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Decentralization and the Gains from Monitoring

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Abstract

This paper analyzes the delegation of contracting capacity in a moral hazard environment with sequential production in a project which involves a principal and two agents. The agent in charge of the final production can obtain soft information about the other agent's effort choice by investing in monitoring. I investigate the circumstances under which it is optimal for the principal to use a centralized organization in which she designs the contracts with both agents or to use a decentralized organization in which she contracts only one agent, and delegates the power to contract the other agent. It is shown that in this setting a decentralized organization can be superior to a centralized organization. This is because the principal is better off under monitoring and the incentives for an agent to invest in monitoring can be higher in a decentralized organization. The circumstances under which this is true are related to the monitoring costs and the importance of each agent for production. The results explain the recent application of the design-build method in public procurement.

Journal of Economic Literature Classification Numbers: D23, D82, L14, L22.
Keywords: Decentralization of Contracting, Monitoring, Moral Hazard.

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1 Introduction

Motivation. The question whether organizations should be centralized or decentralized has been an important topic in economic theory for the last two decades. Although decentralization is a common feature of economic reality, theory has had difficulty in finding an explanation for the phenomena. This difficulty can be explained by the 'Revelation Principle', which states that under some specific assumptions, a centralized organization cannot be inferior to a decentralized one because "the outcome of any decentralized organization can be mimicked by a centralized organization in which the responsibility of each agent is merely to communicate their information to a central authority and await for instructions on what to do" (Mookherjee [2006, p. 369]).[1] Using this result as a starting point, the literature has relaxed the assumptions underlying the Revelation Principle in an attempt to explain why decentralization may be a better choice for the principal. These assumptions are: (1) the absence of communication, information processing and contract complexity costs (Baron and Besanko [1992], Melumad et al. [1995, 1997], Radner [1993], van Zandt [1996]), (2) the absence of collusion (Laffont and Martimort [1998], Baliga and Sjöström [1998], Macho-Stadler and Pérez-Castrillo [1998], Faure-Grimaud et al. [2003]) and (3) complete commitment and the absence of renegotiation (Poitevin [1995], Faure-Grimaud and Martimort [2001], Jelovac and Macho-Stadler [2002]). A specific topic in this literature is contract delegation, where a centralized organization amounts to a structure where contracts are signed by a central authority while decentralization means that the right to contract is delegated. Though subcontracting also is a pervasive feature, economic theory even had more problems to explain the superiority of decentralization in this context. The contribution of this paper falls in the third strand of the general literature on decentralization. It gives a new explanation for the use of decentralized contracting structures. They can be used by the principal to commit to higher payments to an agent. This provides higher incentives for an agent to invest in information acquisition whose benefits compensate the cost due to the loss of control that decentralization implies for the principal.

Framework. A very stylized model is used to examine the advantages of centralized and decentralized organizations. Two agents work jointly on a project for a principal. The agents choose their inputs sequentially: first agent 1 and then agent 2. They differ in terms of productivity and unit costs. The contract designer faces moral hazard problems because efforts are non–observable and non–verifiable. However, when agent 2 invests in monitoring, he can observe agent 1's effort. The effort still remains unverifiable, however, so contracts cannot be based on this information but monitoring enables the agents' efforts to be better coordinated. Because of limited liability and moral hazard, agents obtain informational rents under efficient contract design. The principal chooses between two organizations: a centralized organization

[1] For a statement of the Revelation Principle see Myerson [1982].

in which she controls the contracts with both agents and a decentralized organization in which she delegates the contract design with agent 1 to agent 2. The principal's problem is to choose the organization which gives her the highest expected utility.

Intuition and Results. The organizational choice for the principal is shown to depend on the trade-off between the gain in information acquisition incentives and the loss of control which decentralization provides. Let us consider these two effects separately. On the one hand, monitoring increases the informational rents of both agents and the principal. Therefore monitoring is efficient when the gains cover the costs (Proposition 1). Furthermore, agent 2 gets greater informational gains from monitoring in a decentralized organization than in a centralized one, because in the former he obtains a higher increases in his informational rent. On the one hand, in a decentralized organization, the principal delegates contracting with agent 1 to agent 2 and, therefore, cannot control it directly. This involves a cost because agent 2 will use his control over agent 1's contract to reallocate efforts and increase his rent (Proposition 2). The advantage of a decentralized organization in this setting is that it increases agent 2's incentives to invest in monitoring. The principal cannot credibly commit to refund the investment because agent 2's investment is non-contractible and done before payments are realized so that agent 2 faces a hold-up problem. Contract delegation is a way to overcome this commitment problem. If contracts are decentralized, agent 2 knows that he obtains a higher informational rent which in turn increases his incentives to invest in monitoring.

It is shown that the choice of efficient organization depends on two factors: the cost of monitoring and the importance of agent 2's contribution for the success of the project (Proposition 3). On the one hand, if monitoring costs are low, agent 2 has enough incentives to monitor irrespective of the organizational choice. In this case the Revelation Principle applies and centralization is the optimal organizational choice. On the other hand, if monitoring costs are high, the costs are always above the benefits and there is no monitoring in either organization. Again, the Revelation Principle means that centralization is superior to decentralization. Finally, for intermediate values of monitoring costs, because agent 2's incentives to monitor are higher in a decentralized organization, the organizational choice determines whether there is monitoring or not. In this case agent 2 only invests in monitoring if the principal chooses a decentralized structure. A decentralized organization is optimal when the gains in information acquisition incentives outweigh the cost of the loss of control. The more important agent 2 is to the success of the project, the more the gains will increase and the more the cost of the loss of control will decrease. Therefore, when agent 2 is sufficiently important for the success of the project and monitoring costs are neither high nor low, decentralization is the optimal organization choice for the principal.

