Information Management in Incentive Problems

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We extend the standard procurement model to examine how an agent is optimally induced to acquire valuable planning information before he chooses an unobservable level of cost-reducing effort. Concerns about information acquisition cause important changes in standard incentive contracts. Reward structures with extreme financial payoffs arise, and super-high-powered contracts are coupled with contracts that entail pronounced cost sharing. However, if the principal can assign the planning and production tasks to two different agents, then all contracting distortions disappear and, except for forgone economies of scope, the principal achieves her most preferred outcome.

I. Introduction

In the standard procurement problem (e.g., Baron and Myerson 1982; Laffont and Tirole 1986), the supplier (the agent) is assumed to have complete information about the operating environment from the outset of his relationship with the procurer (the principal).[1] This may be a reasonable approximation of reality in some

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[1] In some investigations, the assumption of complete information for the agent is relaxed. For example, Lewis and Sappington (1993) allow for the possibility of an ignorant agent, Piccione and Tan (1996) consider competition between expert and nonexpert bidders, and Sobel (1993) analyzes models that differ according to what the agent knows and when he knows it.

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settings. In many relevant settings, however, the agent is not omniscient from the outset, and the principal deems it important to motivate the agent to acquire valuable planning information before he acts. For example, a procurer of specialized services may seek to guarantee that a supplier has examined all possible techniques for producing a critical input before production is undertaken. Similarly, a firm may wish to ensure that a management consultant studies carefully all the firm's idiosyncratic needs and characteristics before implementing actions designed to improve the firm's economic performance.

The purpose of this research is to determine how the properties of standard incentive contracts are altered in the presence of such concerns about information management. We develop a simple procurement model that allows us to determine how to best motivate an agent to acquire, to reveal, and to employ information that is socially valuable. We find that concerns about information management give rise to important qualitative changes in optimal incentive contracts. For instance, extreme reward structures arise when the agent's personal cost of acquiring the valuable planning information is sufficiently pronounced. An unusually large amount of cost sharing is introduced in the high-cost environment, and a super-high-powered incentive scheme (under which the agent is paid more than a dollar for every dollar in cost reduction he achieves) is implemented in the low-cost environment.[2] These extreme reward structures are designed to make it less attractive for the agent to simply posit a guess about the prevailing environment rather than to incur the cost required to identify it precisely.[3]

The manner in which the agent is optimally compensated for his planning (i.e., his information acquisition) activities is also noteworthy. The agent's payoffs are not simply increased uniformly to reimburse him for his planning costs. Instead, the agent forfeits these costs when the environment turns out to be relatively unfavorable and recovers the costs (and more) in the more favorable environment. This reimbursement pattern best mitigates the agent's incentive to remain uninformed while claiming to have learned that the

[2] The implementation of super-high-powered contracts requires that realized production costs be observable. If the agent is able to hide (and absorb) realized costs, he will gain financially from doing so when he is promised more than one dollar for every dollar of cost reduction that he achieves.

[3] Technically, these extreme reward structures emerge because the standard truth-telling constraints do not bind at the solution to the principal's problem. The binding constraints are those that ensure that the agent acquires the valuable planning information.

environment is unfavorable to substantial cost reduction. This reward structure may appear unfair on the surface because it provides particularly generous rewards when the task at hand turns out to be relatively easy and substantial penalties when, by chance, the task is relatively difficult. But our analysis suggests that such extreme reward structures may be the most efficient means of motivating the acquisition of critical planning information.

While we focus on the case in which a single agent both acquires the valuable planning information and carries out production (e.g., because of pronounced economies of scope between the two activities), we also consider the possibility that the planning and production tasks might be assigned to two distinct agents. Although such separation of tasks sacrifices any economies of scope from integrated operation, it turns out to eliminate completely the contracting frictions that arise under unified planning and production. In particular, the principal is able to induce the planning agent to acquire and report truthfully the valuable planning information and to induce the producing agent to deliver the ideal level of effort supply in all environments, without affording any rent to either agent. Task separation is particularly valuable here because it enables the principal to deter the planning agent from exaggerating likely production costs while simultaneously inducing the producing agent to work diligently. These two incentives cannot be created simultaneously under integrated planning and production without the sacrifice of excessive rent. To punish the agent for exaggerating likely costs, he must be penalized when realized costs are relatively low. Such penalties eliminate all incentive to provide cost-reducing effort.

