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Centralization Versus Delegation and the Value of Communication

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1. *Introduction*

Management literature has long debated the comparative advantages of centralized versus decentralized decision making. The usual framework of analysis focuses on an organization that consists of a principal (central management, headquarters) and one or several agents (local managers, divisions). Centralization, it is argued, allows the principal to retain control over important decisions. On the other hand, relevant information is generally dispersed among the members of the organization. To exploit the relevant information for decision making the principal must either elicit information or delegate decision making.

Delegation has not played a prominent role in the work on incentive mechanisms. For the most part, this work has focused on revelation mechanisms in which all agents communicate their information to the principal who then makes all the decisions. The Revelation Principle asserts that the maximum performance attainable by some incentive mechanism can be replicated by a revelation mechanism. In particular, any mechanism involving delegation of decision making can, without loss of performance, be replaced by a completely centralized mechanism.

The reasoning of the Revelation Principle, however, is valid only in a world of unlimited and costless communication. Firms decentralize, as the management literature points out (see, for example, Kaplan [1982]), precisely because communication is costly and managers have limited abilities to communicate and to process information. These costs and limitations seem essential to explaining the creation of organizational

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subunits with considerable decision autonomy, such as divisions and responsibility centers.

In this paper, we do not account explicitly for communication costs (as done, for example, in Hurwicz [1986]). We attempt instead to find out under what conditions the performance of an optimal revelation mechanism can be replicated by a delegation scheme which does not involve communication. We consider a model involving a single privately informed agent. An observable decision is either made by the principal or delegated to the agent.

Under a revelation mechanism, the agent first reports his private information. The decision in question is then made according to a decision rule to which the principal has committed himself. The agent's compensation depends on the report submitted as well as a jointly observed outcome (such as production cost or profit). We refer to this setting as communication-based centralization. In contrast, the agent does not issue a report under a direct delegation scheme. Instead, the agent is given direct responsibility for the decision. Compensation may then depend on the decision made and the jointly observed outcome.

We show that only in special cases are direct delegation schemes performance equivalent to communication-based centralization schemes. The reason is that the agent's communicated message serves not only a planning purpose (improving the decision), but also a control purpose (providing better incentives). This control function of communication has been explored in the papers of Baiman and Evans [1983], Penno [1984], and Melumad and Reichelstein [1987]. In those models the agent is offered a menu of contracts. Based on his private information the agent sends a message to the principal and thereby selects a particular compensation function from the menu. Under a direct delegation scheme without communication, the decision made by the agent substitutes for the message in the contract. In general, this will impose restrictions on the menu of contracts the principal can offer.

In the following section we describe our model and discuss its relation to the existing accounting and management literature. The results of the paper are reported in section 3. We note that without communication, it is always in the principal's interest to delegate authority over jointly observable decisions to the better-informed agent. On the other hand, if the agent can communicate his private information, centralization and delegation schemes are equivalent. These intuitive observations follow immediately once the different organizational settings are stated formally. Proposition 1 provides necessary and sufficient conditions for direct delegation schemes to attain the same performance as communication-based centralization schemes.

A special case of our general framework occurs when the agent has perfect private information. Models of this type were studied, among others, by Baron and Myerson [1982], Antle and Eppen [1985], Ramakrishnan [1986], and Laffont and Tirole [1986]. In Proposition 2 it is shown that, if the agent has perfect private information, direct delegation schemes without communication are performance equivalent to communication-based centralization schemes.

In Melumad and Reichelstein [1987] we show that communication has no value (from a control perspective), if both parties are risk-neutral and the probability distribution of the jointly observed outcome satisfies a certain spanning condition. A generalization of this result is established in Proposition 3. We show that risk-neutrality and the spanning condition are sufficient for direct delegation schemes to perform equally well as communication-based centralization schemes. In section 4 we examine some of the assumptions in our model and indicate directions for future study.

2. *Description of the Model*

We compare alternative organizational settings with respect to the performance attainable. In all cases the agent is assumed to have private information. The agent takes an unobservable action subject to moral hazard. This unobservable action is to be distinguished from the decision, which always remains observable. Our comparison focuses on the role of communication and the responsibility for the decision. We confine our analysis to extreme cases: either there is no communication, or communication possibilities are unlimited; the decision is either made centrally or delegated to the agent. Thus, we obtain four alternative organizational settings.

Our assumptions regarding information and observability parallel those of Demski, Patell, and Wolfson [1984] and Antle and Eppen [1985]. Demski et al. study a model in which the decision concerns the accounting system which can be selected either by the owner of a firm or its management. Antle and Eppen examine capital budgeting in an agency context. There, the observable decision is the amount of capital allocated to a division.

Demski and Sappington [1986; 1987] make different observability assumptions. Specifically, they assume that the decision, once delegated, becomes unobservable to the principal. Therefore, delegation induces an additional moral hazard problem. While in Demski and Sappington [1986] the agent is exogenously endowed with private information, Demski and Sappington [1987] assume the agent is uninformed at the outset. However, private information can be acquired at a cost. Part of the incentive problem then is to motivate the agent to become informed (a related model is Lambert [1986]). In section 4 we discuss how our results would be affected by different observability assumptions.

