$, while q_M^d is implicitely defined by the following equation:

$$2\varphi v'(q_M^d) + (1-2\varphi)v'((1-2\varphi)q_M^d/(1-\varphi)) = \rho\Theta_G + \varphi^2(\rho - 1)\theta_g, \tag{A10}$$

where $\rho \equiv \theta_b/\theta_g > 1$. Note that for $\rho = 1$ we have $q_M^d > q_G^d$, while for ρ large enough we have $q_M^d < q_G^d$. The result then follows from noting that $\partial q_M^d/\partial\rho < 0$, so there exists a unique $\widehat{\rho} > 1$ such that $q_G^d > q_M^d$ if and only if $\rho > \widehat{\rho}$. To see $\partial q_M^d/\partial\rho < 0$, note that by the implicit function theorem, it follows from (A10) that:

$$\frac{\partial q_M^d}{\partial \rho}\left[2\varphi v''(q_M^d) + \frac{(1-2\varphi)^2}{1-\varphi}v''(q_B^d)\right] = \Theta_G + \varphi^2\theta_g,$$

and since $v''(\cdot) < 0$, the term within the bracket in the LHS of the equation is negative. Since the RHS of the equation is positive, it follows that $\partial q_M^d/\partial\rho < 0$. Hence, for $\varphi < \hat{\varphi}$ and $\theta_g/\theta_b \geq \widehat{\rho}$, the solution in (A9) characterizes the optimal project sizes.

For $\varphi < \hat{\varphi}$ and $\theta_g/\theta_b < \widehat{\rho}$ the solution in (A9) violates ($\underline{IC}^\alpha_{M-G}$) and ($\underline{IC}^\alpha_{B-G}$) implying that $q_G = q_M$ in the optimal contract, and from all binding constraints, we have:

$$\begin{aligned}
t_G^\alpha &= \theta_b q_M \ (= \theta_g q_M + \Delta\theta q_M), & t_G^\beta &= \theta_g q_M, \\
t_M^\alpha &= \theta_b q_M, & t_M^\beta &= \theta_b q_M, \\
t_B^\alpha &= \theta_b q_B, & t_B^\beta &= \theta_b q_B.
\end{aligned}$$

After substituting for the transfers in the objective function, the principal's problem is to maximize:

$$\left[1-(1-\varphi)^2\right]\left[v(q_M) - \Theta_B q_M\right] + (1-\varphi)^2\left[v(q_B) - \Theta_B q_B\right],$$

subject to (A8). It follows that the optimal project sizes are characterized by:

$$\varphi(2-\varphi)v'(q_M^d) + (1-\varphi)(1-2\varphi)v'(q_B^d) = \Theta_B, \text{ where } q_B^d = \frac{1-2\varphi}{1-\varphi}q_M^d. \ \blacksquare$$

Proof of Corollary 1.

The proof directly follows from comparing $\mathcal{P}^c$ and $\mathcal{P}^d$. The incentive compatibility constraints in $\mathcal{P}^d$ are stronger and therefore the principal's choices are more restricted in $\mathcal{P}^d$ compared to $\mathcal{P}^c$. $\blacksquare$

Proof of Lemma 1.

The proof directly follows from the discussion. $\blacksquare$

Proof of Lemma 2.

In order to show that there exists $\varphi^- \in (0, 1/2)$ such that the constraint (PIC) does not bind, we verify that the optimal contract as identified in Proposition 1 satisfies (PIC) for all

φ smaller than some $\varphi^- > 0$. To see this, first recall from Proposition 1 that, for $\varphi \in (0, \hat{\varphi})$, optimal project sizes q_M^c and q_B^c are characterized by:

$$2\varphi v'(q_M^c) + (1-2\varphi)v'(q_B^c) = \Theta_B \text{ and } q_B^c = \frac{1-2\varphi}{1-\varphi} q_M^c. \tag{A11}$$

Hence, for $\varphi \to 0$ we have $q_B^c = q_M^c = q_B^*$, and with these values, (PIC) is satisfied in equality. Using this, we show that (PIC) is non-binding for φ small enough. Defining the function $q_M(x) = (1-\varphi)x/(1-2\varphi)$, (A11) implies that q_B^c is defined by:

$$2\varphi v'(q_M(q_B^c)) + (1-2\varphi)v'(q_B^c) = \Theta_B.$$

Differentiating the expression with respect to φ yields:

$$2v'(q_M^c) + 2\varphi v''(q_M^c)\left[\frac{1}{(1-2\varphi)^2} q_B^c + \frac{1-\varphi}{1-2\varphi}\frac{\partial q_B^c}{\partial \varphi}\right] - 2v'(q_B^c) + (1-2\varphi)v''(q_B^c)\frac{\partial q_B^c}{\partial \varphi} = 0.$$

