Performance Aggregation and Decentralized Contracting*

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Abstract

We examine how accounting and reporting practices that aggregate or disaggregate the contributions of different economic agents influence the choice of organizational form. We consider a principal/multi-agent model where the principal either contracts with all parties directly or delegates part of the contracting authority to one of the agents. Delegating contracts promote better risk-sharing and generate implicit incentives for the higher-level agent but they also entail a loss of control in motivating the lower-level agent. However, when performance is aggregated, delegated contracting rights to a higher level agent render contracts more interdependent and create spillovers up and down the hierarchy. Spillovers alter both agents’ behaviors and potentially sway a principal’s choice of organizational form. We demonstrate that accounting practices that aggregate the performance contributions of different economic agents can complement organizational forms characterized by greater decentralization. In contrast, accounting practices that capture the performance contributions of each agent separately tend to favor more centralized organizational forms. Our findings suggest that in settings where performance measurement systems are more aggregate, decentralization is more prevalent.

Keywords: Delegation; Hierarchies; Incentives; Multi-agent contracting; Performance evaluation

JEL-code: L22, M12, M4
1. Introduction

Corporate hierarchies and practices such as outsourcing and subcontracting are described often as ways to organize and motivate work in settings where multiple economic agents jointly contribute to production (e.g., Williamson 1975, Jensen and Meckling 1976). At the same time, contracting theories suggest that organizational forms and structures affect and are affected by other organizational practices including how various parties are evaluated and compensated (e.g., Grossman and Hart 1986, Milgrom and Roberts 1992). In this paper, we examine how accounting practices that report the performance of different economic agents in an aggregate or disaggregate fashion critically influence the choice of organizational form. For example, we find that accounting practices that aggregate the performance contributions of different economic agents complement organizational forms characterized by greater decentralization or delegation. In contrast, we find that accounting practices that capture the performance of economic agents in a disaggregate fashion may be better suited for more centralized organizations.

To examine the relation between organizational form and performance measurement practices, we consider a simple agency model where a risk-neutral owner engages two risk-averse agents (labeled A and B) tasked with the production of joint output. When two or more agents are involved in joint production, one of the more important design considerations is whether the owner contracts with all parties directly or delegates part of the contracting authority to one of the agents. In this spirit, we refer to a centralized organization as one where the owner contracts with both agents and a decentralized organization as one where the owner contracts with one agent (say Agent A) and delegates to Agent A the authority to contract with the second agent (Agent B). We compare the efficiency of these two organizational forms under two alternative assumptions about how the two agents are evaluated. We refer to measurement practices that
capture the contribution of each agent separately as *disaggregate* accounting and practices that capture agents’ contributions jointly as *aggregate* accounting.\(^1\)

As an illustrative example of our model, consider an owner (an individual or a company) involved in the completion of a large scale project. The owner can contract directly with multiple parties required to complete the project or she can hire a manager with responsibility to hire other workers as necessary. In the construction industry, for example, general contractors often do some construction work themselves but, more typically, retain several subcontractors to perform most of the other tasks. Importantly, subcontractors are usually hired and compensated by general contractors without direct input from owners. Of course, elements of both centralized and decentralized contracting arrangements are common in practice. Unit managers in divisionalized corporations, for instance, are evaluated usually by both their immediate superiors as well as by more senior managers in the corporate hierarchy.

Elements of both aggregate and disaggregate accounting are also common in practice. In performance evaluation setting, measurement choices are guided in large part by the ease with which the performance of disparate agents can be measured separately. For instance, in production settings where output is easily divisible or produced in a series of discrete separable steps, the performance of workers in each step is, in principle, measurable. In divisionalized corporations, for example, measuring and reporting divisional income for two division managers separately may be just as convenient as reporting aggregate corporate income. In other settings, such separation is much more difficult. For example, in project construction settings, it may be very difficult to verifiably separate the contribution of a general contractor’s organizational work

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\(^1\) In particular, we assume disaggregate accounting implies that there is a single performance measure that reflects each agent’s unique contribution to firm value. In contrast, aggregate accounting implies that the agents are evaluated on joint output only or on some other indicator of their joint production.
from the contributions of subcontractors because many of the tasks are intertwined or overlap in
time.2

For both disaggregate and aggregate accounting, we illustrate how the two agents’
behaviors under decentralized contracting compare with centralized contracting. We identify
three distinct effects.

First, we note that if Agent A is responsible for contracting with Agent B, then, by
definition, Agent B’s incentives cascade down from Agent A’s incentives rather than reflect the
principal’s objectives. Hence, decentralized contracting typically give rise to a control loss
relative to centralized contracting because Agent A’s incentives are not perfectly aligned with the
principal’s objectives. Control losses are common in hierarchical organizations (Calvo and
Wellisz 1978, Melumad et al. 1995, Williamson 1967) and manifest in our model as more muted
incentives for Agent B.

Second, we show that decentralized contracting motivates Agent A to provide more effort
than under centralized contracting because decision rights over contracting enables Agent A to
share some of his compensation risk with Agent B. In particular, Agent A reduces some of his
compensation risk by basing Agent B’s compensation partly on his own performance. Risk
sharing with Agent B enables Agent A to bear more risk overall, which then manifests in our
model as steeper incentives and higher effort for Agent A.

Third, we show that decentralized contracting generates an implicit incentive for Agent A
in the sense that his motivation to provide effort derives not only from his explicit contract with
the principal but also implicitly via his ability to contract with Agent B. Implicit incentives arise
under decentralized contracting for two reasons. First, because Agent B’s compensation is based

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2 In construction settings, much of the work done by general contractors usually precedes the hiring of
subcontractors, albeit there are some tasks that are simultaneous or even follow those of subcontractors.
partly on Agent A’s performance, Agent A has an implicit incentive to decrease his effort in order to economize on paying Agent B. Second, because at the time of contract acceptance Agent B’s beliefs about his compensation are potentially influenced by Agent A’s effort, Agent A has an implicit incentive to increase his effort in order to influence those beliefs. When the latter incentive to increase effort is stronger (conversely, weaker) than the former incentive to decrease effort, we describe the implicit incentive as being favorable (conversely, unfavorable).

Taken together, the comparison of decentralized and centralized contracting under disaggregate accounting generally revolves around a comparison of the aforementioned three effects, i.e., control loss, risk sharing and implicit incentives. Whereas the control loss effect favors centralized contracting, the risk sharing effect favors decentralized contracting. Hence, whether centralized or decentralized contracting is ultimately preferable for the principal depends on the extent to which the third effect, the implicit incentive, is favorable or unfavorable. For instance, for identical agents evaluated under disaggregate accounting, we show that decentralized contracting is more profitable than centralized contracting if the implicit incentive is not too unfavorable. Conversely, we find that centralized contracting is more profitable than decentralized contracting if the implicit incentive is sufficiently unfavorable.

With aggregate accounting, where agents are evaluated jointly on their aggregate performance, the control loss, risk sharing and implicit incentive effects manifest jointly as well. Importantly however, contracts under a decentralized structure are more interdependent and incentives are intertwined as if both agents are responsible for both tasks. We refer to this effect

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3 Agent A can influence Agent B’s beliefs about his future compensation if, for instance, Agent A performs at least some of his duties prior to hiring Agent B and Agent B has some awareness of Agent A’s performance. In construction settings, for example, subcontractors such as electricians and plumbers are likely cognizant of at least some of the project organization work done by the general contractor prior to accepting their employment. Agent A’s implicit incentives to increase his effort in our setting is akin to the types of implicit incentives that arise in dynamic contexts where past performance often conditions future beliefs and contracts (e.g., Christensen et al. 2013; Arya and Mittendorf 2011; Autrey et al., 2010; Feltham et al. 2006; Christensen, et al. 2003; Holmström 1999; Indjejikian and Nanda 1999; Gibbons and Murphy 1992).
as *incentive spillovers* and note that they influence the behavior of both agents. In particular, we find that spillovers can sway the tradeoff for both agents in a complementary way in the sense that both agents exert more effort under decentralized contracting than under centralized contracting. This contrasts with disaggregate accounting where delegating contracting rights to a higher-tier agent always dampens the performance of agents in lower tiers of the hierarchy (i.e., Agent B).

The idea that aggregate accounting generates spillovers under decentralized contracting raises the possibility that aggregate accounting practices complement decentralization more so than disaggregate accounting practices. To address this question, we compare the owner’s profit with an aggregate performance measure to her profit with disaggregate measures assuming decentralized contracting prevails. In particular, we consider a setting where an aggregate measure is simply the sum of two constituent (and statistically independent) disaggregate measures so that, by construction, aggregation implies a loss of performance-relevant information. Despite this loss of information, we find that aggregate accounting may be more profitable than disaggregate accounting if the spillover effects are sufficiently consequential.