Practical Application. The results of the paper help to understand the coexistence of centralized and decentralized organizations in numerous cases. One of these is the construction sector. We find that contractors (principals) who order a construction facility can adopt either policy: they contract directly with an architect (agent 1) and a constructor (agent 2), or they contract only a constructor who himself contracts the architect. Centralization has been and still is the prominent method used in public procurement. However, recently, with the implementation of the design-build method in which the public agency often only contracts a single agent who subcontracts services from other agents, decentralization has become widely used.[2] Decentralization implies that the constructor extracts part of the architect's rent, which means that the architect makes less effort at delivering a good blueprint.[3] This yields an efficiency loss to the principal. However, because the constructor obtains a higher rent under decentralization his incentives to monitor the architect's effort also increase. Indeed, we observe that under decentralization of contracts the architect is often directly employed by the constructor (who makes an investment in integration), which makes monitoring more efficient than in a centralized structure in which the architect has his own office. Our results suggest that a decentralized structure should be used when the constructor's contribution is especially important for the success of the project and the cost of integration is neither too high nor too low. Therefore, for small firms and small projects (where the relative costs of integration are high) we find no integration and the principal has to contract both agents independently. This is the choice of most private promoters in housing construction. For large firms and large projects (where the relative costs of integration are low) the integration or monitoring decision does not depend on the choice of organization. Again, independent contracting is the superior choice in this case. This is what we find in prestigious architectural projects in which project planning and execution are assigned independently. Finally, for intermediate firm sizes and projects, decentralization can be superior to centralization. In this case, integration allows more efficient coordination of planning and construction activities than centralization. We find decentralized organizations, for example, in transportation projects, the construction of water and waste water plants or electric power facilities.[4]

Contribution and Relation to the Literature. The paper is related to two strands of the literature. First, it is related to the literature on delegation under incomplete contracting. As the theory of incomplete contracts points out, the form of contracts is limited by the existence of institutional restrictions, the costs of writing the contracts, or the lack of information when signing the agreements (Tirole [1999]). In this paper the crucial incompleteness comes from the fact that agent 2's monitoring decision is not contractible. The fact that a noncontractible investment decision can lead to an inefficient investment when there is ex-post negotiation is known as the hold-up problem (Klein et al. [1978]). Grossman and Hart [1986], Hart and

[2] See Shore and Commander [2003] for this.

[3] Indeed this is a major source of conflict in the application of the design-build method as indicated by Shore and Commander [2003].

[4] See Shore and Commander [2003] for details.

Moore [1990], and Aghion and Bolton [1992] have shown that the correct allocation of property rights can solve this problem. While these models are based on the relationship between two parties, in this paper the hold-up problem comes from the principal's inability to commit not to tax away the benefits generated by agent 2's monitoring investment concerning a third party's effort. The new insight is that contract delegation can be used by the principal as an ex-ante commitment to pay agent 2 a higher informational rent. This increases his incentives to invest in monitoring. Some authors also have analyzed how the delegation of authority affects an agent's incentive to invest in monitoring. Aghion and Tirole [1997] show in a single-principal single-agent framework that delegation of authority from the principal to the agent credibly increases the agent's incentives to acquire information about a project. Dessein [2002] in a similar setting analyses how the delegation of authority affects the use of private information of a better informed agent. He shows that the principal prefers to delegate control to the agent as long as the incentive conflict is not too large relative to the principal's uncertainty about the environment. The main difference to this literature is that delegation of authority in this paper merely implies the right to subcontract another agent (agent 2 subcontracts agent 1). So here a principal multi-agent model is applied. Furthermore, opposite to Aghion and Tirole [1997] information acquisition is not about the value of the project but about the effort choice of the other agent. Directly, this neither improves the value of the project nor changes agent 2's effort choice because he is a follower of agent 1's effort choice. However, the direct effect of agent 2's investment is that agent 1 will modify his effort choice because he knows that upon agent 2's investment his own effort will be observed.

Another link to the incomplete contracting literature is the exclusion of message games. If agents share observable but unverifiable information, Maskin [1977] has shown that the principal can extract this information by designing a mechanism under which agents send messages about their information. This is because the mechanism implements truthful revelation as a Nash equilibrium. Moore and Repullo [1988] have shown that this can be also achieved by subgame perfect implementation. Following this mechanism design approach some authors have derived results under which delegation performs as well as the best message-dependent contract. In a principal multiple-agent model with moral hazard this has been done by Baliga and Sjöström [1998], and in the context of a hold-up problem by Roider [2006]. Following the incomplete contracting literature in this paper I assume from the beginning that the principal cannot ask for reports. The incomplete contracting literature has justified this because the results from the complex mechanism-design approach rely to a great extend on the rationality of all players and are not always renegotiation-proof though the main criticism to this approach is that this kind of mechanisms are not observed in practice (Bolton and Dewatripont [2005]).

Second, the paper is related to the literature on contract delegation. Models that compare centralized and decentralized contracting structures where the principal faces a moral hazard problem with two agents are analyzed in Baliga and Sjöström [1998], Macho–Stadler and Pérez–

Castrillo [1998], and Jelovac and Macho-Stadler [2002].[5] Macho–Stadler and Pérez–Castrillo (1998) show that contract delegation is equivalent to the centralization of contracting when the contract designer cannot prevent collusive behavior in the centralized structure. The disadvantage of delegation lies in the loss of control which implies additional costs for the contract designer because of collusive behavior. However, in their paper agents are not better informed than the principal. In Baliga and Sjöström [1998] agents can share information that is not available for the principal. They show that decentralization may be preferable if agents have limited liability, share hard information, can collude and base side-contracts on that information. A difference to their paper is that here information is soft.[6] Therefore collusion is no issue in this paper.[7] A major difference with Jelovac and Macho-Stadler [2002] is that while they assume that the principal cannot commit to sign all contracts before the actions are chosen, I assume that contracts are signed before the agents make their effort choices. Therefore, there is no commitment advantage in this sense in a decentralized organization. However, the main difference to these models is the assumption of this paper that an agent can invest in information acquisition. So, the paper gives a completely new explanation for the superiority of contract decentralization compared to contract centralization.

Outline. The paper is organized as follows. Section 2 sets out the model. Section 3 presents the results and the subsections provide the solutions of the corresponding stage games. Section 4 concludes. Proofs are generally confined to the Appendix.

2 The model

2.1 Description of the model

Production. The principal (P) hires two agents (A1 and A2) in a project to produce output x. To produce this output agent 1 and then agent 2 choose their effort e_i, $i = 1, 2$, where $e_i \in [0, 1]$. Output x depends on the agents' efforts e_1 and e_2, and a noise term through a production function. For simplicity, it is assumed that x can take two values, $x \in \{0, \overline{x}\}$. Let

[5] For an overview of the literature that compares centralized and decentralized contracting under adverse selection see Mookherjee [2006] and Poitevin [2000].

[6] As pointed out by Baliga [1999], anecdotal evidence suggests that information or at least part of it is often unverifiable. This is either because all the information cannot be measured accurately or part of the information is manipulated by one of the agents.