Our investigation of these information management issues proceeds as follows. The model of integrated planning and production on which we focus is described in Section II. The incentive scheme that optimally induces planning and production by a single agent is characterized in Section III. Section IV analyzes the case in which the planning and production tasks are assigned to two distinct agents. Extensions of our analysis are discussed in Section V. Proofs of all findings are provided in the Appendix.

Before proceeding, we explain how our analysis differs from others in the literature. Many studies incorporate information management issues but do not analyze how information acquisition is optimally motivated. To illustrate, papers in the auction literature (e.g., Milgrom and Weber 1982; Matthews 1984) consider the incentives that agents have to become better informed about the object being sold before participating in the auction. Craswell (1988) addresses similar issues in his investigation of legal rules, and Lewis and Sappington (1994) ask whether a seller should allow buyers to become perfectly informed about their tastes for the seller's product (at no personal cost). Studies that do consider explicitly how to best motivate information acquisition by an agent include Lambert (1986), Demski and Sappington (1987), Prendergast (1993), and Liu (1995). In contrast to our analysis, these studies do not couple the initial information acquisition problem with a subsequent moral hazard problem.[4] Taylor (1995) analyzes a (double) moral hazard setting in which competing suppliers deliver both diagnostic and repair services. In contrast to our approach, Taylor assumes that repair is not possible without diagnosis and adopts a nonstochastic repair technology.[5]

The gains from task separation in our model provide a direct contrast with the gains from task unification identified in other recent models in the literature (e.g., Baron and Besanko 1992; Gilbert and Riordan 1995). These other models entail two adverse selection problems, and a double marginalization of information rents is avoided through unified supply by a single agent. In contrast, our model incorporates two moral hazard problems, and critical conflicts in motivating desired activities are alleviated through task separation.[6]

II. Description of the Model

There are two parties in the model on which we focus: a principal and an agent. The principal hires the agent to complete a project (e.g., the production of a specialized input). The agent can deliver effort (e), which serves to reduce the measured cost of completing the project. The agent can also acquire private knowledge (θ) about the environment in which he and the principal are operating. For simplicity, we take the environment to be either low-cost (θ_L) or high-cost (θ_H); $\phi_L \in (0, 1)$ (respectively, ϕ_H) will denote the probability that the environment is low-cost (high-cost). The expected net

[4] In direct contrast to the current analysis, Crémer and Khalil (1992) and Lewis and Sappington (1996) examine how best to deter an agent from acquiring information that provides rents but has no social value. Also see Crémer, Khalil, and Rochet (1996), and recall Hirshleifer's (1971) seminal work, which demonstrates how private information acquisition can preclude socially desirable risk sharing.

[5] Taylor (1995) focuses on competition among suppliers and the double moral hazard problem that arises because product performance is affected both by the repair service that suppliers provide and by the care that consumers supply. Although it arises for a different reason, Taylor's finding that suppliers may provide free diagnostic checks is similar in spirit to our finding that, with unified planning and production, the agent does not recover his planning costs in the high-cost environment.

[6] Section IV cites additional studies of the optimal choice between task integration and task separation.

revenues from the project are sufficiently large even in the high-cost environment that the project is always undertaken.

Stochastic elements render the cost of the project, c, a random variable, even when the agent's effort, e, and the environment, θ, are known. We shall denote by $C(e, \theta)$ the expected cost of completing the project in environment $\theta \in \{\theta_L, \theta_H\}$ when the agent delivers effort e. The expected cost of completing the project is lower in the low-cost environment for any level of effort delivered by the agent. The agent's effort reduces expected production costs and does so most effectively in the low-cost environment. Diminishing returns are present in both environments but are less pronounced in the low-cost environment. Furthermore, the rate at which the marginal impact of effort declines as effort increases is small in both environments. Formally, letting the subscript e denote the partial derivative with respect to e, we make the following assumptions: $C(e, \theta_L) < C(e, \theta_H)$; $C_e(\cdot) < 0$; $|C_e(e, \theta_L)| > |C_e(e, \theta_H)|$; $C_{ee}(\cdot) > 0$; $C_{ee}(e, \theta_H) \leq C_{ee}(e, \theta_L)$; and both $C_{eee}(e, \theta_L)$ and $C_{eee}(e, \theta_H)$ are small in absolute value for all $e \geq 0$.[7]