The principal-agent literature in accounting and economics has considered the classic problem of responsibility assignment in organizations from a variety of perspectives. The advantages and disadvantages of decentralized contracting, for instance, have been linked to the possibility of side contracting and collusive behavior among agents (e.g., Tirole 1986, Laffont and Martimort 1998, Macho-Stadler and Perez-Castrillo 1998, Baliga and Sjöström 1998, Feltham and Hofmann 2007), to the presence of contracting imperfections including restrictions on communication (Melumad et al. 1992, 1995, 1997), and to the possibility that agents’ efforts may be strategic complements (e.g., Jelovac and Macho-Stadler 2002).

Our model abstracts away from most of these considerations. In particular, we feature a linear-exponential-normal (LEN) model without strategic complementarities or substitutabilities,
communication, collusion, or side contracting.\textsuperscript{4} Perhaps the closest reference to our study is Hortala-Vallve and Villalba (2010). They also compare centralized and decentralized contracting in a LEN model but they do not compare alternative performance measurement practices nor do they highlight the role of implicit incentives in assessing the efficiency of decentralized contracting.

Despite the simplifications of our model, we show that contracting structure still matters. Moreover, we expect that the forces we highlight such as risk sharing, control loss, implicit incentives and effort spillovers likely prevail in more general models because these are precisely the kinds of effects attributed to observed practices such as outsourcing and subcontracting (e.g., Eccles 1981). Our results also give some insight about the types of performance measurement practices that drive the use of (or are associated with) subcontracting and outsourcing versus the performance measurement practices of more vertically integrated organizations where typically contractual rights are concentrated at higher levels in the hierarchy.

The remainder of the paper is organized as follows. Section 2 presents the model as well as the timeline in both a centralized and a decentralized contracting structure. Section 3 compares centralized and decentralized contracting structures assuming disaggregate accounting. Section 4 compares centralized and decentralized contracting structures assuming aggregate accounting. Section 5 illustrates the complementarity between aggregate accounting and decentralized contracting. Section 6 concludes.

2. The Model

We consider a single-period model where a risk-neutral principal hires two agents, agents A and B, to jointly produce output $x$. We assume the output can be expressed as

\textsuperscript{4} For example, under centralized contracting, we do not allow Agent A to offer a side-contract to Agent B. Similarly, under decentralized contracting, we do not allow the owner to offer a side-contract to Agent B.
\[ x = b_ia_i + b_ia_b + \theta \]  
(1)

where \( a_i \) represents the activities of Agent \( i = A, B \), \( b_i \) is the marginal productivity of Agent \( i \)'s effort, and \( \theta \sim N(0, \sigma_\theta^2) \) represents other factors unrelated to the efforts provided by the agents.

We assume agents A and B are risk averse with identical preferences characterized by negative exponential utility functions with risk aversion coefficient \( r \); assuming different preferences with \( r_A \neq r_B \) does not qualitatively affect our results. The agents provide costly effort to the tune of \( \frac{1}{2}a_i^2 \) but their efforts are not directly observable or verifiable.\(^5\)

We assume that the agents’ compensation contracts, \( z_A \) and \( z_B \) are linear functions of verifiable measures of their performance. With aggregate accounting, we assume joint output \( x \) (or another metric of joint output) is the only verifiable performance measure. With disaggregate accounting, we assume there are two distinct measures;

\[ y_i = b_ia_i + \varepsilon_i, \quad i = A, B \]  
(2)

where \( \varepsilon_i \sim N(0, \sigma_i^2) \) and \( \varepsilon_A \) and \( \varepsilon_B \) are uncorrelated.

Finally, we assume that the agents’ compensation is set to ensure that they accept their contract and, without loss of generality, we set their reservation certainty equivalent to zero. The timeline of our model unfolds as follows:

**Stage 1:**

The principal chooses Agent A’s contract \( z_A \) to maximize her expected net payoff, which is the difference between her gross payoff, \( x \), and the compensation of \( c_A \), paid to Agent A.

**Stage 2:**

\(^5\) We preclude the possibility of agent collusion and note that both the agents’ marginal products (the \( b_i \)s) and their effort disutilities (the \( \frac{1}{2}a_i^2 \)s) are independent. Although these are simplifications, they ensure that all possible interactions between the two agents manifest through the focal features of our model, i.e., through the contracting structure and/or through the characteristics of the performance measures.
After accepting the contract offered by the principal, Agent A chooses his effort $a_A$.

Stage 3:
The principal and both agents observe a signal of the form $\Psi = b_A a_A + \psi$ where $\psi \sim N(0, \sigma_\psi^2)$ is potentially correlated with the performance measure(s) that will ultimately be realized for Agent A. In particular, we assume $\psi$ is correlated with $\theta$ in the aggregate accounting setting and $\varepsilon_A$ in the disaggregate accounting setting. We assume $\Psi$ is soft unverifiable information and thus cannot be explicitly contracted on.\(^6\)

Stage 4:
This is the contracting stage for Agent B. Based on $\Psi$, Agent B accepts his contract $z_B$ and chooses his effort $a_B$. Importantly, the principal chooses $z_B$ under centralized contracting but that choice is delegated to Agent A under decentralized contracting. We also preclude the possibility of side-contracting. That is, under centralized contracting Agent A cannot offer a side-contract to Agent B. Similarly, under decentralized contracting, the principal cannot offer a side-contract to Agent B.

Stage 5:
The performance measures are realized, the agents are compensated and the principal obtains her payoff.

The timeline outlined above is the same for centralized and decentralized contracting except for Stage 4. In Stage 4, under centralized contracting the principal contracts with Agent B

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\(^6\) $\Psi$ is unverifiable in the sense that no outside authority responsible for enforcing a contract can observe the signal directly. However, because $\Psi$ is commonly observed by all parties, one approach to rendering it verifiable is through a revelation mechanism where all parties truthfully reveal their information to an outside authority or a court of law. We preclude such mechanisms because, as Hermalin and Katz (1991) note, such a characterization of courts is not descriptive of practice. That said, we allow for the possibility that $\Psi$ may be indirectly useful in structuring compensation arrangements. Indirect contracting based on unverifiable information also manifests in dynamic settings where contracts are renegotiated based on unverifiable information revealed at interim stages (e.g., Hermalin and Katz 1991; Christensen et al., 2013).
whereas under decentralized contracting Agent A contracts with Agent B. The solution to the incentive problem for both decentralized and centralized structures is by backward induction which we demonstrate in sections 3 and 4. In section 3, we compare the profitability of centralized versus decentralized contracting structures assuming disaggregate accounting. In section 4, we compare the profitability of centralized versus decentralized contracting assuming aggregate accounting. Finally in section 5 we compare aggregate accounting with disaggregate accounting, assuming a decentralized contracting structure and a particular aggregation rule.

3. Disaggregate Performance Measures and Organizational Form

Our characterization of disaggregate performance measures is straightforward. Given $y_i = b_i a_i + \epsilon_i, i = A, B$, we write the agents’ compensation as

$$c_i(y_A, y_B) = f_i + v_i y_i + \delta_i y_j, \quad i, j = A, B \quad \text{with } i \neq j,$$

where $f_i$ is the fixed component of agent $i$’s compensation, $v_i$ is the incentive rate for own performance $y_i$, and $\delta_i$ is the incentive rate for the performance of the other agent $j$. In addition, we assume that $\Psi = b_A a_A + \psi$ is positively correlated with Agent A’s performance measure $y_A = b_A a_A + \epsilon_A$. That is, $\text{Cov}(y_A, \psi) = \rho \sigma_A \sigma_\psi > 0$.

In what follows, we characterize the optimal contracts under centralized and decentralized structures separately and then compare the agents’ effort and the principal’s expected net payoff under both organizational forms.

3.1 Centralized contracting

Under centralized contracting, the derivation of the agents’ efforts and the principal’s expected profit is straightforward. We state the results in Lemma 1 below and defer the details to the Appendix.
Lemma 1:

In an organization characterized by *disaggregate performance measures* and *centralized contracting*, the agents’ efforts, their incentive contracts, and the principal’s expected profit are:

\[ a^\text{DC}_i = b_i v^\text{DC}_i , \quad i=\text{A,B} \]  

\[ v^\text{DC}_i = \frac{b_i^2}{b_i^2 + r\sigma_i^2} ; \quad \delta^\text{DC}_i = 0 , \quad i=\text{A,B} \]  

and

\[ \pi^\text{DC} = \frac{1}{2} \left( \frac{b_A^4}{b_A^4 + r\sigma_A^2} + \frac{b_B^4}{b_B^4 + r\sigma_B^2} \right) . \]  

As expected, Lemma 1 suggests that agents’ centralized contracts are separable because the performance of one agent is not informative about the other agent’s effort. The principal’s expected net payoff in (6) provides a benchmark against which we compare the consequences of decentralized contracting in section 3.2.