Thus, we have:

$$\left.\frac{\partial q_B^c}{\partial \varphi}\right|_{\varphi=0} = \left.\frac{2[v'(q_B^c) - v'(q_M^c)]}{v''(q_B^c)}\right|_{\varphi=0} = \frac{2[v'(q_B^*) - v'(q_B^*)]}{v''(q_B^*)} = 0,$$

where the second equality follows from $q_B^c = q_M^c = q_B^*$ for $\varphi = 0$. Now, differentiating the second equation in (A11), we have:

$$\frac{\partial q_B^c}{\partial \varphi} = \frac{1-2\varphi}{1-\varphi}\frac{\partial q_M^c}{\partial \varphi} - \frac{1}{1-\varphi} q_M^c,$$

and therefore:

$$\left.\frac{\partial q_M^c}{\partial \varphi}\right|_{\varphi=0} = \frac{1}{1-\varphi} q_B^* > 0,$$

since $\partial q_B^c/\partial\varphi = 0$ and $q_M^c = q_B^*$ at $\varphi = 0$. That is, at $\varphi = 0$, (PIC) is satisfied with $q_B^c = q_M^c = q_B^*$ and $\partial q_M^c/\partial\varphi > 0 = \partial q_B^c/\partial\varphi$, which implies that (PIC) is strictly satisfied for φ close to zero. Since Φ^c violates (PIC) at $\varphi = 1/2$ from Lemma 1, there exists $\varphi^- \in (0, 1/2)$ such that (PIC) is satisfied for $\varphi < \varphi^-$.

To see that Φ^c violates the constraint for $\varphi \geq 1/2$, consider q_M^c characterized in Proposition 1. Again, at $\varphi = 1/2$, we have $q_M^c = q_B^*$ and by Lemma 1, (PIC) is violated. By the implicit function theorem, it follows for $\varphi > 1/2$ that:

$$\frac{\partial q_M^c}{\partial \varphi} = \frac{\Delta\theta}{v''(q_M^c)(1-\varphi)^2} < 0,$$

where the inequality follows from $v''(\cdot) < 0$. As a result, we have for $\varphi > 1/2$ that $q_B^* > q_M^c$. Also, Proposition 1 implies $q_M^c > q_B^c$, and thus it follows from the concavity of $v(q) - \Theta_b q$ that the ranking $q_B^* > q_M^c > q_B^c$ implies:

$$\max_q v(q) - \Theta_B q = v(q_B^*) - \Theta_B q_B^* > v(q_M^c) - \Theta_B q_M^c > v(q_B^c) - \Theta_B q_B^c.$$

This establishes that (PIC) is violated for all $\varphi \geq 1/2$. By continuity, there exists some $\varphi^+ \in [\varphi^-, 1/2)$ such that (PIC) is violated for all $\varphi > \varphi^+$. ■

Proof of Proposition 3.

For $\varphi \geq 1/2$, Lemma 2 shows that (PIC) is a binding constraint at the optimum. Since (IC_g), $(\underline{PC}_M)$, and (PC_B) are also binding, binding (PIC) can be rewritten as:

$$v(q_B) - \Theta_B q_B = v(q_M) - \Theta_B q_M, \tag{A12}$$

and hence the principal's payoff $\pi(\Phi)$ can be rewritten as:

$$\varphi^2 \left[v(q_G) - \Theta_G q_G - 2\left(\frac{2\varphi - 1}{\varphi} \Delta\theta q_M + \frac{1-\varphi}{\varphi} \Delta\theta q_B \right) \right] + (1-\varphi^2)\left[v(q_B) - \Theta_B q_B \right], \tag{A13}$$

which is to be maximized subject to (A12). Note that for $\varphi = 1/2$ the objective function simplifies to:

$$\left[v(q_G) - \Theta_G q_G - \Delta\theta q_B \right]/4 + 3\left[v(q_B) - \Theta_B q_B \right]/4,$$

which is independent of q_M. Maximizing this expression with respect to q_G and q_B, and setting $q_M = q_B$ satisfies (A12) and yields a maximizer that coincides with the expression in the proposition.

We next show that, for $\varphi > 1/2$, a solution satisfies $q_M = q_B$. To see this, note first that, for $\varphi > 1/2$, expression (A13) is strictly decreasing in q_M. Moreover note that (A12) is satisfied whenever $q_M = q_B$. These two observations imply that project sizes with $q_M > q_B$ are not optimizing (A13), since it yields less payoff than project sizes with $q_M = q_B$. Likewise, $q_B > q_M$ is not optimal for the following reason. Using (A12), we can express (A13) as:

$$\varphi^2 \left[v(q_G) - \Theta_G q_G - 2\left(\frac{2\varphi - 1}{\varphi} \Delta\theta q_M + \frac{1-\varphi}{\varphi} \Delta\theta q_B \right) \right] + (1-\varphi^2)\left[v(q_M) - \Theta_B q_M \right]. \tag{A14}$$

Thus, the solution maximizes (A14) subject to (A12). Note however that (A14) is decreasing in q_B. Project sizes with $q_B > q_M$ does not maximize (A14) subject to (A12), since it yields less than project sizes with $q_B = q_M$ which satisfies (A12).