The agent delivers effort at a constant personal cost, which is normalized to unity. The principal can observe realized production costs, c, but cannot observe the agent's effort supply, e. To motivate effort supply, the principal requires the agent to bear a portion of realized production costs. For simplicity, we assume that the principal implements compensation structures that are linear in observed cost.[8] The term R_j will denote the lump-sum payment that the principal promises to the agent when he claims to have discovered that $\theta = \theta_j$ for $j = L, H$; $1 - r_j$ will denote the corresponding fraction of realized production costs that the principal promises to reimburse. The agent bears the remaining fraction, $r_j > 0$, of realized costs. We shall denote by $k > 0$ the private cost that the agent must incur to determine whether the environment is high-cost or low-cost. The principal knows the magnitude of this cost but cannot verify directly whether the agent has incurred the cost. Thus the possibility arises

[7] We assume that it is always optimal for the principal to induce the agent to deliver a strictly positive, finite level of effort. This will be the case, e.g., if $C_e(0, \theta_H) = -\infty$ and $\text{limit}_{e \to \infty} |C_e(e, \theta_L)| < 1$. The assumption that $C_e(e, \theta_L)$ is strictly less than $C_e(e, \theta_H)$ is employed in the proof of proposition 1. More generally, the agent's effort can have the same marginal impact on expected production costs in both environments. When it does, however, the agent's information is valuable for planning purposes only to the extent that it influences the principal's input, as described below.

[8] Linear reward structures may be optimal, e.g., when the principal knows the mean of c conditional on e and θ, but has no other knowledge of the distribution of c. Laffont and Tirole (1986) specify conditions under which linear reward structures are optimal.

that the agent may claim to have studied diligently and identified the prevailing environment when, in fact, he has not.

The principal, like the agent, may supply an unobservable productive input (I) to the project. The principal's input increases at a decreasing rate the value (V) the principal derives from the project and is more effective at enhancing value in the low-cost environment. Formally, $V_I(I, \theta_i) > 0$, $V_{II}(\cdot) < 0$ for $i = L, H$, and $V_I(I, \theta_L) > V_I(I, \theta_H)$ for all $I \geq 0$. Since knowledge of θ informs the ideal choice of I, the principal may rationally induce the agent to discover the realization of θ at private cost k even when k is large and the agent's optimal effort supply does not vary much with θ. We assume that the principal always induces information acquisition by the agent.[9] To abstract from double moral hazard problems, we also assume that the value the principal ultimately derives from her interaction with the agent is inherently difficult to measure and thus is noncontractible.

The interaction between the principal and the agent proceeds as follows. First, the principal offers the agent two distinct reward structures. The agent then decides whether to incur investigation costs, k, in order to discover the environment in which he is operating. He will do so if his expected return under the announced reward structures exceeds his reservation profit level, which is normalized to zero. Having decided whether to incur cost k, the agent next reports his (alleged) finding to the principal. We shall use (R_j, r_j) to denote the reward structure the principal assigns to the agent when he reports the prevailing environment to be θ_j ($j = L, H$). After he is assigned a reward structure, the agent can choose to leave the principal's employ without further penalty.[10] If the agent anticipates

[9] Such behavior is optimal whenever the difference between

$$\max_{I_i, e_i} \left\{ \sum_{i=L}^{H} \phi_i [V(I_i, \theta_i) - C(e_i, \theta_i) - I_i - e_i] \right\}$$

and

$$\max_{I, e} \left\{ \sum_{i=L}^{H} \phi_i [V(I, \theta_i) - C(e, \theta_i) - I - e] + k \right\}$$

is sufficiently large. This will be the case even if k is large and $|C_e(e, \theta_H) - C_e(e, \theta_L)|$ is small for all $e > 0$ as long as $V_I(I, \theta_L) - V_I(I, \theta_H)$ is sufficiently large for all $I > 0$.

[10] Limits on termination penalties are common in practice. Chung (1992) and Stole (1992), e.g., point out that courts often refuse to enforce large termination penalties and provide possible explanations (see also Sappington 1983). The qualitative conclusions that we report below require only that termination penalties be sufficiently small, not that they be absent. If unbounded termination penalties (or initial bonds) were feasible, the principal could extract all rent from the agent and induce efficient behavior by promising to deliver the realized surplus to the agent in return for an initial payment equal to the maximum expected net return from

nonnegative profit from continuing in the principal's employ, however, he remains and next chooses how much effort to supply. Production costs are then observed publicly, and the principal delivers the promised reimbursement to the agent. This interaction between the principal and agent is not repeated, and no renegotiation of contracts is permitted.