3.2 Decentralized contracting

With decentralized contracting, the principal chooses contract \( z_A = (f_A, v_A, \delta_A) \) but delegates the choice of contract \( z_B = (f_B, v_B, \delta_B) \) to Agent A. Moreover, as we noted in section 2, all parties observe a common signal, \( \Psi = b_A a_A + \psi \), before Agent B accepts his contract \( z_B \) from Agent A and before his choice of \( a_B \). This implies that Agent B’s certainty equivalent from accepting Agent A’s contract depends on the realization of \( \Psi \) and is given by

\[ CE_B(\Psi, z_B; a_B, \hat{a}_A) = E(c_B \mid \Psi; a_B, \hat{a}_A) - \frac{1}{2} a_B^2 - \frac{r}{2} \text{Var}(c_B \mid \Psi; a_B, \hat{a}_A) \]  

where \( \hat{a}_A \) represents Agent B’s conjecture with respect to Agent A’s action. Substituting \( c_B \) and \( y_B \) into (7) and differentiating with respect to \( a_B \) yields Agent B’s optimal choice of effort,

\[ a^\text{DD}_B = b_B v^\text{DD}_B , \]
where the superscript “DD” refers to the combination of disaggregate information and decentralized contracting.

To induce Agent B to accept contract $z_B$ in Stage 4, Agent A offers a fixed salary that reflects the signal $\Psi$ observed in the prior stage. Setting (7) equal to zero and using (8), we write Agent B’s incentive rationality constraint as

$$f^D_B(\Psi) = \frac{1}{2} r \text{Var}(y_A | \Psi; \hat{A}_A) \delta^2_B + \frac{1}{2} \left( b^2_B + r \sigma^2_B \right) v^2_B - E(y_A | \Psi; \hat{A}_A) \delta_B - b^2_B v^2_B$$  \hspace{1cm} (9)

where $\text{Var}(y_A | \Psi; \hat{A}_A) = \sigma^2_A (1 - \rho^2)$ and $E(y_A | \Psi; \hat{A}_A) = b_A \hat{A}_A + \frac{\rho \sigma_A}{\sigma} (\Psi - b_A \hat{A}_A)$.  \hspace{1cm} (10)

In Stage 4 then, Agent A chooses Agent B’s contract $z_B$ to maximize his certainty equivalent conditional on $\Psi$,  

$$CE_A(z_A, z_B | \Psi; a_A, \hat{A}_B) = E(c_A - c_B | \Psi; a_A, \hat{A}_B) - \frac{r}{2} \text{Var}(c_A - c_B | \Psi; a_A, \hat{A}_B)$$  \hspace{1cm} (11)

subject to Agent B’s IC and IR constraints given by (8) and (9) respectively. Given the expressions for $c_A$ and $c_B$ in (3) and substituting the IC and IR constraints, the solution to Agent A’s unconstrained maximization problem yields Agent B’s contract,

$$v^D_B = h \delta^D_B$$  \hspace{1cm} and  \hspace{1cm} $$\delta^D_B = \frac{1}{2} v^D_A$$  \hspace{1cm} (12)

where $h = \frac{b^2_B + r \sigma^2_B}{b^2_B + 2 r \sigma^2_B}$.

Two notable observations emerge from (12). First, we note that Agent B’s incentives $(v^D_B, \delta^D_B)$ cascade down from Agent A’s incentives, $(v^D_A, \delta^D_A)$, rather than reflect the principal’s objectives. For instance, Agent B is compensated on $y_B$ (i.e., $v^D_B \neq 0$) if and only if Agent A is also compensated on $y_B$ (i.e., $\delta^D_A \neq 0$). Second, Agent B is compensated on $y_A$ (i.e., $\delta^D_B > 0$) despite the fact that $y_A$ only captures Agent A’s contribution to firm value. Setting $\delta^D_B > 0$
reflects Agent A’s motivation to share risk with Agent B. For example, the coefficient $\frac{1}{2}$ multiplying $v_A^{DD}$ in (12) reflects the fraction of total risk that is efficiently borne by Agent B.\footnote{We note that in a more general setting where $r_A \neq r_B$, the coefficient multiplying $v_A^{DD}$ in (12) is $\frac{\left(\frac{\sigma_A}{\sigma} - 1\right)}{\left(\frac{\sigma_A}{\sigma} + 1\right)}$, which is the ratio of Agent B’s risk tolerance to the sum of the risk tolerances of the two agents.}

In Stage 2, prior to the observation of $\Psi$, Agent A chooses his effort $a_A$ to maximize his certainty equivalent given by

$$CE_A(z_A, z_B, a_A, \hat{a}_B) = E(c_A - c_B; a_A, \hat{a}_B) - \frac{1}{2}a_A^2 - \frac{r}{2} \text{Var}(c_A - c_B; a_A, \hat{a}_B)$$

which implies that:

$$a_A^{DD} = b_A v_A^{DD} + \left(\frac{\sigma_A}{\sigma} - 1\right) b_A \delta_B^{DD},$$

where $\delta_B^{DD}$ is defined in (12).

Expression (14) suggests that Agent A’s motivation to perform his task derives from two sources; explicitly via his contract with the principal through the $b_A v_A$ term in (14) and implicitly via his relationship with Agent B through the $\left(\frac{\sigma_A}{\sigma} - 1\right) b_A \delta_B$ term in (14).

Implicit incentives arise under decentralized contracting for two reasons. First, because Agent B’s compensation is based partly on $v_A$ (i.e., through the $\delta_B v_A$ component in (3)), Agent A has an implicit incentive to decrease his effort in order to economize on paying Agent B. This is the $-b_A \delta_B^{DD}$ term. Second, because at the time of contract acceptance Agent B’s beliefs about his compensation are potentially influenced by Agent A’s effort, Agent A has an implicit incentive to increase his effort in order to influence those beliefs.\footnote{Agent A’s implicit incentives to increase his effort and thereby influence Agent B’s beliefs is similar to the types of implicit incentives that arise in dynamic contexts where past performance conditions future beliefs (e.g., Christensen et al. 2013; Gibbons and Murphy 1992).} When the latter incentive to increase effort
is stronger (conversely, weaker) than the former incentive to decrease effort, we describe the implicit incentive as being favorable (conversely, unfavorable).

In Stage 1, the principal chooses \( z_A = (f_A, v_A, \delta_A) \) to maximize her expected net payoff, \( E(x - c_A) \), subject to the two agents’ incentive compatibility constraints, (8) and (14), Agent A’s individual rationality constraint that the certainty equivalent in (13) be greater than zero, and Agent A’s choice of Agent B’s incentive rates, (12). We have:

**Lemma 2:**

In an organization characterized by *disaggregate performance measures* and decentralized *contracting*, the agents’ efforts, their incentive contracts, and the principal’s expected profit are:

\[
\begin{align*}
  a_A^{DD} &= b_A \left( v_A^{DD} + (\rho \sigma_A - 1) \sigma_B^{DD} \right), \quad a_B^{DD} = b_B v_B^{DD} \quad (15a) \\
  v_A^{DD} &= \frac{b_A^2 \left( 1 + \frac{1}{2} \left( \frac{\rho \sigma_A}{\sigma_V} - 1 \right) \right)}{b_A^2 \left( 1 + \frac{1}{2} \left( \frac{\rho \sigma_A}{\sigma_V} - 1 \right) \right)^2 + r \sigma_A^2 \left( \frac{1 + \rho^2}{2} \right)}, \quad \delta_A^{DD} = \frac{b_B^2 / h}{b_B^2 + r \sigma_B^2 + r \sigma_B^2 \left( \frac{1 + k}{h} \right)^2} \quad (15b) \\
  v_B^{DD} &= h \delta_A^{DD}, \quad \delta_B^{DD} = \frac{1}{2} v_A^{DD} \quad \text{where } h = \frac{b_B^2 + r \sigma_B^2}{b_B^2 + 2 r \sigma_B^2}, \quad (15c)
\end{align*}
\]

and

\[
\pi^{DD} = 1 + \frac{b_A^4 \left( 1 + \frac{1}{2} \left( \frac{\rho \sigma_A}{\sigma_V} - 1 \right) \right)^2}{2 b_A^2 \left( 1 + \frac{1}{2} \left( \frac{\rho \sigma_A}{\sigma_V} - 1 \right) \right)^2 + r \sigma_A^2 \left( \frac{1 + \rho^2}{2} \right)} + \frac{1}{2} b_B^4 \left( b_B^2 + r \sigma_B^2 + r \sigma_B^2 \left( \frac{1 + k}{h} \right)^2 \right) \quad (15d)
\]

**3.3 Comparing Centralized and Decentralized Contracting**

To illustrate the advantages and disadvantages of decentralized contracting, we compare the agents’ efforts to their corresponding effort under centralized contracting. For Agent A, we have:

\[
a_A^{DD} - a_A^{DC} = \frac{b_A^3}{b_A^2 + r \sigma_A^2 \left( 1 + \frac{\rho^2}{2} \right)} - \frac{1}{b_A^2 + r \sigma_A^2} \cdot \quad (16)
\]
The ratio \( \frac{r\sigma_A^2(1+\rho^2)}{2} \) in (16) highlights two distinct effects that distinguish centralized and decentralized contracting for Agent A. The first effect is due to the risk borne by Agent A under decentralized contracting. This is represented by \( r\sigma_A^2(1+\rho^2) / 2 \) which is less than the corresponding term under centralized contracting, given by \( r\sigma_A^2 \). We label this effect a “risk-sharing” effect. Intuitively, decentralized contracting motivates Agent A to provide more effort in Stage 2 because their joint observation of \( \Psi \) later in Stage 3 enables him to share his \( y_A \)-related compensation risk with Agent B. Of course, if \( \rho^2 \to 1 \) so that the signal \( \Psi \) reveals \( y_A \) perfectly, then decentralized contracting does not offer risk sharing opportunities because once \( \Psi \) is observed there is no \( y_A \)-related compensation risk left to be shared.