[7] As pointed out by Itoh [1993], when efforts cannot be monitored (or information about efforts is soft), the role of side contracting is only that of mutual risk sharing. Because agents are assumed to be risk neutral in the model of this paper they cannot benefit by side contracting. So, there is no incentive to collude.

$P(e_1, e_2)$ be the probability of obtaining the high outcome $\overline{x}$ (the project is a success) when efforts e_1 and e_2 are chosen. Let $P(e_1, e_2) = e_1^{\alpha} e_2^{\beta}$ with $\alpha > 0$, $\beta > 0$, $\alpha + \beta < 1$. So, higher values of α and β indicate situations in which the agents efforts are more productive in the sense that the probability of having a success increases.[8]

Information and contracts. Output is the only publicly observable and contractible variable. Hence agents are compensated by the principal with a wage or payment schedule contingent on output. The payment for a high outcome, is $w_i(\overline{x}) = \overline{w}_i$, and the payment for a low outcome is normalized zero, $w_i(0) = 0$.[9] Efforts are non-contractible and non-observable. However, upon an investment of size I agent 2 can observe agent 1's effort choice. Monitoring agent 1's effort does not enable contracts to be based on this information because information is soft. Agent 2's investment in monitoring generates a signal σ which is publicly observable but also not contractible. If agent 2 invests in *m*onitoring $\sigma = m$, when he does *n*ot invest in monitoring $\sigma = n$. Thus the investment under monitoring is $I_m = I$ and under no monitoring $I_n = 0$. It is assumed that all payments must be non-negative which can be interpreted as a limited liability assumption due to institutional restrictions.

Utility and payoffs. Agents are risk neutral and have additively separable utility functions. Agent i's expected utility is given by

$$\begin{aligned} EU_{1,\sigma} &= P(e_{1,\sigma}, e_{2,\sigma})\overline{w}_1 - ce_{1,\sigma} \\ EU_{2,\sigma} &= P(e_{1,\sigma}, e_{2,\sigma})\overline{w}_2 - ce_{2,\sigma} - I_\sigma \end{aligned}$$

where $c > \overline{x}$ indicates agent i's unit cost of effort.[10] The reservation utility of agent i is denoted $\underline{U}_i$ and normalized zero. The principal is assumed risk neutral. The objective of the principal is to maximize

$$EU_{P,\sigma} = P(e_{1,\sigma}, e_{2,\sigma})(\overline{x} - \overline{w}_1 - \overline{w}_2).$$

Organizational structures. The principal chooses between two organizational structures. She can either contract both agents directly, or delegate the contracting of agent 1 to agent 2. We also say that she chooses between a centralized organization (C) and a decentralized

[8] As is shown by Jelovac and Macho-Stadler [2002], without further assumptions about the functional form of $P(e_1, e_2)$ no general insights about the comparisons of structures can be obtained. Baliga and Sjöström [1998] also analyze a special model in which they assume that effort can attain only two values.

[9] As pointed out by a referee, this can be done without loss of generality. If the payment for a low outcome realization were denoted $w_i(0) = \underline{w}_i$, we would easily obtain $\underline{w}_i = 0$ as a result. Therefore, the simplification used in the paper has the advantage that we save on notation without losing generality.

[10] The assumption that both agents have the same unit cost of effort is not essential for the results. The assumption $c > \overline{x}$ guarantees that in equilibrium efforts are strictly less than unity which means that we have no border solutions.

organization (D), respectively. In a centralized structure the principal solves

$$\max_{\overline{w}_1 \geq 0, \overline{w}_2 \geq 0} EU_{P,\sigma} = P(e_{1,\sigma}, e_{2,\sigma})(\overline{x} - \overline{w}_1 - \overline{w}_2)$$

and in a decentralized structure she solves

$$\begin{aligned} \max_{\overline{w}_2 \geq 0} EU_{P,\sigma} &= P(e_{1,\sigma}, e_{2,\sigma})(\overline{x} - \overline{w}_2) \\ \text{s.t. } \overline{w}_1 &\in \arg\max_{\overline{w}_1 \geq 0} EU_{2,\sigma} = P(e_{1,\sigma}, e_{2,\sigma})(\overline{w}_2 - \overline{w}_1) - ce_{2,\sigma} - I_\sigma \end{aligned}$$

where $e_{1,\sigma} = e_{1,\sigma}(\overline{w}_1, \overline{w}_2)$ and $e_{2,\sigma} = e_{2,\sigma}(\overline{w}_1, \overline{w}_2)$ denote the equilibrium effort levels chosen by the agents.

Timing. At stage 1 of the game, the principal decides whether she contracts both agents directly (centralization) or whether she delegates the contracting of agent 1 to agent 2 (decentralization). At stage 2, agent 2 decides whether to invest amount I which allows him to monitor agent 1's production effort or to invest nothing (which implies that he ignores this effort). At stage 3, after agent 2's investment decision has been observed, the output contingent contracts between the principal and the agents are signed. At stage 4, agent 1 chooses his effort. At stage 5, agent 2 makes his effort choice, which is contingent on agent 1's effort choice if agent 2 has invested in monitoring. Finally, the outcome is realized and the agents are paid.

2.2 Practical Application

The assumptions of the model can be discussed in the context of the construction example. First, note that incentive contracts are explicitly defined as types of contracts in public procurement. An example is the federal acquisition regulation (FAR) in the US.[11] Furthermore, incentives are often given implicitly by including past performance in public projects as a criteria for eligibility for future projects.[12] Second, though in many projects design and construction are separated into several phases, recently, for more and more projects contracts are awarded before both agents complete their efforts. This is due to such economic factors as "a greater number of complex transactions at the inception of projects, which create a desire for more definitive budget plans early in the project" (Shore and Commander [2003, p. 217]). Third,

[11] The FAR is the primary regulation used by all Federal Executive agencies to acquire supplies and services with appropriated funds. It became effective on April 1, 1984, and is issued within applicable laws under the joint authorities of the Administrator of General Services, the Secretary of Defense, and the Administrator for the National Aeronautics and Space Administration. In the March 2005 edition, FAR [2005] further on, subpart 16.4 is on incentive contracting.