To define formally the principal's problem with unified planning and production by a single agent, [P], the following additional notation is helpful. Let $\pi_{ji}(e) \equiv R_j - r_j C(e, \theta_i) - e$ denote the agent's expected profit when he delivers effort e under reward structure (R_j, r_j) when he knows that $\theta = \theta_i$. Similarly, let $\pi_{jo}(e) \equiv R_j - r_j[\phi_L C(e, \theta_L) + \phi_H C(e, \theta_H)] - e$ denote the agent's expected profit when he does not know the actual realization of θ, but claims to have discovered that $\theta = \theta_j$, and so operates under reward structure (R_j, r_j). It is also convenient to define $\pi_i(e) \equiv \pi_{ii}(e)$, $e_i \equiv \text{argmax}_e\, \pi_i(e)$, $e_{ji} \equiv \text{argmax}_e\, \pi_{ji}(e)$, and $e_{jo} \equiv \text{argmax}_e\, \pi_{jo}(e)$. This notation enables us to state [P] as

$$\underset{R_i, r_i, I_i}{\text{maximize}} \sum_{i=L}^{H} \phi_i[V(I_i, \theta_i) - (1 - r_i)C(e_i, \theta_i) - R_i - I_i] \quad (1)$$

subject to, for all $i, j = L, H$,

$$\pi(k) \equiv \phi_L \pi_L(e_L) + \phi_H \pi_H(e_H) - k \geq 0, \quad (2)$$

$$\pi(k) \geq \max\{\pi_{Lo}(e_{Lo}), \pi_{Ho}(e_{Ho})\}, \quad (3)$$

$$\pi_i(e_i) \geq 0, \quad (4)$$

and

$$\pi_i(e_i) \geq \pi_{ji}(e_{ji}) \quad \text{for } j \neq i. \quad (5)$$

The objective function in [P] (expression [1]) reflects the principal's desire to maximize her expected net return from the project. This net return is the difference between the expected value of the project, $V(\cdot)$, and the sum of the principal's direct investment costs, I, and her expected payments to the agent, $R + (1 - r)C(\cdot)$. The individual rationality constraint (expression [2]) ensures that the agent anticipates nonnegative profit when he pays k to discover the environment in which he operates. The information acquisition constraint (expression [3]) ensures that the agent prefers to incur cost k to become informed about the operating environment rather than remain uninformed. The voluntary participation constraints

the operation. This is the well-known prescription for resolving moral hazard concerns when the agent is risk neutral, his legal liability is unlimited, and he initially has no private information about the operating environment.

(expression [4]) guarantee that after he discovers the exact nature of the operating environment, the agent finds it profitable to continue in the principal's employ. The truth-telling constraints (expression [5]) ensure that the agent will report his findings truthfully after he discovers the environment in which he operates.[11]

Before we proceed to characterize the solution to [P], it is useful to review briefly the reward structure the principal implements in the standard procurement problem (e.g., Laffont and Tirole 1986), where the agent is perfectly informed about the operating environment before contracting with the principal.[12] This reward structure, which consists of two compensation schedules, $(\tilde{R}_H, \tilde{r}_H)$ and $(\tilde{R}_L, \tilde{r}_L)$, has four distinguishing characteristics. First, the agent earns no rent in the high-cost environment. Second, cost sharing is introduced in the high-cost environment (so $\tilde{r}_H < 1$). Third, the agent is paid a fixed fee in the low-cost environment and bears all realized production costs (so $\tilde{r}_L = 1$). Fourth, in the low-cost environment, the agent's expected profit is identical under the two compensation structures offered by the principal.[13]

The rationale for these features is straightforward. The binding constraint for the principal is to prevent the agent from claiming to be operating in the high-cost environment when, in fact, he is operating in the low-cost environment. To prevent such cost exaggeration, the principal distorts the reward structure that the agent will select in the high-cost environment $(\tilde{R}_H, \tilde{r}_H)$ to make it particularly unattractive in the low-cost environment, while ensuring that the contract is at least compensatory in the high-cost environment. To do so, the principal sets the $(\tilde{R}_H, \tilde{r}_H)$ contract to provide exactly zero rent in the high-cost environment. Furthermore, cost sharing is introduced $(\tilde{r}_H < 1)$, and the lump-sum payment $(\tilde{R}_H)$ is reduced by the amount of the principal's expected cost-sharing payments to the agent in the high-cost environment. Since these cost-sharing payments exceed the corresponding payments the principal would make under the $(\tilde{R}_H, \tilde{r}_H)$ contract in the low-cost environment, the $(\tilde{R}_H, \tilde{r}_H)$ contract is rendered differentially unattractive to the agent

[11] The revelation principle (e.g., Myerson 1979) ensures that the principal's problem is formulated without loss of generality. We assume that this problem is strictly concave.