Second, expression (16) illustrates that decentralized contracting generates an “implicit” incentive for Agent A as long as \( \frac{\rho\sigma_A}{\sigma_y} \neq 1 \). We label settings where \( \frac{\rho\sigma_A}{\sigma_y} > 1 \) as “favorable” because they motivate an increase in effort, and conversely we label settings where \( \frac{\rho\sigma_A}{\sigma_y} < 1 \) as “unfavorable” because they motivate a decrease in effort. As noted earlier, implicit incentive arise in our model because Agent B’s compensation is based on Agent A’s performance and because Agent B’s beliefs about his compensation are potentially influenced by Agent A’s effort. From (16), we note that favorable implicit incentives reinforce the risk-sharing effect so that Agent A always provides more effort under delegated contracting than under centralized contracting. In contrast, unfavorable implicit incentives counteract the risk-sharing effect so that the combined effect is potentially ambiguous. We have:

**Proposition 1.**
With disaggregate performance measures, Agent A provides more effort under decentralized contracting than under centralized contracting if and only if his implicit incentives are not too unfavorable. In particular, \( a_{DD}^A \geq a_{DC}^A \) if and only if
\[
\frac{p\sigma_A}{\sigma_\Psi} \geq \sqrt{2(1 + \rho^2)} - 1. 
\]

**Proof:** See Appendix.

To illustrate the tradeoff underlying Proposition 1, consider a setting where \( y_A \) is a “garbled” version of \( \Psi \) (e.g., \( y_A = \Psi + \gamma \) where \( \gamma \sim N(0, \sigma^2_\gamma) \) is an independent noise term). It follows that decentralized contracting generates a risk sharing benefit because \( \rho^2 = \frac{\sigma^2_\Psi}{(\sigma^2_\Psi + \sigma^2_\gamma)} < 1 \) but does not generate implicit incentives because \( \frac{p\sigma_A}{\sigma_\Psi} = 1 \). Hence, the condition in Proposition 1 is easily met. Now consider a different setting where \( \Psi \) is a “garbled” version of \( y_A \) (e.g., \( \Psi = y_A + \gamma \) where \( \gamma \sim N(0, \sigma^2_\gamma) \) is an independent noise term). In this case \( \frac{p\sigma_A}{\sigma_\Psi} = \rho^2 < 1 \) and it is easy to show that the unfavorable implicit incentives outweigh the risk sharing benefits of decentralized contracting.

The comparison of Agent B’s effort under centralized and decentralized contracting is more straightforward. We have:
\[
a_{DD}^B - a_{DC}^B = \frac{b^3}{b^2 + r\sigma^2_\Psi + r\sigma^2_\Psi(\frac{1-h}{h})^2} - \frac{b^3}{b^2 + r\sigma^2_\Psi} < 0 \quad \text{where} \quad h = \frac{b^2 + r\sigma^2_\Psi}{b^2 + 2r\sigma^2_\Psi}. 
\]

In contrast to Agent A, we note that Agent B’s incentives are always more muted under decentralized contracting because of the additional risk premium term \( r\sigma^2_\Psi(\frac{1-h}{h})^2 \). This reflects a “control loss” because delegated contracting implies that Agent B’s incentives in essence cascade down from Agent A’s incentives rather than reflect the principal’s objectives.
Taken together, the preceding discussion suggests that the principal’s preference for a decentralized contracting structure reflects a tradeoff between the potential benefits of a more productive Agent A (due to risk sharing and implicit incentives) and the control loss associated with a less productive Agent B. Clearly, a setting where Agent A’s contribution to joint output is much more significant than Agent B’s contribution favors decentralization. Conversely, a setting where Agent B’s contribution is much more significant favors centralization. Of course, this would also suggest that the principal’s choice of whom to anoint as Agent A versus Agent B matters. To bypass such concerns, we consider a “standard” setting with identically productive agents (i.e., \( b_A = b_B = b \)) and equally precise performance measures (i.e., \( \sigma_A^2 = \sigma_B^2 = \sigma^2 \)) so that the agents A and B are a priori interchangeable. This implies that \( \pi^{DC} \) in Lemma 1 and \( \pi^{DD} \) in Lemma 2 can be rewritten as:

\[
\pi^{DC} = \frac{b^4}{b^2 + r\sigma^2} \tag{19a}
\]

and

\[
\pi^{DD} = \frac{1}{2} \frac{b^4 \left( 1 + \frac{1}{2} \left( \rho\sigma_\psi - 1 \right) \right)^2}{b^2 \left( 1 + \frac{1}{2} \left( \rho\sigma_\psi - 1 \right) - r\sigma^2 \left( \frac{1 + \rho^2}{2} \right) \right)^2 + r\sigma^2 + \frac{b^4}{(b^2 + r\sigma^2)^2}} \tag{19b}
\]

A comparison of (19a) and (19b) suggests the following proposition:

**Proposition 2.**

*With disaggregate performance measures and identical agents, the principal prefers decentralized contracting if and only if agent A’s implicit incentives are not too unfavorable. In particular, \( \pi^{DD} \geq \pi^{DC} \) if and only if

\[
\frac{\rho\sigma}{\sigma_\psi} \geq \sqrt{2(1 + \rho^2)(1 + k_1)} - 1 \tag{20}
\]

where \( 0 < k_1 < \frac{1}{2} \) is defined in the Appendix.*
Proof: See Appendix.

We note that the condition in favor of decentralized contracting in Proposition 2 is stricter than the condition in Proposition 1 (because $k_i > 0$). This reflects the fact that the benefits of a more productive Agent A are partially offset by a less productive Agent B. Consider for instance the setting illustrated earlier for Proposition 1 where $y_A$ is a garbled version of $\Psi$ and there are no implicit incentives (i.e., $\frac{\rho^a}{\sigma^a} = 1$). Whereas $\frac{\rho^a}{\sigma^a} = 1$ implies that decentralized contracting always generates risk-sharing benefits, these benefits must be substantial enough to outweigh the control loss due to Agent B. For the example under consideration, we can show that the risk sharing benefits outweigh the control loss if and only if $\rho^2$ is not too large.

Taken together, Propositions 1 and 2 suggest that, with disaggregate measures, decentralized contracting is more profitable than centralized contracting if implicit incentives are not too unfavorable and/or risk-sharing benefits are substantial. Conversely, we find that centralized contracting is more profitable than decentralized contracting if implicit incentives are sufficiently unfavorable and/or risk-sharing benefits are immaterial.

4. Aggregate Performance Measures and Organizational Form

In this section, we consider how an aggregate performance measure affects the tradeoff between centralization and decentralization. This aggregate measure may be output $x$ itself or some other indicator of the agents’ joint output. For example, in the construction setting cited earlier, the interrelated nature of the work performed by a general contractor and a subcontractor may make it more natural to measure their contribution jointly rather than separately. Assuming the aggregate performance measure is output $x = b_Aa_A + b_Ba_B + \theta$ with $\theta \sim N(0, \sigma^2\theta)$, we write the agents’ compensation as

$$c_i(x) = f_i + v_i x , \quad i=A,B$$

(21)
where $f_i$ is the fixed component of agent $i$’s compensation and $v_i$ is the incentive rate on aggregate output. As in section 3, we assume that the principal and both agents observe an unverifiable signal $\Psi = b_A a_A + \psi$. In addition, we assume that $\Psi$ is positively correlated with output $x = b_A a_A + b_B a_B + \theta$ where $\text{Cov}(x, \psi) = \rho_{\psi \sigma_{\psi}} > 0$.