We adopt the following assumptions and notation. The agent receives his private information, denoted by $\theta \in \Theta$, prior to contracting.[1] The

[1] Our analysis remains essentially unchanged if private information is acquired after contracting. The difference is that in the latter case, the agent's expected utility payoff—over his private information and outcome—has to meet the market alternative. For an analysis of postcontract private information, see Dye [1983] and Penno [1984].

principal's beliefs regarding θ are represented by a probability distribution $N(\theta)$. By $a \in A$ we represent the agent's unobservable action. The contractual arrangement specifies who is in charge of the decision $d \in D$. The two parties can contract on a jointly observable outcome $x \in X$. This outcome is the realization of a random variable whose probability distribution $F(x \mid d, \theta, a)$ is parameterized by a triple (d, θ, a).[2]

With the exception of Proposition 3, we consider general utility functions $U(\cdot)$ and $V(\cdot)$ for principal and agent, respectively. It is assumed that the agent's (principal's) utility is increasing (decreasing) in the agent's compensation. Furthermore, the agent's preferences are such that a sufficiently high monetary penalty can offset any benefits associated with the other variables. Formally, we require that for any utility level V^* and any (d, θ, a, x) there exists a payment $\bar{H}$ such that, $V(d, \theta, a, x, \bar{H}) \leq V^*$.

The alternative organizational settings are described below.

2.1 CENTRALIZATION WITHOUT COMMUNICATION

We begin with the simplest scenario in which there is no communication and the principal makes the decision in question on the basis of his prior information only. In this case, the sequence of events (subsequent to signing the contract) can be represented by the following timetable.

Principal selects $d \in D$	Agent selects $a \in A$	Outcome $x \in X$ realized	$H_1(x)$ paid

Note that the agent knows the principal's decision $d \in D$, yet the choice of $d \in D$ cannot rely on θ in this case. The corresponding optimization problem becomes:[3,4]

$$P1\colon \max_{H_1(x),d} E_\theta\{E_x[U(d, \theta, a(\theta), x, H_1(x)) \mid d, a(\theta), \theta]\}$$

subject to:

$$\forall \theta \in \Theta\colon E_x[V(d, \theta, a(\theta), x, H_1(x)) \mid d, a(\theta), \theta] \geq \bar{V}$$

$$\forall \theta \in \Theta\colon a(\theta) \in \operatorname*{argmax}_{\bar{a} \in A} \{E_x[V(d, \theta, \bar{a}, x, H_1(x)) \mid d, \bar{a}, \theta]\}.$$

Here, E_θ and E_x stand for the expectation operators with respect to

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[2] Since most of our results are based on general arguments, we leave unspecified some of the mathematical properties of the spaces and functions involved. No additional assumptions are needed if X, A, Θ, and D are finite sets.

[3] In $P1$, as well as the subsequent programs, the optimization is carried out over the compensation function, the decision, and the action choices. However, to highlight the different scenarios, we represent only those variables that the principal controls directly.

[4] For any θ, the agent may have multiple actions which maximize his utility. By $a(\theta)$ we denote the principal's selection from the set of maximizers.

the probability measure induced by N and F respectively. That is:

$$E_\theta\{E_x[U(d, \theta, a(\theta), x, H_1(x)) \mid d, a(\theta), \theta]\}$$
$$\equiv \int_\Theta \int_X U(d, \theta, a(\theta), x, H_1(x))\, dF(x \mid d, \theta, a(\theta))\, dN(\theta).$$

The first constraint in Program 1 represents the individual rationality constraint in which $\bar{V}$ denotes the agent's reservation utility. That this constraint must be satisfied for all $\theta \in \Theta$ reflects the assumption that the agent receives his private information prior to contracting.[5] Note that we do not impose any further constraints on the class of admissible contracts. In particular, we disregard possible limits on the agent's liability, i.e., bounds on the financial penalty that can be imposed on the agent for any particular combination of outcomes. We examine this issue in section 4.

2.2 COMMUNICATION-BASED CENTRALIZATION

We next consider a scenario wherein the agent can communicate his private information to the principal. From the Revelation Principle we know that there is no loss of generality (from a performance perspective) in restricting attention to revelation mechanisms, i.e., mechanisms for which the agent maximizes his utility payoff by revealing his true environment. Let $\delta(\cdot)$ denote the decision rule to which the principal has committed himself.

Agent communicates $\theta \in \Theta$	Principal implements $\delta(\theta)$	Agent selects $a \in A$	Outcome $x \in X$ realized	$H_2(\theta, x)$ paid

$$P2: \max_{H_2(\theta,x),\delta(\theta)} E_\theta\{E_x[U(\delta(\theta), \theta, a(\theta), x, H_2(\theta, x)) \mid \delta(\theta), a(\theta), \theta]\}$$

subject to:

$$\forall \theta \in \Theta: E_x[V(\delta(\theta), \theta, a(\theta), x, H_2(\theta, x)) \mid \delta(\theta), a(\theta), \theta] \geq \bar{V}$$

$$\forall \theta \in \Theta: (\theta, a(\theta)) \in \operatorname*{argmax}_{(\bar{\theta},\bar{a})} \{E_x[V(\delta(\bar{\theta}), \theta, \bar{a}, x, H_2(\bar{\theta}, x)) \mid \delta(\bar{\theta}), \bar{a}, \theta]\}.$$

The incentive compatibility constraint in $P2$ has two components. It must be in the agent's best interest to take the action $a(\theta)$ and, at the same time, to reveal his private information truthfully. Note that communication-based centralization implies an indirect form of delegation since the agent effectively makes the decision by sending a particular message. However, we distinguish conceptually between this framework and the following.

[5] In a generalized formulation, the compensation function will induce the agent to quit after receiving unfavorable information (see Melumad [1988] for an account of this generalization). Our results carry over to this case with minor modifications.

2.3 DIRECT DELEGATION

In this case, there is no communication between principal and agent. The agent is given complete discretion over the decision and is held accountable for his choice.