[12] See FAR [2005], subpart 36.3.

though the FAR generally prevents construction contracts from being awarded to a single firm that supplies both architectural and engineering services (i.e. requires contract centralization), most states have legislations that allow for exceptions like the use of the design-build method (i.e. allow contract decentralization).[13] This means that there are two types of structures: centralized with two independent contractors or decentralized with a general contractor that subcontracts design or which supplies both services as an integrated design-construction firm. Furthermore, legislation does not apply to specific projects but describes exemptions in general terms. For example, many states in the US have agreed to use the design-build method for constructing water and waste water plants (Shore and Commander [2003, p. 218]). This allows the principal to commit ex-ante to the use of a centralized or decentralized structure such as is assumed in this paper. Fourth, we observe "an increase in technological complexity and innovation in building material components and systems, which causes product suppliers and fabricators to take on more responsibility for design and quality control" and the existence of "growing concern about disputes and litigation" (Shore and Commander [2003, p. 217]), which indicates that design and construction efforts are complementary and only partly verifiable.

Finally, effort coordination between designer and engineering firms becomes more and more important. This includes "the need (for the engineer or constructor) to visualize and brainstorm the project with the architect at an early stage" and "to discuss ideas while the construction documentation continues" (Wilking, B. [2003, p. 187]). This gives potential scope for monitoring. Indeed, we observe that changes in legislation have led firms to invest in vertical integration providing both design and building activities. One of the reasons for this is that the benefits from a better effort coordination with the architect are higher for a contractor that is a general contractor (i.e. subcontracts the architect) than for a constructor that is a simple contractor. The monitoring investment I may be the salary of supervisors who monitor agent 1's effort and inform agent 2, the installation of a costly monitoring technology, and activities that guarantee the coordination of efforts such as the participation in preconstruction conferences or coordinated site visits, for example. Notice also that the constructor (agent 2) must invest before actions are taken and that his investments are observable for the architect but at least partly non-verifiable and, hence, non-contractible.

3 Results

As usual, the game is solved by backward induction. We start by analyzing the effort choice contingent on agent 2's monitoring decision. Then, we determine the optimal wage contracts in

[13] See FAR [2005], article 36.209 and Shore and Commander [2003] for this. Lam et al. [2006] report that more than one-third of the construction projects in the US and up to 50% in Japan use the design-build approach.

a centralized and a decentralized organization, respectively. Next, agent 2's monitoring decision is analyzed. Finally, we determine the optimal organizational choice as a function of agent 2's incentives to invest in monitoring.

3.1 Effort choice

First, I analyze the two final stages of the game which are common in the centralized and the decentralized structure. If agent 2 makes no investment and therefore does *not* monitor agent 1's effort choice ($\sigma = n$), even though efforts are chosen sequentially, the subgame at stage 4 is equivalent to a simultaneous effort choice game:

$$\begin{aligned} e_{1,n} &\in \arg\max_{a_1} P(a_1, e_{2,n})\overline{w}_1 - ca_1 && (1) \\ e_{2,n} &\in \arg\max_{a_2} P(e_{1,n}, a_2)\overline{w}_2 - ca_2 \ . && (2) \end{aligned}$$

On the other hand, if agent 2 invests the amount I which enables him to *monitor* agent 2's effort choice ($\sigma = m$), at stage 5, agent 2 chooses his effort as a function of agent 1's effort and his own wage:

$$e_{2,m} \in \arg\max_{a_2} EU_2 = P(a_1, a_2)\overline{w}_2 - ca_2 - I. \qquad (3)$$

At stage 4, agent 1 chooses his effort by anticipating the reaction of agent 2 to his own effort choice:

$$e_{1,m} \in \arg\max_{a_1} EU_1 = P(a_1, e_{2,m})\overline{w}_1 - ca_1. \qquad (4)$$

Given our assumptions about the production function, we can state the following lemma.

Lemma 1. *The SPNE effort levels at stage 4 are:*

$$\begin{aligned} e_{1,\sigma} &= \gamma_\sigma^{1-\beta}\lambda\alpha c^{-1}\left(\overline{w}_1^{1-\beta}\overline{w}_2^{\beta}\right)^{\frac{1}{1-\alpha-\beta}} \text{ and} \\ e_{2,\sigma} &= \gamma_\sigma^{\alpha}\lambda\beta c^{-1}\left(\overline{w}_1^{\alpha}\overline{w}_2^{1-\alpha}\right)^{\frac{1}{1-\alpha-\beta}} , \ \sigma \in \{n, m\} , \end{aligned}$$

where $\lambda = \left(\alpha^\alpha\beta^\beta c^{-(\alpha+\beta)}\right)^{\frac{1}{1-\alpha-\beta}}$, $\gamma_n = 1$ *and* $\gamma_m = (1-\beta)^{-\frac{1}{1-\alpha-\beta}}$. [14]

Conditions (1) and (2) are the incentive compatibility constraints when agent 2 does not monitor agent 1's effort, and (3) and (4) are the incentive compatibility constraints under

[14] Notice that $\overline{w}_i$ here denotes the net wage of agent i. As the reader will see below, the net payments coincide with gross payments in a centralized structure. However, in a decentralized structure, agent 2 subcontracts agent 1. Therefore, part of the gross wage payments he receives must be transferred to agent 1.

monitoring. The equilibrium effort of each agent increases with his own wage and with his partner's salary. This is because an increase in the partner's salary means that the partner chooses higher effort which makes a higher outcome more likely and thereby increases the marginal benefit of own effort. Given the effort levels in Lemma 1, the expected utilities of the principal and the two agents are given by:

$$\begin{aligned} EU_{P,\sigma} &= \gamma_\sigma^\alpha \lambda \left(\overline{w}_1^\alpha \overline{w}_2^\beta\right)^{\frac{1}{1-\alpha-\beta}} (\overline{x} - \overline{w}_1 - \overline{w}_2) && (5) \\ EU_{1,\sigma} &= \gamma_\sigma^\alpha \left(1 - \gamma_\sigma^{1-\alpha-\beta}\alpha\right) \lambda \left(\overline{w}_1^{1-\beta} \overline{w}_2^\beta\right)^{\frac{1}{1-\alpha-\beta}} && (6) \\ EU_{2,\sigma} &= \gamma_\sigma^\alpha (1-\beta) \lambda \left(\overline{w}_1^\alpha \overline{w}_2^{1-\alpha}\right)^{\frac{1}{1-\alpha-\beta}} - I_\sigma. && (7) \end{aligned}$$

In addition to the incentive constraints (1) and (2), and (3) and (4), respectively, the contracts to agents 1 and 2 must satisfy the participation constraints $EU_i \geq 0$, $i = 1, 2$, and the limited liability constraint $\overline{w}_i \geq 0$. From (6) we see that the participation constraint holds whenever the limited liability constraint is fulfilled. From (7) we see that in case of agent 2, additionally, investment costs cannot be to high for the participation constraint to hold.