In what follows, we characterize the optimal contracts under centralized and decentralized structures, and compare the agents’ effort and the principal’s expected net payoff under both organizational forms.

4.1 Centralized and Decentralized contracting

For centralized contracts based on aggregate output $x$, the agents’ efforts, the compensation coefficients and the principal’s profit mirror the corresponding constructs in Lemma 1 but for the fact that Agent B’s contract can now be conditioned on the observation of $\Psi$. We state these without proof in the following Lemma:

**Lemma 3:**

In an organization characterized by aggregate performance measures and centralized contracting, the agents’ efforts, their incentive contracts and the principal’s expected profit are:

$$a_i^{AC} = b_i v_i^{AC} ; \quad i = A, B$$  

$$v_A^{AC} = \frac{b_A^2}{b_A^2 + r \sigma_\theta^2}$$  

$$v_B^{AC} = \frac{b_B^2}{b_B^2 + r \sigma_\theta^2 (1 - \rho_\theta^2)}$$  

and  

$$\pi^{AC} = \frac{1}{2} \frac{b_A^4}{b_A^2 + r \sigma_\theta^2} + \frac{1}{2} \frac{b_B^4}{b_B^2 + r \sigma_\theta^2 (1 - \rho_\theta^2)}$$

where the superscript “AC” refers to aggregate information and centralized contracting.

With decentralized contracting, the sequence of events and the derivations with an aggregate performance measure parallel our earlier analysis in Section 3. Hence for parsimony we do not repeat it here. We have:
Lemma 4:

In an organization characterized by an aggregate performance measure and decentralized contracting, the agents’ efforts, their incentive contracts and the principal’s expected profit are:

\[ a_{AD}^A = b_A \left( v_{AD}^A + \left( \frac{\rho_{\sigma_2}}{\sigma_2} - 1 \right) v_B^B \right), \quad a_{AD}^B = b_B v_B^B \]  

\[ v_{AD}^A = \frac{b_A^2 \left( 1 + H \left( \frac{\rho_{\sigma_2}}{\sigma_2} - 1 \right) \right) + b_B^2 H}{b_A^2 \left( 1 + H \left( \frac{\rho_{\sigma_2}}{\sigma_2} - 1 \right) \right)^2 + b_B^2 H + r \sigma_0^2 \left[ 1 - H \left( 1 - \rho_0^2 \right) \right]} , \quad v_{AD}^B = H v_{AD}^A \]  

and

\[ \pi_{AD} = \frac{1}{2} \frac{b_A^2 \left( 1 + H \left( \frac{\rho_{\sigma_2}}{\sigma_2} - 1 \right) \right) + b_B^2 H}{b_A^2 \left( 1 + H \left( \frac{\rho_{\sigma_2}}{\sigma_2} - 1 \right) \right)^2 + b_B^2 H + r \sigma_0^2 \left[ 1 - H \left( 1 - \rho_0^2 \right) \right]} \]  

where \( H = \frac{b_A^2 + r \sigma_0^2 \left( 1 - \rho_0^2 \right)}{b_B^2 + 2 r \sigma_0^2 \left( 1 - \rho_0^2 \right)} \) and the superscript “AD” refers to the combination of aggregate information and decentralized contracting.

In contrast to the disaggregate performance measurement in Lemma 2, the highlight of Lemma 4 is that performance aggregation and decentralized contracting renders the agents’ contracts more interdependent. That is, their incentives are intertwined in the sense that both agents are evaluated as if they are responsible for both tasks. This is an important consequence of performance aggregation coupled with decentralized contracts and does not arise in any other setting. In particular, we note that the productivity of Agent B, \( b_B \), affects Agent A’s incentives and correspondingly \( b_A \) affects Agent B’s incentives despite the fact that both output and the agents’ cost of effort are separable in the two agents’ efforts.

4.2 Comparing Centralized and Decentralized Contracting

To illustrate the advantages and disadvantages of decentralized contracting with performance aggregation, we compare the agents’ efforts to their corresponding effort under centralized contracting. For Agent A, we have:
\[ a_{AD}^{AC} - a_{AC}^{AC} = \frac{b_A^3 \left( 1 + \frac{b_A^2}{b_B^2} \left( \frac{H}{1 + H (\sigma_{\theta}^2 - 1)} \right) \right)}{b_A^2 \left( 1 + \frac{b_A^2}{b_B^2} \left( \frac{H}{1 + H (\sigma_{\theta}^2 - 1)} \right) \right)^2 + \sigma_{\theta}^2 (1 - \rho_{\theta}^2) (1 + \left( \frac{1 - H}{H} \right)^2 + r \sigma_{\theta}^2 \frac{\rho_{\theta}^2}{H^2})} - \frac{b_A^3}{b_B^2 + r \sigma_{\theta}^2 (1 - \rho_{\theta}^2)} \]  

(24)

and the corresponding expression for Agent B is:

\[ a_{BD}^{AC} - a_{BC}^{AC} = \frac{b_B^3 \left( 1 + \frac{b_A^2}{b_B^2} \left( \frac{H}{1 + H (\sigma_{\theta}^2 - 1)} \right) \right)}{b_B^2 \left( 1 + \frac{b_A^2}{b_B^2} \left( \frac{H}{1 + H (\sigma_{\theta}^2 - 1)} \right) \right)^2 + r \sigma_{\theta}^2 (1 - \rho_{\theta}^2) (1 + \left( \frac{1 - H}{H} \right)^2 + r \sigma_{\theta}^2 \frac{\rho_{\theta}^2}{H^2})} - \frac{b_B^3}{b_B^2 + r \sigma_{\theta}^2 (1 - \rho_{\theta}^2)} \]  

(25)

where \( H = \frac{b_A^2 + r \sigma_{\theta}^2 (1 - \rho_{\theta}^2)}{b_B^2 + 2 r \sigma_{\theta}^2 (1 - \rho_{\theta}^2)} \).

The comparisons in (24) and (25) suggest that the “risk-sharing” and “implicit incentive” effects identified earlier in Section 3 for disaggregate measures continue to prevail with an aggregate measure. In particular, we note that the ratio \( \frac{\sigma_{\theta}^2 (1 - \rho_{\theta}^2)}{1 + H (\sigma_{\theta}^2 - 1)} \) in the denominator of \( a_{AD}^{AC} \) in (24) parallels a similar ratio in (16). Hence, decentralized contracting facilitates risk sharing and generates implicit incentives for Agent A as before.\(^9\) Similarly, (25) suggest that there is a “control loss” associated with motivating Agent B via a decentralized contract and this is reflected in the additional risk premium in the denominator of \( a_{BD}^{AC} \).

These similarities notwithstanding, the comparisons in (24) and (25) highlight the unique impact of performance aggregation, namely interdependent contracts and intertwined incentives. In particular, we note that both comparisons reflect an additional term which we refer to as “incentive spillover” effects to underscore the notion that the incentive spillover for Agent A depends on \( b_B \) while the incentive spillover for Agent B depends on \( b_A \). While it is clear that

\(^9\) For instance, if \( b_B \rightarrow 0, H \rightarrow \frac{1}{2} \) and the comparison in (24) mirrors exactly the comparison in the disaggregate case in Proposition 1.
these spillover effects sway the tradeoff for both agents, it is particularly salient for Agent B. For instance, unlike Section 3 where decentralized contacting always dampens Agent B’s effort, we find that decentralized contracting with an aggregate measure can enhance Agent B’s effort if incentive spillovers outweigh the control loss effect. We have:

**Proposition 3.**

(i) With an aggregate performance measure, Agent A provides more effort under decentralized contracting than under centralized contracting if and only if Agent A’s implicit incentives are not too unfavorable. In particular, \( a_A^{AD} \geq a_A^{AC} \) if and only if

\[
\frac{\rho_0 \sigma_0}{\sigma_y} \geq 1 - k_2 \quad \text{where } k_2 > 0 \text{ is defined in the Appendix.} \tag{26}
\]

(ii) With an aggregate performance measure, Agent B provides more effort under decentralized contracting than under centralized contracting if Agent B’s incentive spillovers are not too small (i.e., \( b_A \) is not too small) and Agent A’s implicit incentives are not too favorable (i.e., \( \rho_0 \sigma_0 / \sigma_y \) is not too large).

**Proof:** See Appendix.

Part (i) of Proposition 3 suggests that the risk sharing and implicit incentive effects for Agent A identified earlier (Section 3 and Proposition 1) are not substantively affected by incentive spillovers due to performance aggregation. For instance, expression (24) shows that when Agent A’s implicit incentives are favorable (or not too unfavorable), then the spillover effect reinforces Agent A’s incentives to provide effort.