Agent selects $d \in D$	Agent selects $a \in A$	Outcome $x \in X$ realized	$H_3(d, x)$ paid

$$P3: \max_{H_3(d,x)} E_\theta\{E_x[U(d(\theta), \theta, a(\theta), x, H_3(d(\theta), x)) \mid d(\theta), a(\theta), \theta]\}$$

subject to:

$$\forall \theta \in \Theta: E_x[V(d(\theta), \theta, a(\theta), x, H_3(d(\theta), x)) \mid d(\theta), a(\theta), \theta] \geq \bar{V}$$

$$\forall \theta \in \Theta: (d(\theta), a(\theta)) \in \underset{(\bar{d},\bar{a})}{\operatorname{argmax}} \{E_x[V(\bar{d}, \theta, \bar{a}, x, H_3(\bar{d}, x)) \mid \bar{d}, \bar{a}, \theta]\}.$$

Note that in this case the function $d(\cdot)$ does not denote a decision policy formulated by the principal but an optimal decision for the agent given his information and the compensation function $H_3(d, x)$.

2.4 DIRECT DELEGATION AND COMMUNICATION

The final setting to be considered allows for communication and leaves responsibility for the decision with the agent.

Agent communicates $\theta \in \Theta$	Agent selects $d \in D$	Agent selects $a \in A$	Outcome $x \in X$ realized	$H_4(d, \theta, x)$ paid

$$P4: \max_{H_4(d,\theta,x)} E_\theta\{E_x[U(d(\theta), \theta, a(\theta), x, H_4(d(\theta), \theta, x)) \mid d(\theta), \theta, a(\theta)]\}$$

subject to:

$$\forall \theta \in \Theta: E_x[V(d(\theta), \theta, a(\theta), x, H_4(d(\theta), \theta, x)) \mid d(\theta), \theta, a(\theta)] \geq \bar{V}$$

$$\forall \theta \in \Theta: (d(\theta), \theta, a(\theta)) \in \underset{(\bar{\theta},\bar{d},\bar{a})}{\operatorname{argmax}} \{E_x[V(\bar{d}, \theta, \bar{a}, x, H_4(\bar{d}, \bar{\theta}, x)) \mid \bar{d}, \theta, \bar{a}]\}.$$

A schematic summary of the four programs is given below:

	Centralization	*Delegation*
No communication	$P1$	$P3$
Communication	$P2$	$P4$

3. *Results*

To establish an ordering among the four organizational settings, we compare the performances attainable, i.e., the values of the respective optimization programs. Denoting these values by $\Gamma(\cdot)$, we obtain the following.[6]

[6] We do not address the question of the existence of a solution for these programs. If the sets X, Θ, D, and A are continuum sets, the value $\Gamma(\cdot)$ may represent a supremum rather than a maximum.

LEMMA. $\Gamma(P1) \leq \Gamma(P3) \leq \Gamma(P2) = \Gamma(P4)$.

Proof. (*i*) To see that $\Gamma(P1) \leq \Gamma(P3)$, consider a solution $(H_1(x), d^*)$ to $P1$. Define:

$$H_3(d, x) = \begin{cases} H_1(x) & \text{if } d = d^* \\ -K & \text{otherwise} \end{cases}$$

The constant K is chosen large enough to effectively force the agent to make the decision d^*.[7] It is readily verified that the agent's action choice remains unaltered.

(*ii*) Clearly, $\Gamma(P4) \geq \Gamma(P3)$, since the principal can always choose to ignore the agent's message.

(*iii*) To show that $\Gamma(P2) \geq \Gamma(P4)$, consider a solution $H_4(d, \theta, x)$ to $P4$ which induces the agent to adopt the decision policy $d(\theta)$. Define $H_2(\theta, x) \equiv H_4(d, \theta, x)$ and $\delta(\theta) \equiv d(\theta)$. Under this communication-based centralization scheme the principal carries out those decisions that the agent would take under $H_4(d, \theta, x)$. The agent has an incentive to take the same actions. Since the payoffs are unchanged as well, we find that $\Gamma(P2) \geq \Gamma(P4)$. The proof that $\Gamma(P4) \geq \Gamma(P2)$ follows along the lines of the argument in (*i*).

In summary, the lemma says that if the agent can communicate his private information, it does not matter who makes the observable decision. On the other hand, delegation is (weakly) preferred by the principal in the absence of communication.[8] It appears that in "many cases" the last inequality will be strict. For a simple illustration consider the case in which the agent is indifferent to the decision (in particular, the decision does not affect the probability distribution over outcomes). Yet, from the principal's perspective, the optimal (first-best) decision varies with the agent's information. In this case $\Gamma(P3) > \Gamma(P1)$, since the principal may simply adopt the compensation function $H_1(x)$ (which solves $P1$) and delegate the decision. The agent then has a weak, but sufficient, incentive to implement the decisions preferred by the principal.

What remains to be explored is when delegation schemes attain the same performance as communication-based centralization schemes. In other words, is it sufficient to contract on the delegated decision only, or is there a need to elicit information from the agent and implement a decision according to some prespecified rule? A direct delegation scheme

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[7] We note that in a continuous setting, the forcing contract $H_3(d, x)$ could be made smooth.

[8] It is claimed by Lal [1986] that setting the price centrally is preferable to delegating the pricing decision in a world of symmetric information, while under asymmetric information the converse is true. This claim is in contradiction to our finding, which is independent of the information structure. The reason for this contradiction is that in Lal [1986] the delegated pricing decision is assumed to be unobservable by the principal under symmetric information, while it is assumed to be observable in the asymmetric information case.

would reduce the cost of communication, in particular, if the set of alternative decisions is small compared to the set of environments for the agent. It also appears that a direct delegation scheme involves a lesser degree of commitment than a communication-based centralization scheme.

The essential argument in comparing Programs 2 and 3 is that communication serves a *planning* as well as a *control* purpose in Program 2. The planning function of the agent's message is that it determines decision via the decision rule $\delta(\cdot)$. The control function of communication is that the compensation scheme can be tailored to the agent's privately observed environment. Effectively, the principal offers a menu of compensation functions from which the agent selects one by sending his message. As a consequence, the principal may achieve better risk sharing, mitigate the moral hazard problem, and economize on the agent's expected compensation payment. To realize any of those gains, however, the menu of contracts has to have the self-selection property.