For an optimal solution, we therefore have $q_B = q_M$ so that (A12) is satisfied and (A13) simplifies to:

$$\varphi^2 \left[v(q_G) - \Theta_G q_G + 2\Delta\theta q_M \right] + (1-\varphi^2)\left[v(q_G) - \Theta_B q_M \right].$$

Again, optimizing with respect to q_G and q_M and setting $q_B = q_M$ yields the expression in the proposition. ■

Proof of Proposition 4.

From Lemma 2, $\pi(\Phi^{\widetilde{c}}) = \pi(\Phi^c)$ for $\varphi \leq \varphi^-$, and hence by Corollary 1, $\pi(\Phi^{\widetilde{c}}) > \pi(\Phi^d)$ at $\varphi = \varphi^-$. Continuity then implies the existence of $\varphi^c > \varphi^-$, such that for $\varphi \leq \varphi^c$, $\pi(\Phi^{\widetilde{c}}) \geq \pi(\Phi^d)$. To see the existence of φ^d, recall first from Proposition 3 that, for $\varphi \geq 1/2$, the optimal q_M and q_B are bunched in $\Phi^{\widetilde{c}}$. For $\varphi \geq 1/2$, it can be easily verified that $\Phi^{\widetilde{c}}$ satisfies all constraints in $\mathcal{P}^d$, and hence can be implemented in $\mathcal{P}^d$. Since $\Phi^{\widetilde{c}} \neq \Phi^d$ and $\Phi^{\widetilde{c}}$ is not a solution to $\mathcal{P}^d$, it follows, for $\varphi \geq 1/2$, that $\pi(\Phi^d) > \pi(\Phi^{\widetilde{c}})$. By continuity there exists a $\varphi^d > \varphi^+$ such that for all $\varphi > \varphi^d$, $\pi(\Phi^d) \geq \pi(\Phi^{\widetilde{c}})$. ■

Proof of Proposition 5.

The binding constraints in $\mathcal{P}^u$ are (IC^g_{G-M}), (IC^g_{M-B}), $(\underline{PC_M})$ and (PC_B). It is straightforward to verify that other constraints are satisfied by the solution without them. From the binding constraints, the transfers are:

$$t_G = \theta_g q_G + \Delta\theta q_M, \quad t_M = \theta_b q_M = \theta_g q_M + \Delta\theta q_M, \quad t_B = \theta_b q_B, \text{ where } q_M = q_B,$$

implying the agents' rents. Substituting for the transfers with $q_M = q_B$ in the objective function and optimizing in the project sizes give the expressions in Proposition 5.

7.1 Proof of Corollary 2.

We compare $\mathcal{P}^d$ and $\mathcal{P}^u$. From direct comparison, the incentive constraints in $\mathcal{P}^u$ are stronger and hence this problem is more restrictive to the principal compared to $\mathcal{P}^d$. ■

Proof of Proposition 6.

Since the principal's problem is isomorphic to a standard screening problem, its solution is also standard. In the optimal contract, the incentive constraints for $\gamma = G$ and $\gamma = M$, and participation constraints for $\gamma = B$ are binding: $(IC\gamma_{gg-bg})$, $(IC\gamma_{gb-bb})$ and $(PC\gamma_{bb})$. It can be easily verified that the solution satisfies the other constraints. From the binding constraints, since $t_{\gamma_{gb}} = t_{\gamma_{bg}} = t_M$ and $q_{\gamma_{gb}} = q_{\gamma_{bg}} = q_M$, we have:

$$\begin{aligned}
t_G &= \Theta_G q_G + \frac{\Delta\theta}{1-\varphi} q_M + \Delta\theta q_B, \\
t_M &= \left(\Theta_M + \frac{\varphi}{1-\varphi}\Delta\theta\right) q_M + \Delta\theta q_B, \\
t_B &= \left(\Theta_B + \frac{\varphi}{1-\varphi}\Delta\theta\right) q_B.
\end{aligned}$$

Substituting for the transfers and optimizing with respect to the project sizes yield the expression in Proposition 6. ■

Proof of Proposition 7.