Part (ii) of Proposition 3 is a unique consequence of performance aggregation. In particular, it suggests that the strength of Agent B’s incentive spillovers depends critically on Agent A. Of course, if \( b_A \) is small, then the incentive spillovers for Agent B are also small because Agent B’s incentives necessarily cascade down from Agent A. Moreover, if Agent A’s
implicit incentives are unusually strong then again the incentives that cascade down to Agent B are relatively weak. Hence, the incentive spillover effect is muted as well.

Overall, Proposition 3 implies that if Agent A’s implicit incentives are extreme (either too favorable or too unfavorable), then the incentives of the two agents will diverge under decentralized contracts so that one will provide more effort while the other will provide less effort than under centralized contracts. On the other hand, if Agent A’s implicit incentives are modest (neither too favorable nor too unfavorable), then both agents will likely provide more effort with decentralized contracts than with centralized contracts.

To illustrate the principal’s overall preference taking into account both agents’ contributions, we again consider a parsimonious setting with identical agents (i.e., $b_A = b_B = b$) so that the Agents A and B are a priori interchangeable. This implies that:

$$\pi^{AC} = \frac{1}{2} \frac{b_A^4}{b^2 + r\sigma_\theta^2} + \frac{1}{2} \frac{b_A^4}{b^2 + r\sigma_\theta^2 (1 - \rho_\theta^2)}$$ (27a)

and

$$\pi^{AD} = \frac{1}{2} \frac{b_A^4 \left(1 + H \frac{\rho_\theta \sigma_\theta}{\sigma_\nu}ight)^2}{b^2 \left[\left(1 + H \left(\frac{\rho_\theta \sigma_\theta}{\sigma_\nu} - 1\right)\right)^2 + H + r\sigma_\theta^2 (1 - H) + r\sigma_\theta^2 H \rho_\theta^2\right]}$$ (27b)

where $H = \frac{b^2 + r\sigma_\theta^2 (1 - \rho_\theta^2)}{b^2 + 2r\sigma_\theta^2 (1 - \rho_\theta^2)}$. A comparison of (27a) and (27b) suggests the following proposition.

**Proposition 4.**

*With aggregate performance measures and identical agents, the principal prefers decentralized contracting if and only if Agent A’s implicit incentives are not too extreme.*

**Proof:** See Appendix.

Our analysis in this section suggests that the use of aggregate performance measures in decentralized contracting environments gives rise to positive spillover effects. Moreover, Propositions 3 and 4 imply that spillover effects coupled with modest implicit incentives jointly
promote a preference for decentralized contracting. This suggests that aggregate performance measures potentially complement decentralized contracting practices, and perhaps more so than disaggregate measures. For instance, whereas with disaggregate measures Agent B always delivers lower profits with decentralized contacting than with centralized contracting, with an aggregate measure Agent B can potentially generate more profit with decentralized contracting than with centralized contracting (see Proposition 3). We address the potential for complementarity between aggregate performance measures and decentralized contracting in the next section.

5. Complementarities between Aggregate Performance Measurement and Decentralized Contracting

To investigate whether aggregate performance measures complement decentralized contracting more so than disaggregate measures, in this section we compare the principal’s profit with an aggregate performance measure to her profit with disaggregate measures assuming decentralized contracting is the norm.

Comparing a single aggregate measure to a pair of disaggregate measures requires a rule as to how to combine two measures into one or a formula as to how to separate an aggregate measure into two disaggregate ones. For our model, we adopt a simple aggregation rule which specifies that the aggregate measure is the arithmetic sum of two disaggregate measures. In particular, we assume that the disaggregate measures are as specified in Section 3, i.e.,

\[ y_A = b_A a_A + \varepsilon_A \] and \[ y_B = b_B a_B + \varepsilon_B, \]

and write the aggregate measure as \( Y = y_A + y_B \). To further simplify the analysis, we also assume identical agents (i.e., \( b_A = b_B = b \)) and comparable performance measures (i.e., \( \sigma^2_A = \sigma^2_B = \sigma^2 \)) so that the agents A and B are a priori interchangeable. This implies that \( Y = b(a_A + a_B) + \varepsilon_A + \varepsilon_B \) with \( \text{Var}(Y) = 2\sigma^2 \). Finally, as in
Section 3, we assume that the signal $\psi$ is correlated with agent A’s disaggregate report, \[
\text{Cov}[\psi, y_A] = \rho \sigma \sigma_v, \text{ so that } \text{Cor}[Y, \psi] = \frac{1}{2} \rho \text{ and } \text{Var}[Y | \psi] = \sigma^2(2 - \rho^2).
\]

If $Y = y_A + y_B$ as described above, then evaluating agents’ performances based on $Y$ necessarily implies a loss of performance-relevant information, i.e., on an agent-by-agent comparison, the signal-to-noise ratio decreases. Hence, it is straightforward to show that, under centralized contracting, the principal always prefers disaggregate reporting, i.e., $\pi^{AC} < \pi^{DC}$.

Our objective is demonstrate that, despite the loss of performance-relevant information, aggregate accounting can complement decentralized contracting in the sense that $\pi^{AD} > \pi^{DD}$.

From (19b), we have an expression for $\pi^{DD}$ for identical agents:

\[
\pi^{DD} = \frac{1}{2} b^2 \frac{1}{b^2 \left[1 + \frac{1}{2} \left(\frac{\sigma}{\sigma_v} - 1\right)^2 + r \sigma^2 \left(1 + \rho^2\right)\right] + \frac{1}{b^2}} \frac{1}{2} b^4 \left[1 + \frac{1}{2} \left(\frac{\sigma}{\sigma_v} - 1\right)^2 + r \sigma^2 \left(1 + \rho^2\right)\right].
\]  

(28)

We also have an expression for $\pi^{AD}$ in (27b) which, under the simplifying assumptions of this section, translates to:

\[
\pi^{AD} = \frac{1}{2} b^2 \frac{b^4 \left(1 + H \frac{\sigma}{\sigma_v}\right)^2}{\left[1 + H \left(\frac{\sigma}{\sigma_v} - 1\right)^2 + H\right] + 2 r \sigma^2 (1 - H) + r \sigma^2 H \rho^2},
\]  

(29)

where $H = \frac{\varepsilon^2 + r^2 \sigma^2 (2 - \rho^2)}{b^2 + 2 r \sigma^2 (2 - \rho^2)}$. We have:

**Proposition 5.**

*With decentralized contracting and identical agents, the principal prefers an aggregate performance measure if and only if Agent A’s implicit incentives are not too extreme.*

**Proof:** See Appendix.

In general, aggregation coarsens performance-relevant information and suggests a preference for disaggregate information. Yet, Proposition 5 suggests that, under decentralized
contracting, there is a countervailing effect. As we noted earlier in Section 4, positive spillover effects due to aggregation coupled with the implicit incentives that arise in decentralized contracting potentially motivate both agents to be more productive. If the joint effects of the positive spillovers and implicit incentives are sufficiently pronounced, then a single aggregate performance measure may be more profitable than a pair of disaggregate measures.

6. Conclusion

We examine whether accounting practices that measure the performance of different economic agents either jointly or separately influence the decision to delegate contracting rights in an organization.

In particular, we compare the profitability of a centralized structure where all contracts are centrally determined to a decentralized structure where individuals in higher tiers of a hierarchy set the contracts for others. For both disaggregate and aggregate performance measures, we identify circumstances under which a decentralized contracting structure is better than a centralized structure and vice versa. Decentralized contracting, for instance, improves risk sharing among agents in a hierarchy but also implies a loss of control. Decentralized contracting also implies that higher-tier agents (i.e., those responsible for contracting) face implicit incentives that derive from their own contracting authority rather than from their relationship with the principal. Implicit incentive of higher-tier can be beneficial or detrimental to an owner depending on the nature of information that governs the agency relationship.

With aggregate performance measures, where agents are evaluated jointly on their aggregate performance, contracts under a decentralized structure are more interdependent and incentives spill over as if both agents are responsible for both tasks. The implication is that, under some circumstances, incentives for higher-tier agents can complement or reinforce the incentives for lower-tier agents. Indeed, we find that if the spillover effects are sufficiently complementary,
then aggregate performance measures may be better than disaggregate measures despite the coarseness usually associated with aggregation.