3.2 Wage contracts under centralization

Consider first a centralized organization in which the principal decides the contracts of both agents. Denote the payments in a centralized organization by $\overline{w}_i^C$. In this case the net payments in (5) are just the wage paid by the principal ($\overline{w}_i = \overline{w}_i^C$). From (5) we find that the principal's problem at stage 3 is[15]

$$\max_{\overline{w}_1^C \geq 0, \overline{w}_2^C \geq 0} EU_{P,\sigma} = \gamma_\sigma^\alpha \lambda \left(\overline{w}_1^C\right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\overline{w}_2^C\right)^{\frac{\beta}{1-\alpha-\beta}} (\overline{x} - \overline{w}_1^C - \overline{w}_2^C). \quad (8)$$

The optimal wages and expected utilities for the centralized organization are given in the following lemma.

Lemma 2. *In a centralized organization the optimal contracts are: $\overline{w}_1^C = \alpha\overline{x}$ and $\overline{w}_2^C = \beta\overline{x}$. Efforts are: $e_{1,\sigma}^C = \gamma_\sigma^{1-\beta}\frac{\alpha^2}{c}\mu$ and $e_{2,\sigma}^C = \gamma_\sigma^\alpha \frac{\beta^2}{c}\mu$. Expected utilities are*

$$EU_{P,\sigma}^C = \gamma_\sigma^\alpha(1-\alpha-\beta)\mu,\ EU_{1,\sigma}^C = \gamma_\sigma^\alpha \left(1 - \gamma_\sigma^{1-\alpha-\beta}\alpha\right)\alpha\mu, \text{ and } EU_{2,\sigma}^C = \gamma_\sigma^\alpha (1-\beta)\beta\mu - I_\sigma$$

with $\mu = \lambda \left(\alpha^\alpha \beta^\beta \overline{x}\right)^{\frac{1}{1-\alpha-\beta}}$.

[15] As we see later on, in equilibrium $EU_{2,\sigma} > 0$, so that the participation constraint is slack.

In a centralized organization the agents' wages are proportional to their productivity parameter and independent from the productivity of their partner. Furthermore, the more important an agent's contribution to the success of the project, the higher his wage is. Each agent's effort depends positively on the other agent's productivity parameter: i.e., α and β, respectively. This arises from the complementarity of efforts in the production function.

The result in Lemma 2 makes it possible to compare the expected utilities of the principal and the agents in a centralized organization under monitoring with those obtained when there is no monitoring. The following proposition gives us the value of information in a centralized organization.

Proposition 1. *The value of information*

For any given monitoring investment, I, the principal and agents obtain a positive gain from monitoring. The gain is increasing in both agent's productivity parameter.

The advantage of monitoring is that agent 1's effort has a positive externality on agent 2's effort. If agent 1 increases his effort and agent 2 can observe this increase in effort, he knows that the marginal gain from his own effort, i.e. the probability of a high outcome, is higher. Therefore he also increases his effort. As a result the probability that the project will be a success is higher, which benefits the principal as well as the two agents. Furthermore, with higher productivity parameters, agents choose greater efforts. Our assumptions about the production technology imply that the marginal productivity of effort is higher for both agents. Thus, the more productive agents are, the more the gains from monitoring increase.[16] One of the implications of this result is that agent 2 effectively monitors agent 1's effort once his investments are made because he is better off under monitoring than without it.

3.3 Wage contracts under decentralization

In a decentralized organization the principal only contracts agent 2, who separately contracts agent 1. Remember that even when agent 2 monitors agent 1's effort choice, contracts can not be contingent on the latter's effort since it is not verifiable. Thus, contracts are based on final output only. Denote the payment agent 2 receives from the principal by $\overline{w}_2^D$ and the payment from agent 2 to agent 1 by $\overline{w}_1^D$. Setting the net payments in (5)-(7) as $\overline{w}_1 = \overline{w}_1^D$ and

[16] Winter [2006] obtains a similar result. He shows that under complementarity for a large domain of information structures, more transparency among coworkers makes it easier for the principal to provide incentives.

$\overline{w}_2 = \overline{w}_2^D - \overline{w}_1^D$, at stage 3, the principal obtains her optimal wage contract with agent 2 from[17]

$$\max_{\overline{w}_2^D \geq 0} EU_{P,\sigma} = \gamma_\sigma^\alpha \lambda \left(\overline{w}_1^D\right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\overline{w}_2^D - \overline{w}_1^D\right)^{\frac{\beta}{1-\alpha-\beta}} \left(\overline{x} - \overline{w}_2^D\right) \quad (9)$$

$$\text{s.t. } \overline{w}_1^D \in \arg\max_{\overline{w}_1^D \geq 0} EU_{2,\sigma} = \gamma_\sigma^\alpha (1-\beta) \lambda \left(\overline{w}_1^D\right)^{\frac{\alpha}{1-\alpha-\beta}} \left(\overline{w}_2^D - \overline{w}_1^D\right)^{\frac{1-\alpha}{1-\alpha-\beta}} - I_\sigma. \quad (10)$$

In a decentralized organization before the principal determines the wage to agent 2, she must anticipate the wage agent 2 will pay agent 1. Elementary calculations show that this wage in equation (10) is $\overline{w}_1^D = \alpha \overline{w}_2^D$. The wage agent 1 receives when the outcome is high increases with his productivity as well as with the wage agent 2 receives from the principal. The following lemma summarizes the equilibrium values in a decentralized organization.

Lemma 3. *In a decentralized organization the optimal contracts are* $\overline{w}_2^D = (\alpha+\beta)\overline{x}$ *and* $\overline{w}_1^D = \alpha(\alpha+\beta)\overline{x}$. *Efforts are* $e_{1,\sigma}^D = \delta_1 e_{1,\sigma}^C$ *and* $e_{2,\sigma}^D = \delta_2 e_{2,\sigma}^C$. *Expected utilities are:*

$$EU_{P,\sigma}^D = \delta_P \gamma_\sigma^\alpha (1-\alpha-\beta)\mu, \; EU_{1,\sigma}^D = \delta_1 EU_{1,\sigma}^C, \textit{ and } EU_{2,\sigma}^D = \delta_2 \gamma_\sigma^\alpha (1-\beta)\beta\mu - I_\sigma.$$

where $\delta_1 = \left(\left(\frac{1-\alpha}{\beta}\right)^\beta (\alpha+\beta)\right)^{\frac{1}{1-\alpha-\beta}}$, $\delta_2 = \left(\left(\frac{1-\alpha}{\beta}\right)^{1-\alpha} (\alpha+\beta)\right)^{\frac{1}{1-\alpha-\beta}}$ *and* $\delta_P = (\alpha+\beta)^{-1}\delta_1$.