Penno [1984] and Melumad and Reichelstein [1987] studied the value of communication for agencies in which there is no observable decision $d \in D$ to be made. In Penno's model, a menu of contracts leads to improved risk sharing. Melumad and Reichelstein consider the case of risk-neutral parties. In some cases, a menu of contracts is shown to be valuable because it improves action choices and/or reduces the agent's expected compensation. In other cases, the self-selection conditions prove so restrictive that communication has no value from a control perspective.

The results on the value of communication suggest why there may be a performance loss in moving from communication-based centralization to direct delegation. Under a direct delegation scheme, the decision takes the place of the message in the compensation function. Therefore, the two settings yield the same performance if the delegated decision and the message are equivalent means of communication. To make this idea precise, we introduce the following terminology.

DEFINITION 1. Given a feasible solution $(H_2(\theta, x), \delta(\theta))$ to the communication-based centralization program, $P2$, the compensation function $H_2(\theta, x)$ is said to be *compatible* with the decision rule $\delta(\theta)$, if for all $\theta, \bar{\theta} \in \Theta$: $\delta(\theta) = \delta(\bar{\theta})$ implies $H_2(\theta, x) = H_2(\bar{\theta}, x)$ for all $x \in X$.

The compatibility requirement says that whenever two different messages result in the same decision according to the decision rule $\delta(\cdot)$, these two messages have to induce identical compensation functions.

PROPOSITION 1. Direct delegation is performance equivalent to communication-based centralization, i.e., $\Gamma(P2) = \Gamma(P3)$, if and only if there exists an optimal solution for $P2$, $(H_2^*(\theta, x), \delta^*(\theta))$, such that $H_2^*(\theta, x)$ is compatible with $\delta^*(\theta)$.

Proof. (*if*) Let $(H_2^*(\theta, x), \delta^*(\theta))$ be such that it attains the value $\Gamma(P2)$ and that $H_2^*(\theta, x)$ is compatible with $\delta^*(\theta)$. We may then define the following solution to $P3$:

$$H_3{}^*(d, x) = \begin{cases} H_2{}^*(\theta, x) & \text{if} \quad \delta^*(\theta) = d \quad \text{for some } \theta \in \Theta \\ -K & \text{otherwise.} \end{cases}$$

This function is well defined whenever the pair $(H_2{}^*(\theta, x), \delta^*(\theta))$ satisfies the compatibility requirement. It is easy to verify that for any $\theta \in \Theta$ the compensation function $H_3(d, x)$ induces the agent to select $d = \delta^*(\theta)$. Furthermore, the agent will make the same action choice and receive the same compensation as under $(H_2{}^*(\theta, x), \delta^*(\theta))$. Hence $\Gamma(P2) \leq \Gamma(P3)$. Recalling from the above lemma that $\Gamma(P2) \geq \Gamma(P3)$, we conclude that $\Gamma(P2) = \Gamma(P3)$.

(*only if*) Let $H_3{}^*(d, x)$ be an optimal solution to Program 3 such that the agent makes the decision $d(\theta)$ at $\theta \in \Theta$. Consider the pair $(H_2(\theta, x), \delta(\theta))$ defined as follows: $H_2(\theta, x) \equiv H_3{}^*(d(\theta), x)$ and $\delta(\theta) \equiv d(\theta)$. First, note that $H_2(\theta, x)$ is compatible with $\delta(\cdot)$. Second, the agent has an incentive to tell the truth under $H_2(\theta, x)$ since if he could gain by misrepresenting his true type $\theta \in \Theta$ in $P2$, then $d(\theta)$ would not have been his optimal decision under $H_3(d, x)$. Finally, $(H_2(\theta, x), \delta(\theta))$ induces the same action choices and payoffs as $H_3{}^*(d, x)$. Hence, the value of the program associated with $(H_2(\theta, x), \delta(\theta))$ equals $\Gamma(P3)$. By hypothesis, $\Gamma(P3) = \Gamma(P2)$. Therefore, we have constructed an optimal solution for $P2$ with the property that the compensation function is compatible with the decision rule.

Proposition 1 formalizes our discussion of the planning and control purpose of communication. For a direct delegation to be performance equivalent to the optimal communication-based centralization scheme, it is necessary and sufficient that there be an optimal solution to $P2$ which does not distinguish between any two environments from a control perspective whenever these two environments are not distinguished from a planning perspective. We note that this condition will be trivially satisfied, if the optimal decision rule in $P2$ amounts to a one-to-one correspondence between environments and decisions.

The following example illustrates the use of Proposition 1. We imagine a scenario in which the observable decision concerns the purchase of a productive input. Only for certain θs will the benefit associated with this input exceed its acquisition cost. There are four possible environments and two decisions—purchase or no purchase. The essential feature of the example is that every optimal contract for $P2$ involves a menu with at least three distinct compensation functions. It then follows from Proposition 1 that no delegation scheme can attain the value of the optimal scheme in $P2$. Independent of the structure of the decision rule $\delta(\cdot)$, the optimal menu cannot be compatible with $\delta(\cdot)$. That is, because the size of the optimal menu of contracts for $P2$ exceeds the number of decisions available to the agent, the jointly observed d cannot convey all the information conveyed by the message θ.