Finally, we note that our results provide some insight about the types of performance measurement systems we observe in practice. For instance, we expect economic arrangements where most activities are organized inside the firm (e.g., vertically integrated firms) are also settings where more detailed or disaggregate accounting practices prevail. In contrast, we expect organizations that rely more heavily on suppliers and contractors beyond the boundary of the firm to employ less detailed or more aggregate accounting practices.
References


Appendix A – Proofs

Proof of Lemma 1

We solve for the optimal contract under centralized contracting and disaggregate reporting using backwards induction. Under centralized contracting, Agent B’s certainty equivalent from accepting the principal’s contract in Stage 4 is characterized by

\[ CE_B(\Psi; z_B, a_B, \hat{a}_A) = E(c_B | \Psi; a_B, \hat{a}_A) - \frac{1}{2}a_B^2 - \frac{r}{2} \text{Var}(c_B | \Psi; a_B, \hat{a}_A), \]

where \( z_B = (f_B, v_B, \delta_B) \), \( c_B \) is defined in (3) and \( \hat{a}_A \) represents Agent B’s conjecture with respect to Agent A’s action. Substituting (2) and (3) and differentiating with respect to \( a_B \) provides Agent B’s optimal choice of effort,

\[ a_B^{DC} = b_B v_B^{DC}, \]

where the superscript “DC” refers to the combination of disaggregate information and centralized contracting.10

In Stage 4, the principal chooses \( z_B = (f_B, v_B, \delta_B) \) to maximize her expected net payoff, \( (b_B a_B - c_B) \), subject to Agent B’s incentive compatibility constraint in (A2) and the individual rationality constraint that the Agent B’s certainty equivalent in (A1) be greater than his reservation certainty equivalent of zero. Substituting the IC and IR constraints and solving for the unconstrained maximization problem in terms of \( v_B \) and \( \delta_B \) yields:

\[ v_B^{DC} = \frac{\delta_B}{b_B + r \sigma_B}; \quad \delta_B^{DC} = 0. \]

In turn, Agent A’s certainty equivalent from accepting the principal’s contract in Stage 1 is characterized by

---

10 We note that agent i’s action choice is independent of the other agent’s action choice. Hence, any pair of linear contracts induces a unique dominant strategy in the subgame played by the agents (Holmstrom and Milgrom 1990).
\[ CE_A(z_A, a_A, \hat{a}_B) = E(c_A; a_A, \hat{a}_B) - \frac{1}{2}a_A^2 - \frac{L}{2} \text{Var}(c_A; a_A, \hat{a}_B), \quad (A4) \]

where \( z_A = (f_A, v_A, \delta_A) \), \( c_A \) is defined in (3) and \( \hat{a}_B \) represents Agent A’s conjecture with respect to Agent B’s action. Substituting (2) and (3) and differentiating with respect to \( a_A \) provides Agent A’s optimal choice of effort,

\[ a_A^{DC} = b_A v_A^{DC}. \quad (A5) \]

In Stage 1, the principal chooses \( z_A = (f_A, v_A, \delta_A) \) to maximize her expected net payoff, \((b_Aa_A - c_A)\), subject to Agent A’s incentive compatibility constraint in (A5) and the individual rationality constraint that the Agent A’s certainty equivalent in (A4) be greater than his reservation certainty equivalent of zero. Substituting the IC and IR constraints and solving for the unconstrained maximization problem in terms of \( v_A \) and \( \delta_A \) yields:

\[ v_A^{DC} = \frac{b_A^1}{b_A^1 + \rho \sigma_A^2}; \quad \delta_A^{DC} = 0. \quad (A6) \]

Finally, solving for the principal’s expected profit yields

\[ \pi^{DC} = \frac{1}{2} \left( \frac{b_A^1}{b_A^1 + \rho \sigma_A^2} + \frac{b_A^2}{b_A^2 + \rho \sigma_A^2} \right). \quad (A7) \]

**Proof of Proposition 1**

From (16), it is evident that \( a_A^{DD} \geq a_A^{DC} \) if, and only if, \( \frac{(1 + \rho^2)^{-1}}{\left(1 + \frac{\rho \sigma_A}{\sigma_A^2} - 1\right)^2} \leq 1 \). Rearranging terms, it follows that \( a_A^{DD} \geq a_A^{DC} \) if, and only if,

\[ \left(1 + \frac{1}{2} \left(\frac{\rho \sigma_A}{\sigma_A^2} - 1\right)\right)^2 \geq \frac{(1 + \rho^2)}{2}. \quad (A8) \]

Hence, the condition \( \frac{\rho \sigma_A}{\sigma_A^2} \geq \sqrt{2(1 + \rho^2)} - 1 \) in Proposition 1 follows easily.

**Proof of Proposition 2**
From (19) \( \pi^{DD} \geq \pi^{DC} \) if, and only if,

\[
\frac{1}{2} \frac{b^4 \left(1 + \frac{\rho^2}{\sigma^2} \right)}{b^4 \left(1 + \frac{\rho^2}{\sigma^2} \right) + \rho^2} \geq \frac{b^4}{b^4 + \rho^2} \tag{A9}
\]

This is equivalent to:

\[
\left( \frac{\rho^2}{\sigma^2} + 1 \right)^2 > 2(1 + \rho^2) \left( 1 + \frac{\rho^2}{b^4 (b^4 + 3\sigma^2)} \frac{r^2 \sigma^4 (b^4 + 3\sigma^2)}{(b^4 + 3\sigma^2)^2} \right) \tag{A10}
\]

which implies that \( \pi^{DD} \geq \pi^{DC} \) if, and only if,

\[
\frac{\rho^2}{\sigma^2} \geq \sqrt{2(1 + \rho^2)(1 + k_1)} - 1 \tag{A11}
\]

where \( 0 < k_1 = \frac{r^2 \sigma^4 (b^4 + 3\sigma^2)}{b^4 (b^4 + 3\sigma^2)^2} < \frac{1}{2} \).

**Proof of Proposition 3**

**Part (i)**

From (24), \( a_A^{AD} > a_A^{AC} \) if and only if

\[
\frac{b_A^2 \left( 1 + \frac{b_2}{b_1} \frac{H}{(1 + H \frac{\rho^2}{\sigma^2} - 1)} \right)}{b_A^2 \left( 1 + \frac{b_2}{b_1} \frac{H}{(1 + H \frac{\rho^2}{\sigma^2} - 1)} \right) + r \sigma^2} \geq \frac{b_A^2}{b_A^2 + r \sigma^2} \tag{A12}
\]

where \( H = \frac{b^4 + 3\sigma^2 (1 - \rho^2)}{b^4 + 2\rho^2 (1 - \rho^2)} \). Rearranging and simplifying, we have: \( a_A^{AD} > a_A^{AC} \)

\[
\Longleftrightarrow \quad b_A^2 b_2 \frac{H^2 \left( \frac{\sigma^2}{\rho^2} - 1 \right)}{(1 + H \frac{\rho^2}{\sigma^2} - 1)^2} + b_A^2 r \sigma^2 \left( 1 + \frac{b_2}{b_1} \frac{H}{(1 + H \frac{\rho^2}{\sigma^2} - 1)} - \frac{(1 + H (1 - \rho^2))}{(1 + H (1 - \rho^2))} \right) \geq 0 \tag{A13}
\]

\[
\Longleftrightarrow \quad \left( \frac{\rho^2}{\sigma^2} - 1 \right)^2 H r \sigma^2 + \left( \frac{\rho^2}{\sigma^2} - 1 \right) \left( H + 2 r \sigma^2 + \frac{b_2}{b_1} H r \sigma^2 \right) + r \sigma^2 \left( 1 + \frac{b_2}{b_1} - \rho^2 \right) \geq 0 \tag{A14}
\]

The quadratic in terms of \( \frac{\rho^2}{\sigma^2} - 1 \) has no positive roots; this implies that the solution for \( \frac{\rho^2}{\sigma^2} \)

that solves (A14) is less than one. Solving for the quadratic yields:

\[
a_A^{AD} > a_A^{AC} \quad \text{if and only if} \quad \frac{\rho^2}{\sigma^2} \geq 1 - k_2 \tag{A15}
\]
where \( 0 < k_2 = \left[ \frac{1}{2} \left( \frac{b_2}{b_1} + \frac{1}{r_\sigma^2} \right) - \frac{1}{4} \left( \frac{b_2}{b_1} + \frac{1}{r_\sigma^2} \right)^2 - \frac{(1 - \rho_2^2 + k_2^2)}{H} \right] < 1. \) (A16)

Part (ii)

From (25), \( a_B^{AD} > a_B^{AC} \) if and only if

\[
\frac{b_B^2}{b_B^3} \left( \frac{1 + \frac{\rho_2 \sigma_2}{\sigma_\psi}}{H} \right)^2 - \frac{b_A^2}{b_B^3} \left( \frac{1 + \frac{\rho_2 \sigma_2}{\sigma_\psi}}{H} \right) \left( 1 + \frac{\rho_2 \sigma_2}{\sigma_\psi} \right) \left( 1 + \frac{r \sigma_\theta^2 (1 - \rho_2^2)}{H^2} \right) \leq 0. \]  
(A17)

Rearranging and simplifying, we have: \( a_B^{AD} > a_B^{AC} \)

\[
\Leftrightarrow b_A^2 \left( \frac{1 - H^2 + \frac{\rho_2 \sigma_2}{\sigma_\psi}}{H} \right) - b_B^2 \left( \frac{1 - H^2 + \frac{\rho_2 \sigma_2}{\sigma_\psi}}{H} \right) \left( 1 + \frac{r \sigma_\theta^2 (1 - \rho_2^2)}{H^2} \right) \left( 1 - H^2 + \frac{\rho_2^2}{1 - \rho_2^2} \right) \leq 0. \]  
(A18)

(A18) requires that \( \frac{(1 - H^2 + \frac{\rho_2 \sigma_2}{\sigma_\psi})}{(1 + \frac{r \sigma_\theta^2 (1 - \rho_2^2)}{b_\psi^2})} < (1 + \frac{r \sigma_\theta^2 (1 - \rho_2^2)}{b_\psi^2}) \); otherwise the expression is always positive.