[12] Formally, this reward structure is the solution to [P] in the setting in which $k = 0$. Although the two models are similar in spirit, our model with $k = 0$ differs from Laffont and Tirole's (1986) model because we focus on linear reward structures and allow the impact of the agent's effort on realized costs to vary with the realization of θ (i.e., we do not restrict $C_e(e, \theta_L) = C_e(e, \theta_H)$ for all $e \geq 0$).

[13] More formally, $\max_e \{\tilde{R}_L - \tilde{r}_L C(e, \theta_L) - e\} = \max_e \{\tilde{R}_H - \tilde{r}_H C(e, \theta_L) - e\}$. Technically, this equality holds because the $\pi_L(e_L) \geq \pi_{HL}(e_{HL})$ truth-telling constraint ([5] in [P]) binds at the solution to [P] when $k = 0$.

when he knows that he is operating in the low-cost environment. Of course, whenever the agent is induced to deliver cost-reducing effort in the high-cost environment (so $\tilde{r}_H > 0$), he will command rents in the low-cost environment because of his inherent cost advantage. To limit these rents while maximizing the total expected surplus in the low-cost environment, the reward structure that the agent selects in the low-cost environment $(\tilde{R}_L, \tilde{r}_L)$ involves no cost sharing $(\tilde{r}_L = 1)$ and pays the agent a fixed fee equal to the sum of the agent's expected (efficient) operating costs in the low-cost environment and the rents he could secure by claiming to be operating in the high-cost environment.[14]

III. Integrated Planning and Production

Having characterized the solution to the standard problem in which information acquisition (planning) is not a concern, we now examine the optimal incentive contract when the principal must motivate a single agent to carry out both production and planning.

We begin by noting that the standard $\{(\tilde{R}_i, \tilde{r}_i)\}$ reward structure described above will induce the agent to become informed when his planning costs are sufficiently small. This is the case because the informed agent can tailor his effort supply to the prevailing environment and retain the associated cost savings. These cost savings will outweigh planning costs that are sufficiently small, as proposition 1 reports.[15]

PROPOSITION 1. If k is sufficiently small, then the standard reward structure $\{(\tilde{R}_i, \tilde{r}_i)\}$ induces the agent to acquire, report truthfully, and employ the valuable planning information (i.e., the standard reward structure constitutes the solution to [P]).

Proposition 1 indicates that the standard prescription offered in the incentive literature is the correct one not only when the agent is perfectly informed about the operating environment from the outset of his relationship with the principal, but also when the agent's private cost of becoming so informed is sufficiently small. As this

[14] Formally,

$$\tilde{R}_L = \min_e \,[C(e, \theta_L) + e] + \tilde{r}_H[C(\tilde{e}_H, \theta_H) - C(\tilde{e}_{HL}, \theta_L)] + \tilde{e}_H - \tilde{e}_{HL},$$

where $\tilde{e}_H \equiv \text{argmin}_e\, [\tilde{r}_H C(e, \theta_H) + e]$ and $\tilde{e}_{HL} \equiv \text{argmin}_e\, [\tilde{r}_H C(e, \theta_L) + e]$.

[15] Technically, when k is sufficiently small, neither the individual rationality constraint (2) nor the information acquisition constraint (3) binds at the solution to [P]. As is evident from the proof of proposition 1, this conclusion holds when $C_e(e, \theta_L) < C_e(e, \theta_H)$ for all $e \geq 0$ so that the cost-minimizing level of effort varies with θ. If $C_e(e, \theta_L) = C_e(e, \theta_H)$ for all $e \geq 0$, then the standard reward structure will not induce information acquisition for any $k > 0$.

cost increases, however, the standard prescription will not be correct. Additional incentive will be required to motivate the agent to become informed rather than to claim to have discovered the prevailing environment when, in fact, he has not done so.

Notice that the agent can always remain uninformed and simply claim to have incurred cost k and learned that he is operating in the high-cost environment. Doing so might be particularly attractive to the agent because it allows him to simultaneously exaggerate both the planning costs that he has incurred and his expected operating costs. To deter such behavior, the principal reduces to the greatest extent possible the agent's equilibrium expected payoff in the high-cost environment. Since the agent is always free to leave the principal's employ, the maximum penalty that can be imposed on the agent in the high-cost environment is the forfeiture of his investigation costs, k. Thus the agent is promised only zero ongoing expected profit when he discovers that he is operating in the high-cost environment, leaving him with an expected net loss of k in this event.