EXAMPLE

Let $X = \{x_1, x_2\}$ with $x_2 > x_1$, $A = \{a_0, a_1\}$, $D = \{d_0, d_1\}$, and $\Theta = \{\theta_1, \theta_2, \theta_3, \theta_4\}$. We denote by q_i the prior probability of θ_i and let x_i be a monetary outcome which can be either high or low. The probability of obtaining a particular outcome depends on the environment θ_i, the agent's action choice as well as the decision d_i. We assume that the principal and the agent have the following preferences:

$$U(d, \theta, a, x, H) = x - H - c(d)$$

$$V(d, \theta, a, x, H) = H - W(a).$$

Here, $c(d_1) > 0$ can be interpreted as the acquisition cost of the production input; this cost is borne by the principal. $W(\cdot)$ represents the cost associated with the agent's action choice. We set $c(d_0) = 0$ and suppose that $W(a_1) > W(a_0) = 0$. For simplicity, the reservation utility is set equal to zero. Program 2 then takes the following form.

$$\underset{H_2(\cdot,\cdot),\delta(\cdot)}{\text{Max}} \sum_{i=1}^{4} \sum_{j=1}^{2} \{[x_j - H_2(\theta_i, x_j) - c(\delta(\theta_i))] \cdot \Pr[X = x_j \mid \delta(\theta_i), \theta_i, a(\theta_i)]\} q_i$$

subject to:

$$\forall \theta_i\colon \sum_{j=1}^{2} H_2(\theta_i, x_j) \cdot \Pr[X = x_j \mid \delta(\theta_i), \theta_i, a(\theta_i)] - W(a(\theta_i)) \geq 0$$

$\forall \theta_i$:

$$(\theta_i, a(\theta_i)) \in \underset{(\bar\theta,\bar a)}{\text{argmax}} \left\{ \sum_{j=1}^{2} H_2(\bar\theta, x_j) \cdot \Pr[X = x_j \mid \delta(\bar\theta), \theta_i, \bar a] - W(\bar a) \right\}.$$

To solve for the optimal scheme, we first need to specify how the probability of a high return, i.e., $x = x_2$, depends on (d, θ, a). We suppose that in state θ_1 neither increased effort nor the purchase of the input, i.e., $d = d_1$, improves the probability of obtaining x_2. In contrast, we suppose that in $\theta \in \{\theta_2, \theta_3, \theta_4\}$, the probability of a high outcome is responsive to the agent's effort choice and the availability of the productive input. Thus, if the return x_2 is sufficiently large, the principal will design the solution $(H_2(\theta, x), \delta(\theta))$ to $P2$ such that:

$$a(\theta_1) = a_0 \quad \text{and} \quad a(\theta_i) = a_1 \qquad 2 \leq i \leq 4$$

$$\delta(\theta_1) = d_0 \quad \text{and} \quad \delta(\theta_i) = d_1 \qquad 2 \leq i \leq 4.$$

In Appendix A we establish that the least expensive way for the principal to induce truthfulness and implement these action choices is to design a menu consisting of three different compensation functions. Since there are only two alternative decisions, the menu *cannot* be compatible with the decision rule. It then follows from Proposition 1 that no delegation scheme can attain the performance of $P2$.

A special, though frequently studied, case of our general agency model is one in which the agent acquires perfect private information; i.e., the agent can anticipate the observable outcome x with certainty. Models of this type have been studied, among others, by Baron and Myerson [1982], Riordan [1984], Antle and Eppen [1985], and Ramakrishnan [1986]. In our model, perfect private information corresponds to the case in which the distribution $F(x \mid d, \theta, a)$ concentrates its entire probability mass on one point. With a slight abuse of notation we denote this point by $x(d, a, \theta)$. It can be shown that in the absence of the observable decision $d \in D$ there is no value to offering a menu of contracts in a world of perfect private information. In other words, communication has no value from a control perspective in this case. The intuition behind this result is roughly the following. Given perfect private information, every compensation function in the menu will induce a unique outcome/payment point. The principal can line up these outcome/payment combinations to create a single contract based on the observed outcome only. Formally, one takes the upper envelope of the menu of compensation functions. This construction will leave the incentives and payoffs unchanged. In the presence of the decision $d \in D$ we obtain the following result.

PROPOSITION 2. If the agent has perfect private information, direct delegation is performance equivalent to communication-based centralization.

Proof. See Appendix B.

The proof for Proposition 2 exploits the fact that with perfect private information any solution to Program 2, $(H_2(\theta, x), \delta(\theta))$, can be replaced with another solution, $(\hat{H}_2(\theta, x), \hat{\delta}(\theta))$, which satisfies the requirement of decision-rule compatibility. Moreover, the solution $(\hat{H}_2(\theta, x), \hat{\delta}(\theta))$ leaves the agent's incentives unchanged and leads to the same payoffs for both parties. The claim then follows from Proposition 1, which says that $P2$ and $P3$ are equivalent if there exists an optimal solution to $P3$ which satisfies decision-rule compatibility.

In Melumad and Reichelstein [1987], we examine an agency model in which there is no observable decision to be made. It is shown that a menu of contracts is not needed for control purposes if the parties are risk neutral and the conditional probability distribution $F(x \mid \cdot)$ satisfies a spanning condition. To formalize the definition of spanning, suppose first that X, A, D, and Θ are finite sets. For notational convenience we define a new variable which represents the effect of the triple (d, θ, a) on the probability distribution of x. We write $z = h(d, \theta, a)$ so that two combinations (d, θ, a) and $(\bar{d}, \bar{\theta}, \bar{a})$ will be assigned the same value z if and only if they induce the same probability distribution for x.

Formally, suppose that X, A, D, and Θ are finite sets and define:

$$Z = \{z \mid z = h(d, \theta, a) \text{ for } d \in D, \theta \in \Theta, a \in A\}.$$

Let $|Z| = m$ and $|X| = n$ and denote the probability of x given z by $p(x_i \mid z_j)$, i.e., $p(x_i \mid z_j) = F(x_i \mid z_j) - F(x_{i-1} \mid z_j)$ for $2 \le i \le n$ and $p(x_1 \mid z_j) = F(x_1 \mid z_j)$.