Since (IC_G^α) and (PC_γ^α) for $\gamma \in \{M, B\}$ are binding in $\mathcal{P}^d$, again, transfers to the middle-agent is:

$$t_G^\alpha = \theta_g q_G + \Delta\theta q_M, \quad t_M^\alpha = \theta_b q_M, \quad t_B^\alpha = \theta_b q_B.$$

These transfers induces agent α's truthful report for given q_G, q_M and q_B. Suppose that agent α receives these transfers through agent β, and the principal can perfectly monitor the cash flow from agent β to agent α. That is, the principal pays t_γ to agent β, who in turn pays t_γ^α to agent α out of t_γ under the principal's perfect monitoring of this cash flow. Then, by letting $\Phi^\beta \equiv \{q_\gamma, t_\gamma\}$, $\gamma \in \{G, M, B\}$, the principal's problem is:

$$\mathcal{P}^d : \max_{\Phi^\beta} \pi(\Phi^\beta) = \varphi^2 [v(q_G) - t_G] + 2\varphi(1-\varphi) [v(q_M) - t_M] + (1-\varphi)^2 [v(q_B) - t_B],$$

subject to

$$\begin{aligned} & \varphi [t_G - \Theta_G q_G - \Delta\theta q_M] + (1-\varphi) [t_M - \Theta_M q_M] \\ \geq \;& \varphi [t_M - \Theta_M q_M] + (1-\varphi) [t_B - \Theta_M q_B], \end{aligned}$$

$$\begin{aligned} & \varphi [t_M - \Theta_B q_M] + (1-\varphi) [t_B - \Theta_B q_B] \\ \geq \;& \varphi [t_G - \Theta_M q_G - \Delta\theta q_M] + (1-\varphi) [t_M - \Theta_B q_M], \end{aligned}$$

for agent β's truthful report, and

$$t_G - \Theta_G q_G - \Delta\theta q_M \geq 0, \; t_M - \Theta_B q_M \geq 0, \text{ and } t_B - \Theta_B q_B \geq 0,$$

for agent β's participation.[16] Since $t_M = \Theta_B q_M$ and $t_B = \Theta_B q_B$ at the optimum in $\mathcal{P}^d$, with simple rearrangements in the two incentive compatibility constraints for agent β, we can rewrite the problem as:

$$\mathcal{P}^d\text{: } \max_{\Phi^\beta} \pi(\Phi^\beta), \text{ subject to}$$

$$\begin{aligned} & \varphi [t_G - \Theta_G q_G] + (1-\varphi) [t_M - \Theta_M q_M] \\ \geq \;& \varphi [t_M - \Theta_G q_M] + (1-\varphi) [t_B - \Theta_M q_B], \end{aligned} \tag{A15}$$

[16] $t_M - \Theta_M q_M \geq 0$ is implied by $t_M - \Theta_B q_M \geq 0$.

$$t_M - \Theta_G q_M \geq t_G - \Theta_M q_G, \tag{A16}$$

$$t_G - \Theta_G q_G - \Delta\theta q_M \geq 0,\ t_M - \Theta_B q_M = 0,\ \text{and } t_B - \Theta_B q_B = 0. \tag{A17}$$

The incentive compatibility constraints, (A15) and (A16), in $\mathcal{P}^d$ above are implied by incentive constraints in $\widetilde{\mathcal{P}}^d$. That is, (A15) is implied by $(IC\gamma_{gg-bg})$ and $(IC\gamma_{bg-bb})$, and (A15) is implied by $(IC\gamma_{bg-gg})$. That is, incentive compatibility conditions in $\widetilde{\mathcal{P}}^d$ is more restrictive than $\mathcal{P}^d$.

In addition, in $\widetilde{\mathcal{P}}^d$,

$$t_M = \left(\Theta_M + \frac{\varphi}{1-\varphi}\Delta\theta\right) q_M + \Delta\theta q_B \text{ and } t_B = \left(\Theta_B + \frac{\varphi}{1-\varphi}\Delta\theta\right) q_B, \tag{A18}$$

implying from $(IC\gamma_{gg-bg})$ that:

$$t_G - \Theta_G q_G - \frac{\Delta\theta}{1-\varphi} q_M - \Delta\theta q_B \geq 0. \tag{A19}$$

The conditions in (A18) and (A19) are more restrictive than (A17), except for the condition for $t_{M.}$ For $\varphi \geq 1/2$, however, t_M in (A18) is larger than t_M in (A17) for any given q_M,[17] implying that in this range of φ, (A18) and (A19) are more restrictive than (A17). Thus, for $\varphi \geq 1/2$, $\pi(\Phi^d) > \pi(\Phi_\alpha^{\tilde{d}})$, implying the existence of $\widetilde{\varphi}^d < 1/2$, such that for $\varphi \geq \widetilde{\varphi}^d$, $\pi(\Phi^d) \geq \pi(\Phi_\alpha^{\tilde{d}})$. ■

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