In a decentralized structure the contracts of both agents depend on the productivity of both partners. The reason for this is that agent 1's wage depends on agent 2's wage. Therefore, if agent 2 were completely unproductive ($\beta = 0$) and if the principal made agent 2's contract contingent only on his own productivity, the wage of both agents would be zero even if agent 1 were very productive. Therefore, it is clearly optimal to make the wage of both agents depend on both productivity parameters. Lemmas 1 and 2 make it possible to compare the centralized and the decentralized organization. The result is summarized in the following proposition.

Proposition 2. *Centralization versus decentralization*

The principal and agent 1 always obtain a higher expected utility in a centralized organization, while agent 2's expected utility is always higher in the decentralized organization. Furthermore, agent 1's equilibrium effort is higher in a centralized organization while agent 2's equilibrium effort is higher in the decentralized organization. The principal's cost of decentralization decreases with agent 2's productivity parameter and increases with agent 1's.

This result follows from the Revelation Principle. In a centralized organization in which the principal contracts both agents directly, she can offer a contract to agent 1 that is the same he

[17] Again, in equilibrium $EU_{2,\sigma} > 0$, so the participation constraint is slack.

receives from agent 2 in a decentralized organization. Therefore, centralization cannot be worse than decentralization for the principal. The cost of decentralization stems from the fact that agent 2 will distort the contract agent 1 receives in a centralized organization: he keeps part of the payment agent 1 receives from the principal in a centralized organization. Obviously, this decreases agent 1's incentive to choose high effort. Therefore, in equilibrium, his effort is lower in a decentralized organization while agent 2's effort is higher because of the increase in his wage. Clearly, agent 1 is worse off and agent 2 is better off under decentralization. Finally, agent 2's incentives to distort agent 1's effort reduce when he himself is more important for the success of production. Then any distortion of agent 1's effort imposes a higher cost on him. In this case the cost of decentralization is lower.

3.4 Monitoring investment

At stage 2 of the game agent 2 makes his investment decision. If the organization is centralized he will invest in monitoring iff

$$EU_{2,m}^{C} > EU_{2,n}^{C}.$$

From Lemma 2 we find that this is the case when

$$(\gamma_m^\alpha - 1)(1-\beta)\beta\mu > I.$$

Similarly, in a decentralized structure agent 2 will invest in monitoring iff

$$EU_{2,m}^{D} > EU_{2,n}^{D}.$$

From Lemma 3 we find that this is the case when

$$\delta_2(\gamma_m^\alpha - 1)(1-\beta)\beta\mu > I.$$

From proposition 1 we know that $\gamma_m^\alpha \geq 1$. This guarantees that monitoring can be beneficial for agent 2 if the monitoring investment is sufficiently low. From proposition 2 we know that $\delta_2 \geq 1$. This implies that the gains from monitoring are higher for agent 2 in a decentralized organization. Notice that given that agent 2 decides whether to invest in monitoring or not, this means that his expected utility is at least the amount he gets in a centralized organization without monitoring, $EU_{2,\sigma}^{k} \geq (1-\beta)\beta\mu$, $k = C, D$.[18]. I resume this in the following lemma.

Lemma 4. *Irrespective of the organizational structure chosen by the principal, agent 2 will not invest in monitoring if*

$$I \geq \delta_2(\gamma_m^\alpha - 1)(1-\beta)\beta\mu.$$

[18] This can be seen immediately in Lemmas 2 and 3. This proves that the participation constraint of agent 2 in the principal's maximization problem at stage 3 indeed is slack.

Agent 2 will invest in monitoring in a decentralized but not in a centralized organization if

$$\delta_2 \left(\gamma_m^\alpha - 1\right) \left(1 - \beta\right) \beta\mu > I \geq \left(\gamma_m^\alpha - 1\right) \left(1 - \beta\right) \beta\mu.$$

Irrespective of the organizational structure, agent 2 invests in monitoring if

$$\left(\gamma_m^\alpha - 1\right) \left(1 - \beta\right) \beta\mu > I.$$

3.5 Organizational choice

At stage 1, the principal chooses the organization that gives her highest expected utility. Using the results in Lemmas 2-4 we can derive the following result, which is the main result of the paper:

Proposition 3. *Organizational choice*

If monitoring costs are either low or high, the organization is centralized. For intermediate values of monitoring costs both a centralized and a decentralized organization can be optimal. In this case the organization is decentralized if for a given value of agent 1's productivity parameter agent 2's productivity is sufficiently high.

In Proposition 2 we have seen that for a given investment contingent payment schedule a centralized organization is always preferable to a decentralized organization for the principal and agent 2. However, the incentives to invest in monitoring in different organizations are different. Because agent 2 obtains higher gains from monitoring in a decentralized organization than in a centralized organization, decentralization may imply that agent 2 invests in monitoring while centralization may imply that he does not invest.

Now we can distinguish three cases. First, when investment costs are low, agent 2 will monitor in both organizations. So agent 2's investment decision is independent from the principal's organizational choice. Obviously, then, a centralized organization is the principal's optimal choice. Second, when investment costs are high, agent 2 will not invest in monitoring in either organization. Again, agent 2's investment decision is independent from the principal's organizational choice so that centralization is the superior choice. Finally, for intermediate levels of investment costs agent 2 only invests in a decentralized organization. Then, the principal's organizational decision must counterbalance the advantage of centralization (no rent extraction) with the advantage of decentralization (monitoring). We have seen that for a given value of agent 1's productivity parameter α, the cost of decentralization decreases with agent 2's productivity parameter β (Proposition 2), while the gains from monitoring increase with β

(Proposition 1). Thus, for high enough values of β the gains from decentralization compensate its costs.