DEFINITION 2. The distribution $F(x \mid z)$ admits *spanning* if the matrix $\{p(x_i \mid z_j)\}_{\substack{1 \le i \le n \\ 1 \le j \le m}}$ has rank m.

The spanning requirement implies that observing the stochastic outcome x is as "informative" (in a probabilistic sense) as observing the parameter z. Risk-neutral parties will then be indifferent between contracting on x or on z. It follows from Proposition 2 that Programs 2 and 3 would be equivalent, if the variable z were jointly observable. Therefore, given spanning and risk neutrality, we expect Programs 2 and 3 to have the same value.

PROPOSITION 3. Let X, A, D, and Θ be finite sets. Suppose the principal's and the agent's utility functions take the following separable form:

$$U(d, \theta, a, x, H) = u(d, \theta, a) + x - H$$

$$V(d, \theta, a, x, H) = v(d, \theta, a) + H.$$

If $F(x \mid z)$ admits spanning, direct delegation is performance equivalent to communication-based centralization.

Proof. See Appendix B.

The notion of spanning can be extended beyond the finite case. In Melumad and Reichelstein [1987] we show that, when X and Z are intervals on the real line, many of the standard continuous distributions satisfy a generalized spanning condition. The exponential family provides one example. We conjecture that Proposition 3 will also hold in the continuum case.

4. *Discussion*

The preceding analysis has relied on a number of significant assumptions. The purpose of this section is to examine how our results would change if some of these assumptions were relaxed.

First, in many interesting cases the decision will not remain observable to the principal once it has been delegated to the agent. Demski and Sappington [1986] consider a model of this type. The main issue then becomes that by delegating the decision to the agent, the principal subjects himself to an additional moral hazard problem. Without communication possibilities the principal faces the following trade-off: he can either make the decision in ignorance of the actual environment or delegate the decision to the better-informed agent who will serve his own objective. It is simple to construct examples where either one of these considerations becomes dominant. Consequently, we find that, contrary to the lemma of section 3, centralized decision making without communication may be strictly preferred to delegation, if the delegated decision does not remain observable.

Another essential assumption in our model was the feasibility of penalties sufficiently large to prevent the agent from adopting undesired decisions. We recall that the lemma, as well as Proposition 1, relied on the feasibility of forcing contracts which impose sufficiently large penalties. When there are exogenous limits on these penalties, centralized decision making may strictly dominate delegation; i.e., it may be that $\Gamma(P1) > \Gamma(P3)$ and $\Gamma(P2) > \Gamma(P4)$. Also, in Proposition 1, the "*if*" part may no longer be valid, though the "*only if*" part remains unchanged; that is, delegation is equivalent to communication-based centralization only if there exists an optimal compensation function in $P2$ that is compatible with its corresponding decision rule.

In comparing the different organizational scenarios, we assumed that communication possibilities are either unlimited or nonexistent. In general, however, organizations have limited channels of communication. In our model this would correspond to a situation wherein the agent can send messages that belong to a message space which is of smaller size (dimension or cardinality) than the set of possible environments. We note that our results remain essentially unchanged as long as the message space is at least as large as the set of alternative decisions. If this is not the case, a delegation scheme may permit greater flexibility for designing an appropriate menu of compensation functions and, thus, may dominate communication-based centralization.

Our analysis made use of the assumption that the principal can commit to any decision rule. In general, the optimal communication-based centralization scheme has the feature that the principal would prefer another decision than the one specified by the decision rule in $P2$, given the information revealed by the agent. Therefore, the incentive for truthful revelation relies on the principal's ability to commit. Holmstrom [1984], Rogerson [1985], and Melumad and Mookherjee [1986] observe that delegation schemes gain comparative advantage in situations where the principal cannot commit to making a particular decision in response to information provided by the agent, yet he can commit to a delegation contract.

The centralization versus delegation issue remains largely unexplored in organizations with multiple agents (see, for example, Demski and Sappington [1984] and Mookherjee [1984]). Again, one may consider communication-based centralization schemes, wherein all agents reveal their information to the principal who then makes the decision according to a predetermined rule. In contrast, a delegation scheme would put a particular agent in charge of the decision (if the decision in question has multiple components, then these components may be distributed among various agents). Of course, the agent's decision may be based on communication with other agents. An example, which compares the performance attainable under each organizational scheme, can be found in Marschak and Reichelstein [1986]. There, the case of two agents is considered; both agents are assumed to be indifferent to the decision. As in the single-agent case, a communication-based centralization scheme always weakly dominates any other arrangement. Under certain conditions, however, a hierarchical delegation scheme performs equally well. The principal contracts only with one agent, say agent 1, to whom the decision is delegated. Agent 1 receives messages and contracts with agent 2. The comparative advantage of such a hierarchical arrangement is that it reduces the organization's communication requirements.

APPENDIX A

This appendix provides the essential details of the example in section 3. Recall that $X = \{x_1, x_2\}$ with $x_2 > x_1$, $A = \{a_0, a_1\}$, $D = \{d_0, d_1\}$, and $\Theta = \{\theta_1, \theta_2, \theta_3, \theta_4\}$. Let $q_i > 0$ denote the prior probability of θ_i.

First, we specify how the probability of obtaining the high return x_2 depends on the environment, the agent's action choice, and the decision. Specifically, we assume that there is substitution between $d \in D$, $\theta \in \Theta$, and $a \in A$; i.e., for any combination of (d, θ, a), the effect of an increase in one of the variables is identical to an increase in any of the other variables. Formally, let $p_{j+k+1} = \text{Prob}(x_2 \mid d_j, \theta_k, a_1)$, where $j, l = 0, 1$ and $k = 1, 2, 3, 4$. Assume further that $p_i > 0 \; \forall i$, $p_1 = p_2 = p_3$, and $p_4 - p_3 > p_5 - p_4 > p_6 - p_5 > 0$. The specification that $p_1 = p_2 = p_3$ reflects our assumption that if the environment is θ_1, neither increased effort nor the productive input increases the probability of obtaining x_2.