Hence, \( \frac{\rho_2 \sigma_2}{\sigma_\psi} < \frac{2 H - 1 + \frac{r \sigma_\theta^2 (1 - \rho_2^2)}{b_\psi^2}}{H^2 + \frac{\rho_2^2}{1 - \rho_2^2}} \) which establishes that Agent A’s implicit incentives cannot be too favorable.

To establish existence, we solve (A18) for equality to obtain:

\[
\frac{\rho_2 \sigma_2}{\sigma_\psi} = \frac{- \frac{(1 - H^2 + \frac{\rho_2 \sigma_2}{\sigma_\psi})}{2} \left( 1 + \frac{r \sigma_\theta^2 (1 - \rho_2^2)}{b_\psi^2} \right) \left( 1 + \frac{r \sigma_\theta^2 (1 - \rho_2^2)}{b_\psi^2} \right)^2 - \frac{r \sigma_\theta^2 (1 - \rho_2^2)}{b_\psi^2} \left( 1 + \frac{r \sigma_\theta^2 (1 - \rho_2^2)}{b_\psi^2} \right) \left( 1 - H^2 + \frac{\rho_2^2}{1 - \rho_2^2} \right) \left( 1 - H^2 + \frac{\rho_2^2}{1 - \rho_2^2} \right)}{2} \]  
(A19)

which has a positive real root only if \( b_A^2 \), which captures the strength of the spillover effect for Agent B, is sufficiently large. Hence,

\[
0 < \frac{\rho_2 \sigma_2}{\sigma_\psi} \leq \frac{2 H - 1 + \frac{r \sigma_\theta^2 (1 - \rho_2^2)}{b_\psi^2}}{H^2 + \frac{\rho_2^2}{1 - \rho_2^2}}. \]  
(A20)

Proof of Proposition 4

Using (27a) and (27b), \( \pi^{AD} \geq \pi^{AC} \) if and only if
where $H = \frac{b^2 + r\sigma^2_0(1-\rho_0^2)}{b^2 + 2r\sigma^2_0(1-\rho_0^2)}$. Rearranging and simplifying, $\pi^{4D} \geq \pi^{4C}$

$$
\Leftrightarrow \left(1 + H \frac{\rho\sigma_\theta}{\sigma_\nu}\right)^2 \left(r^2\sigma_\theta^4(1-\rho_\theta^2) - b^4\right) + 2\left(1 + H \frac{\rho\sigma_\theta}{\sigma_\nu}\right)Hb^2 \left[2b^2 + r\sigma^2_0(2-\rho_0^2)\right] \\
- \left[2b^2 + r\sigma^2_0(2-\rho_0^2)\right]\left(b^2H(1+H) + r\sigma^2_0[1-H(1-\rho_0^2)]\right) \geq 0
$$

(A22)

When $b^4 < r^2(1-\rho_\theta^2)\sigma^4_\theta$, the quadratic in (A22) has one positive root (and one negative root). Hence, $\pi^{4D} \geq \pi^{4C}$ if and only if $\frac{\rho\sigma_\theta}{\sigma_\nu} \geq R_L$ where $R_L$ solves (A22) with equality.

When $b^4 > r^2(1-\rho_\theta^2)\sigma^4_\theta$, the quadratic equation in (A22) has either 2 positive roots or 2 complex roots. For large values of $\frac{\rho\sigma_\theta}{\sigma_\nu}$, the quadratic is negative. Hence, to establish that the roots are real, it suffices to show that there are values of $\frac{\rho\sigma_\theta}{\sigma_\nu}$ such that (A22) is satisfied. We note that $\pi^{4D} - \pi^{4C}$ achieves its maximum when $\frac{\rho\sigma_\theta}{\sigma_\nu} = \frac{b^2H^2 + r(1-H+H\rho^2)\sigma^2_0}{b^2H^2}$, and at this value, $\pi^{4D} \geq \pi^{4C}$. Hence, when $b^4 > r^2(1-\rho_\theta^2)\sigma^4_\theta$, $\pi^{4D} \geq \pi^{4C}$ if and only if $\frac{\rho\sigma_\theta}{\sigma_\nu} \in [R_L, R_u]$ where $R_L, R_u$ are the two roots solve (A22) with equality.

\[ \square \]

\textbf{Proof of Proposition 5}

From (28) and (29), $\pi^{4D} > \pi^{DD}$ if and only if

\begin{align*}
1 & \frac{b^4\left(1 + H \frac{\rho\sigma_\theta}{\sigma_\nu}\right)^2}{2b^2\left[1 + H\left(\frac{\rho\sigma_\theta}{\sigma_\nu} - 1\right)^2 + H\right] + 2r\sigma^2(1-H) + r\sigma^2H\rho^2} > \\
& \frac{b^4\left(1 + \frac{3}{2}(\frac{\rho\sigma_\theta}{\sigma_\nu} - 1)^2 + r\sigma^2\left(1 + \frac{\rho^2}{2}\right)\right)}{2b^2\left(1 + \frac{3}{2}(\frac{\rho\sigma_\theta}{\sigma_\nu} - 1)^2 + r\sigma^2\left(1 + \frac{\rho^2}{2}\right)\right)} + \frac{b^4}{2b^2 + r\sigma^2 + \frac{\rho^2\sigma_\theta}{(b^2 + r\sigma^2)^2}} \tag{A23}
\end{align*}
With linear transformation, we note that (A23) is satisfied if and only if

$$\Delta = A_0 + A_1 \left( \frac{c_0}{c_v} \right) + A_2 \left( \frac{c_0}{c_v} \right)^2 A_3 \left( \frac{c_0}{c_v} \right)^3 + A_4 \left( \frac{c_0}{c_v} \right)^4 \geq 0.$$  \hspace{1cm} (A24)

where $\Delta$ is a quartic polynomial with the following properties: (i) $\Delta(\frac{c_0}{c_v} = 0) < 0$ because $A_0 < 0$, (ii) $\Delta(\frac{c_0}{c_v} \to \infty) = -\infty < 0$ because $A_4 < 0$, and (iii) zero, two, or potentially four positive roots because the signs of $A_1, A_2, A_3, A_4$ are ambiguous and depend on the relative magnitudes of $b^2$ and $r \sigma^2$. For instance, when $r \sigma^2$ is sufficiently small, $A_1 > 0$ and $A_4 < 0$. Conversely, when $r \sigma^2$ is sufficiently large, $A_1 < 0$ and $A_4 > 0$.

Hence, to establish the proposition, we first demonstrate existence of a $\frac{c_0}{c_v} > 0$ that satisfies (A23) via a numerical example. Consider a setting where $b = 1$, $r = 1$, $\sigma = 1$, and $\rho = 1/2$. It follows then $\pi^{DD} \geq \pi^{DD}$ as long as $\frac{c_0}{c_v} = \frac{1}{2\sigma} \in [4.1563, 6.9416]$.

Given existence, the quartic implies that the solution necessarily lies in an interval $(J_1, J_2)$ where $J_1$ and $J_2$ are two roots that solve the quartic. Hence, implicit incentives are not extreme. Finally, while not required for the proof of the proposition, we can also show that this interval is unique (i.e., the quartic has only two positive roots). \hfill \Box
Appendix B – Summary of key notation

- $x$: output
- $y_i$: disaggregate performance measure of agent $i$, $i=\text{A,B}$
- $Y$: aggregate performance measure of agents A and B
- $\Psi$: signal about agent A’s action
- $a_i$: activity undertaken by agent $i$
- $b_i$: marginal productivity of agent $i$
- $\theta$, $\varepsilon_i$, $\psi$: error terms
- $\sigma^2$, $\sigma^2_i$, $\sigma^2_{\psi}$: variance of error terms
- $\rho$, $\rho_\theta$: correlation coefficients
- $r_i$: agent $i$’s coefficient of absolute risk aversion
- $z_i$: contract offered to agent $i$
- $c_i$: compensation paid to agent $i$
- $f_i$: fixed salary of agent $i$
- $v_i$, $\delta_i$: incentive rates for agent $i$
- $h$, $H$: ratio of incentive rates
- $\pi$: principal’s expected net profit