4 Conclusion

As pointed out by Mookherjee [2006, p. 387], 'the most important lacuna of the existing theoretical incentive-based literature is that it focuses on costs rather than the benefits of delegation'. The present paper contributes to a better understanding of the advantages of contract decentralization because it develops a model that integrates costly information acquisition with incentive considerations. Two agents work jointly on a project for a principal. The agents choose their inputs sequentially: first agent 1, and then agent 2. They differ in their productivity and unit costs. The contract designer faces moral hazard problems because efforts are non–observable and non–verifiable. If agent 2 invests a certain amount of money in monitoring, he obtains perfect information, though unverifiable, about agent 1's effort choice. In this setting agent 2's incentives to invest in monitoring depend on the principal's organizational choice.

The organizational choice for the principal is shown to depend on the trade-off between the loss of control and the gain in information acquisition incentives which decentralization provides. Loss of control means that in a decentralized organization the principal does not control the subcontractor's contract directly and that agent 2 will use the control over agent 1's contract to reallocate efforts and increase his rent. The gain in information acquisition incentives means that in a decentralized structure agent 2's incentives to invest in monitoring are higher than in a centralized structure because in the former the informational rent is higher.

The choice of efficient organization depends on two factors: the cost of monitoring and the importance of agent 2's contribution for the success of the project. On the one hand, if monitoring costs are low, agent 2 invests in monitoring irrespective the principal's organizational choice. In this case the Revelation Principle applies and centralization is the optimal organizational choice. On the other hand, if monitoring costs are high, agent 2 never invests in monitoring. In this case there is no monitoring in either organization. Again, the Revelation Principle shows that centralization is superior to decentralization. Finally, for intermediate values of monitoring costs, agent 2 only invests in monitoring if the principal chooses a decentralized organization. In this case, a decentralized organization is optimal for the principal when her gains from monitoring outweigh the cost of her loss of control. The more important agent 2 is to the success of the project, the more the gains will increase and the more the cost of the loss of control will decrease. Therefore, when agent 2 is sufficiently important for the success of the project and monitoring costs are neither high nor low, decentralization is the optimal organization choice for the principal.

Although the results have been obtained for a very specific model, the results are robust and will also be obtained in more general models. As long as agents obtain informational rents and their efforts are complementary, the effects identified in this paper will be present in other models.[19] Finally, the results have been applied to explain the coexistence of centralized and decentralized organizations in the construction sector, largely due to the introduction of the design-build method in recent years. However, the results can also be applied to such other contexts, as public procurement in defense or I&D or inner–firm organization. Here the general message is that subcontracting can be optimal when it increases the subcontractor's incentives to acquire information in a context with sequential production, soft information and complementarity in hidden effort.

[19] What is needed is $\partial P/\partial e_i > 0$, $\partial^2 P/\partial e_i^2 < 0$, $\partial^2 P/\partial e_1 \partial e_2 > 0$, and $\partial^2 EU_i/\partial e_i^2 < 0$. This means that there must be some complementarity in effort such that there are potential gains from monitoring. If efforts are completely independent (and $\partial^2 P/\partial e_1 \partial e_2 = 0$) there are no gains from monitoring and in a centralized structure the principal contracts only one agent: the one with higher marginal per unit cost contribution. Then, as the Revelation Principle indicates, the principal can never be better off than in a centralized structure.

5 Appendix

5.1 Proof of Proposition 1

From Lemma 2 we have that $EU^C_{P,m} = \gamma^\alpha_m EU^C_{P,n}$, $EU^C_{1,m} = \gamma^\alpha_m \frac{1-\alpha-\beta}{(1-\beta)(1-\alpha)} EU^C_{1,n}$, and $EU^C_{2,m} = \gamma^\alpha_m EU^C_{2,n}$. Consider first the principal and agent 2 who obtain as gains from monitoring $\gamma^\alpha_m = (1-\beta)^{-\frac{\alpha}{1-\alpha-\beta}}$ times the expected rent under no monitoring. It is immediate that $\gamma^\alpha_m \geq 1$ (which proves the first statement) and $\partial\gamma^\alpha_m/\partial\alpha \geq 0$ and $\partial\gamma^\alpha_m/\partial\beta \geq 0$ (which proves the second statement). Now consider agent 1. His expected gains from monitoring are $f \equiv \gamma^\alpha_m \frac{1-\alpha-\beta}{(1-\beta)(1-\alpha)}$ times the expected rent under no monitoring. Taking logarithms we have

$$\ln f = -\frac{\alpha}{1-\alpha-\beta}\ln(1-\beta) + \ln(1-\alpha-\beta) - \ln(1-\beta) - \ln(1-\alpha).$$

We make the following claims:

Claim 1: $\partial f/\partial\beta \geq 0$. This is equivalent to

$$\frac{\partial \ln f}{\partial \beta} = -\frac{\alpha}{(1-\alpha-\beta)^2}\ln(1-\beta) \geq 0,$$

which proves our claim.

Claim 2: $\partial f/\partial\alpha \geq 0$. This is equivalent to

$$\frac{\partial \ln f}{\partial \alpha} = -\frac{1-\beta}{(1-\alpha-\beta)^2}\ln(1-\beta) - \frac{\beta}{(1-\alpha-\beta)(1-\alpha)} \geq 0$$

which is true if

$$g \equiv -\ln(1-\beta) - \frac{\beta(1-\alpha-\beta)}{(1-\beta)(1-\alpha)} \geq 0.$$

This is an increasing function in β ($\frac{\partial g}{\partial \beta} = \beta\frac{(1+\alpha-\beta)}{(1-\alpha)(1-\beta)^2} > 0$) whose value at the minimum is $g(\beta = 0) \equiv 0$. Therefore $g \geq 0$ for all $\beta \geq 0$ which proves our claim. Claim 1 and 2 prove the second statement concerning agent 1.

Claim 3: $f \geq 1$. Because claim 1 shows that f is increasing in β, and at the minimum $f(\beta = 0) = 1$, we immediately have that $f \geq 1$ for all $\beta \geq 0$. This proves the first statement concerning agent 1.