It is immediately verified that if x_2 is sufficiently large (holding all probabilities and costs fixed), the optimal action choices and decisions are:

$$a(\theta_1) = a_0, \quad \text{and} \quad a(\theta_i) = a_1 \qquad 2 \leq i \leq 4,$$

$$\delta(\theta_1) = d_0, \quad \text{and} \quad \delta(\theta_i) = d_1 \qquad 2 \leq i \leq 4.$$

The least expensive menu of compensation functions that implements these action choices and decisions is:

$$H_2(\theta_1, x_2) - H_2(\theta_1, x_1) = 0 \tag{i}$$

$$H_2(\theta_1, x_1) = 0 \tag{ii}$$

$$H_2(\theta_2, x_2) - H_2(\theta_2, x_1) = \frac{W(a_1)}{p_5 - p_4} \tag{iii}$$

$$H_2(\theta_2, x_1) = W(a_1) \cdot \left(2 - \frac{p_5}{p_5 - p_4}\right) \tag{iv}$$

$$H_2(\theta_3, x_2) - H_2(\theta_3, x_1) = H_2(\theta_2, x_2) - H_2(\theta_2, x_1) \tag{v}$$

$$H_2(\theta_3, x_1) = H_2(\theta_2, x_1) \tag{vi}$$

$$H_2(\theta_4, x_2) - H_2(\theta_4, x_1) = \frac{W(a_1)}{p_6 - p_5} \tag{vii}$$

$$H_2(\theta_4, x_1) = W(a_1) \cdot \left(3 - \frac{p_6}{p_6 - p_5}\right). \tag{viii}$$

A point-by-point comparison of the agent's alternative choices verifies that the above menu induces truth telling, as well as the optimal action choices. This menu is also the least expensive way of supporting these action choices. The "slopes" (*i*), (*iii*), (*v*), and (*vii*) are the smallest necessary to induce the optimal actions, and the "intercepts" (*ii*), (*iv*), (*vi*), and (*viii*) are the minimal ones needed to induce truth telling.

To show that $\Gamma(P3) < \Gamma(P2)$, we recall Proposition 1 which says that delegation is performance equivalent to communication-based centralization if, and only if, there exists an optimal solution $H_2(\theta, x)$ to $P2$ that is compatible with the decision rule. For our example, decision-rule compatibility would require that $H_2(\theta_2, x_i) = H_2(\theta_3, x_i) = H_2(\theta_4, x_i)$, $i = 1, 2$.

Note, however, that the menu in (*i*)–(*viii*) results in the following expected payment for the agent: 0 in θ_1, $W(a_1)$ in θ_2, $2W(a_1)$ in θ_3, and $3W(a_1)$ in θ_4. It is easy to verify that any compensation function which does not distinguish between θ_2, θ_3, and θ_4 has to pay the agent more in states θ_3 and θ_4. This follows from the fact that the increments in the probabilities are decreasing, i.e., $p_4 - p_3 > p_5 - p_4 > p_6 - p_5$. Therefore, $\Gamma(P3) < \Gamma(P2)$ in our example.

In comparison, the optimal delegation contract is:

$$H_3(d_0, x_1) = H_3(d_0, x_2) = 0 \qquad (ix)$$

$$H_3(d_1, x_2) - H_3(d_1, x_1) = \frac{W(a_1)}{p_6 - p_5} \qquad (x)$$

$$H_3(d_1, x_1) = W(a_1) \cdot \left(1 - \frac{p_4}{p_6 - p_5}\right). \qquad (xi)$$

This menu yields the following expected payments to the agent:

$$0 \text{ in } \theta_1, \qquad W(a_1) \text{ in } \theta_2, \qquad W(a_1) \cdot \left(1 + \frac{p_5 - p_4}{p_6 - p_5}\right) \text{ in } \theta_3,$$

and

$$W(a_1) \cdot \left(2 + \frac{p_5 - p_4}{p_6 - p_5}\right) \text{ in } \theta_4,$$

and therefore it results in a strictly larger informational rent for the agent than the menu in (*i*)–(*viii*).

APPENDIX B

Proof of Proposition 2. Consider an optimal solution $(H_2(\theta, x), \delta(\theta))$ to $P2$. According to Proposition 1, we have to find an optimal solution $(\hat{H}_2(\theta, x), \hat{\delta}(\theta))$ such that $\hat{H}_2(\theta, x)$ is compatible with $\hat{\delta}(\theta)$. We set $\hat{\delta}(\theta) = \delta(\theta)$ and define:

$$\hat{H}_2(\theta, x) \equiv \max_{\bar{\theta} \in \delta^{-1}(\delta(\theta))} H_2(\bar{\theta}, x), \text{ where } \delta^{-1}(d) \equiv \{\theta, \mid d = \delta(\theta)\}.$$

(To be rigorous, one would have to replace maximum by supremum. The arguments involved in the proof do not hinge upon the existence of a maximum.)

The function $\hat{H}_2(\theta, x)$ is the upper envelope of the family:

$$\{H_2(\overline{\theta}, x)\}_{\overline{\theta} \in \delta^{-1}(\delta(\theta))}.$$

By construction, $\hat{H}_2(\theta, x)$ is compatible with $\overline{\delta}(\theta) = \delta(\theta)$. If $(\theta, a(\theta))$ is the agent's best response to $(H_2(\theta, x), \delta(\theta))$, then:

$$\hat{H}_2(\theta, x(\delta(\theta), \theta, a(\theta))) = H_2(\theta, x(\delta(\theta), \theta, a(\theta))). \qquad (i)$$

It remains to verify that the compensation function $\hat{H}_2(\cdot, \cdot)$ has the self-selection property and that the agent's action choices, as well as the outcomes and payoffs, remain unchanged. Given the environment θ, let $(\overline{\theta}, \bar{a})$ be any response for the agent under $\hat{H}_2(\cdot, \cdot)$. His utility then becomes:

$$V(\delta(\overline{\theta}), \theta, \bar{a}, x(\delta(\overline{\theta}), \theta, \bar{a}), \hat{H}_2(\overline{\theta}, x(\delta(\overline{\theta}), \theta, \bar{a}))), \qquad (ii)$$

which, by construction, equals:

$$V(\delta(\overline{\theta}), \theta, \bar{a}, x(\delta(\overline{\theta}), \theta, \bar{a}), H_2(\theta^*, x(\delta(\overline{\theta}), \theta, \bar{a})))$$

where:

$$H_2(\theta^*, x(\delta(\overline{\theta}), \theta, \bar{a})) \equiv \max_{\tilde{\theta} \in \delta^{-1}(\delta(\overline{\theta}))} H_2(\tilde{\theta}, x(\delta(\overline{\theta}), \theta, \bar{a})).$$

By construction $\delta(\theta^*) = \delta(\overline{\theta})$. Therefore:

$$(ii) = V(\delta(\theta^*), \theta, \bar{a}, x(\delta(\theta^*), \theta, \bar{a}), H_2(\theta^*, x(\delta(\theta^*), \theta, \bar{a}))). \qquad (iii)$$

Thus, the incentive compatibility of $(H_2(\theta, x), \delta(\theta))$ implies:

$$(iii) \leq V(\delta(\theta), \theta, a(\theta), x(\delta(\theta), \theta, a(\theta)), H_2(\theta, x(\delta(\theta), \theta, a(\theta)))). \qquad (iv)$$

Equation (i) shows that:

$$(iv) = V(\delta(\theta), \theta, a(\theta), x(\delta(\theta), \theta, a(\theta)), \hat{H}_2(\theta, x(\delta(\theta), \theta, a(\theta)))).$$

Hence, under $\hat{H}_2(\cdot, \cdot)$, the agent's best response is again $(\theta, a(\theta))$. The utility payoffs for the principal and the agent remain unchanged, proving our claim.

Proof of Proposition 3. Let $(H_2(\theta, x), \delta(\theta))$ denote an optimal solution to $P2$ which induces the agent to take action $a(\theta)$ and report truthfully.

The proof proceeds by defining (in (i)–(iii) below) a compensation $H_3(d, x)$ which is shown to induce action choices, decisions, and utility payoffs identical to those corresponding to the solution of $P2$. Consider first the expected compensation function:

$$G_2(\theta, z) = \sum_{i=1}^{n} H_2(\theta, x_i) \cdot p(x_i \mid z). \qquad (i)$$

Next, define:

$$G_3(d, z) = \max_{\bar{\theta} \in \delta^{-1}(d)} \{G_2(\bar{\theta}, z)\}. \qquad (ii)$$

Finally, given the function $G_3(d, z)$, the spanning assumption implies that we can find a function $H_3(d, x)$ such that:

$$G_3(d, z) = \sum_{i=1}^{n} H_3(d, x_i) \cdot p(x_i \mid z). \qquad (iii)$$

Now consider any pair $(\bar{a}, \bar{d})$ as a candidate for the agent's response in state θ under the function $H_3(d, x)$ defined in (iii) above. The agent's expected utility then becomes:

$$v(\bar{d}, \theta, \bar{a}) + \sum_{i=1}^{n} H_3(\bar{d}, x_i) \cdot p(x_i \mid h(\bar{d}, \theta, \bar{a})). \qquad (iv)$$

By construction:

$$(iv) = v(\bar{d}, \theta, \bar{a}) + G_3(\bar{d}, h(\bar{d}, \theta, \bar{a})) \qquad (v)$$

and:

$$(v) = v(\bar{d}, \theta, \bar{a}) + \max_{\bar{\theta} \in \delta^{-1}(\bar{d})} G_2(\bar{\theta}, h(\bar{d}, \theta, \bar{a})). \qquad (vi)$$

Let $G_2(\theta^*, h(\bar{d}, \theta, \bar{a})) \equiv \max_{\bar{\theta} \in \delta^{-1}(\bar{d})} G_2(\bar{\theta}, h(\bar{d}, \theta, \bar{a}))$. Then:

$$(vi) = v(\bar{d}, \theta, \bar{a}) + \sum_{i=1}^{n} H_2(\theta^*, x_i) \cdot p(x_i \mid h(\bar{d}, \theta, \bar{a})).$$

Note that by definition $\bar{d} = \delta(\theta^*)$. Therefore:

$$(vi) = v(\delta(\theta^*), \theta, \bar{a}) + \sum_{i=1}^{n} H_2(\theta^*, x_i) \cdot p(x_i \mid h(\delta(\theta^*), \theta, \bar{a})). \qquad (vii)$$

Incentive compatibility of the original $(H_2(\theta, x), \delta(\theta))$ implies that:

$$(vii) \leq v(\delta(\theta), \theta, a(\theta)) + \sum_{i=1}^{n} H_2(\theta, x_i) \cdot p(x_i \mid h(\delta(\theta), \theta, a(\theta))).$$

Thus, we have shown that $(a(\theta), \delta(\theta))$ is a best response for the agent when given the contract $H_3(d, x)$ as defined in (i)–(iii) above. Equations (iv)–(vii) show further that the agent's expected compensation and expected utility under $H_3(d, x)$ are identical to those under $(H_2(\theta, x), \delta(\theta))$. The same is true for the principal.

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