5.2 Proof of Proposition 2

First we show that $\delta_P \leq 1$. This is equivalent to

$$(1-\alpha-\beta)\ln\delta_P = (\beta\ln(1-\alpha) - \beta\ln\beta + (\alpha+\beta)\ln(\alpha+\beta)) \leq 0.$$

This is an increasing function in β:

$$\frac{\partial}{\partial\beta}(1-\alpha-\beta)\ln\delta_P = \ln\left(\frac{(1-\alpha)(\alpha+\beta)}{\beta}\right) \geq 0$$

which reaches its maximum at $\beta = 1-\alpha$ with 0. Thus, $(1-\alpha-\beta)\ln\delta_P \leq 0$ for $0 \leq \beta \leq 1-\alpha$. Second, notice that $\delta_1 = (\alpha+\beta)\delta_P < 1$ because $(\alpha+\beta) < 1$ and $\delta_P \leq 1$. Finally, $\delta_2 \geq 1$ is equivalent to

$$(1-\alpha-\beta)\ln\delta_2 = (1-\alpha)\ln(1-\alpha) - (1-\alpha)\ln\beta + \ln(\alpha+\beta) \geq 0.$$

This is a decreasing function of β:

$$\frac{\partial}{\partial\beta}(1-\alpha-\beta)\ln\delta_2 = -\frac{\alpha(1-\alpha-\beta)}{\beta(\alpha+\beta)} \leq 0$$

which reaches its minimum at $\beta = 1-\alpha$ with 0. Thus, $(1-\alpha-\beta)\ln\delta_2 \geq 0$ for $0 \leq \beta \leq 1-\alpha$.

To prove the last statement, notice that if $(1-\alpha-\beta)\ln\delta_P$ is an increasing function in β, so is $\ln\delta_P$ and δ_P.

5.3 Proof of Proposition 3

From Lemma 4 we know that we must distinguish three cases.

Case a): $I \geq \delta_2(\gamma_m^\alpha - 1)(1-\beta)\beta\mu$.

In this case agent 2 will never invest in monitoring. Therefore, the difference between the principal's expected utility in a centralized and a decentralized structure is

$$EU_{P,n}^C - EU_{P,n}^D = (1-\delta_P)(1-\alpha-\beta)\mu \geq 0.$$

Case b): $\delta_2(\gamma_m^\alpha - 1)(1-\beta)\beta\mu > I \geq (\gamma_m^\alpha - 1)(1-\beta)\beta\mu$.

In this case agent 2 invests in monitoring if the principal chooses a decentralized structure and does not invest in monitoring if she chooses a centralized structure. Therefore, the difference between the principal's expected utility in a centralized and a decentralized structure is

$$EU_{P,n}^{C}-EU_{P,m}^{D}=(1-\delta_P\gamma_m^{\alpha})(1-\alpha-\beta)\mu.$$

Notice that

$$(1-\alpha-\beta)\,ln\,(\delta_P\gamma_m^{\alpha})=\beta\ln(1-\alpha)-\beta\ln\beta-\ln(1-\beta)+(\alpha+\beta)\ln(\alpha+\beta)\,.$$

For $\beta=0$ the right-hand side is $\alpha\ln\alpha<0$. For $\beta\to 1-\alpha$, the right-hand side is $-\ln\alpha>0$. Furthermore, the right-hand side of $(1-\alpha-\beta)\,ln\,(\delta_P\gamma_m^{\alpha})$ is an increasing function in β:

$$\frac{\partial}{\partial\beta}(1-\alpha-\beta)\,ln\,(\delta_P\gamma_m^{\alpha})=\ln\left(\frac{(1-\alpha)\,(\alpha+\beta)}{\beta}\right)+\frac{1}{1-\beta}\geq 0.$$

Notice, that $\ln\left(\frac{(1-\alpha)(\alpha+\beta)}{\beta}\right)\geq 0$ has already been demonstrated in the proof of Proposition 2. Thus, for any $0<\alpha<1-\beta$, $\exists\widetilde{\beta}(\alpha)$ such that $(1-\alpha-\beta)\,ln\,(\delta_P\gamma_m^{\alpha})<0$ or $\delta_P\gamma_m^{\alpha}<1$ for $\beta<\widetilde{\beta}(\alpha)$, $(1-\alpha-\beta)\,ln\,(\delta_P\gamma_m^{\alpha})=0$ or $\delta_P\gamma_m^{\alpha}=1$ for $\beta=\widetilde{\beta}(\alpha)$, and $(1-\alpha-\beta)\,ln\,(\delta_P\gamma_m^{\alpha})>0$ or $\delta_P\gamma_m^{\alpha}>1$ for $\beta>\widetilde{\beta}(\alpha)$. This means that

$$EU_{P,n}^{C}-EU_{P,m}^{D}=\begin{cases}>0 & \text{for } \beta<\widetilde{\beta}(\alpha)\\ =0 & \text{for } \beta=\widetilde{\beta}(\alpha)\\ <0 & \text{for } \beta>\widetilde{\beta}(\alpha)\end{cases}.$$

The function $\widetilde{\beta}(\alpha)$ is displayed in Figure 1.

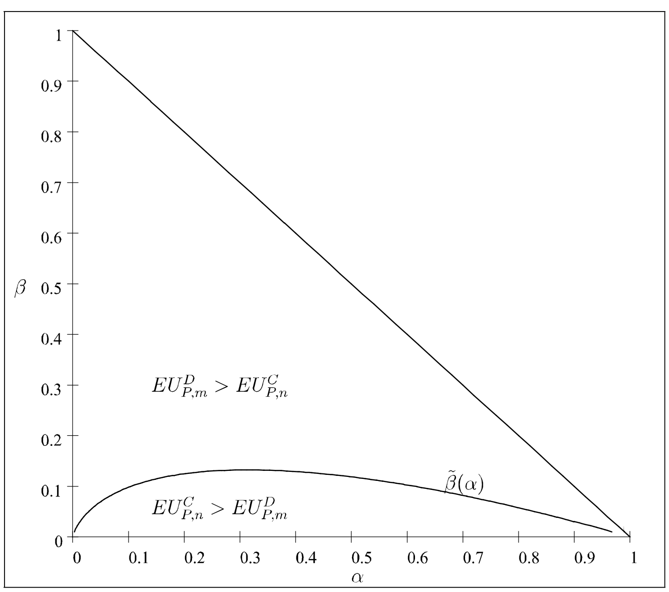

Figure 1: Optimal organizational structures for intermediate investment cost.

Case c): $(\gamma_m^\alpha - 1)(1-\beta)\beta\mu > I$.

In this case, agent 2 invests in monitoring irrespective the organizational structure chosen by the principal. Therefore, the difference between the principal's expected utility in a centralized and a decentralized structure is

$$EU_{P,m}^C - EU_{P,m}^D = (1-\delta_P)\gamma_m^\alpha(1-\alpha-\beta)\mu \geq 0.$$

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