To further reduce the attraction to the agent of remaining uninformed and claiming to know that he is operating in the high-cost environment, the principal implements cost sharing in the (R_H, r_H) contract. As noted above, increased cost sharing coupled with an offsetting decline in lump-sum payment renders the (R_H, r_H) contract differentially unattractive to the agent who has exaggerated his (expected) costs. More cost sharing (i.e., $r_H < \tilde{r}_H < 1$) is implemented when information acquisition is a concern to counteract the agent's enhanced incentive to exaggerate costs in this environment. The enhanced incentive stems from the direct savings (k) that the agent enjoys if he simply claims that costs are high (θ_H) and remains uninformed.

Because the agent forfeits his information acquisition costs when the environment turns out to be high-cost, he must recover these costs in the low-cost environment. For moderate investigation costs (k), full recovery of these costs is ensured simply by increasing by k/ϕ_L the fixed payment (R_L) the agent receives when he claims to have learned that he is operating in the low-cost environment.[16] To receive this fixed payment, the agent must bear all realized production costs (so $r_L = 1$). For moderate values of k, this obligation deters

[16] This increase in R_L is defined relative to the lump-sum payment that provides the agent who operates in the low-cost environment and bears all realized production costs exactly the expected payoff he could secure by claiming to be operating in the high-cost environment. Formally, R_L is increased by k/ϕ_L above $C(e_L, \theta_L) + r_H[C(e_H, \theta_H) - C(e_{HL}, \theta_L)] + e_L - e_{HL}$, where $e_L \equiv \text{argmin}_e\, [C(e, \theta_L) + e]$, $e_H \equiv \text{argmin}_e\, [r_H C(e, \theta_H) + e]$, and $e_{HL} \equiv \text{argmin}_e\, [r_H C(e, \theta_L) + e]$.

the agent from selecting the (R_L, r_L) reward structure unless he is certain that he is operating in the low-cost environment.

For larger values of k, however, the increment in R_L that guarantees full recovery of investigation costs will more than compensate the agent for the obligation to bear all realized production costs. Consequently, the agent would find it profitable to forgo information acquisition and simply claim to know that he is operating in the low-cost environment in order to collect the large lump-sum payment, R_L.[17] To deter such behavior, the principal alters the (R_L, r_L) reward schedule to ensure that it is attractive to the agent only when he is certain that he is operating in the low-cost environment. She does so by implementing a super-high-powered reward structure ($r_L > 1$) in which the agent's compensation increases more rapidly than realized production costs decline.[18] Such a contract offers particularly large payoffs to the agent when realized costs are low but relatively meager payoffs when costs are high. Consequently, the contract will be attractive to the agent only if he is certain that he is operating in the low-cost environment, where equilibrium cost realizations are particularly likely to be low.

In summary, to best motivate information acquisition, the principal allows the agent to recover the planning costs he incurs only when the environment turns out to be the low-cost one. The principal also couples a super-high-powered contract ($r_L > 1$) with a contract that entails considerable cost sharing ($r_H < \tilde{r}_H < 1$). The distortions in both contracts increase as the agent's planning costs increase because higher planning costs make it more tempting for the agent to remain uninformed. These conclusions are recorded in proposition 2.

PROPOSITION 2. There exists a critical level of planning costs ($\underline{k}$) such that if actual planning costs exceed this level (so $k > \underline{k}$), then at the solution to [P] (i) the agent's payoff in the low-cost environment is large relative to his payoff in the high-cost environment (i.e., $\pi_L(e_L) > \pi_{HL}(e_{HL})$); (ii) a super-high-powered reward structure ($r_L > 1$) is implemented in the low-cost environment and considerable

[17] Technically, both information acquisition constraints ([3] in [P]) bind when k is sufficiently large. Therefore, the agent's equilibrium expected profit is exactly the expected profit he could earn by remaining uninformed and claiming either that the environment is high-cost or that it is low-cost.

[18] As noted above, implementation of super-high-powered incentive contracts requires that realized production costs be readily observed and nonmanipulable. The agent would benefit if he could conceal realized costs when he is promised more than one dollar in payments for every dollar by which observed costs decline. Similarly, the principal would gain financially if she could cause realized costs to rise, since her payments to the agent decline as observed costs rise.

cost sharing ($r_H < \tilde{r}_H < 1$) is implemented in the high-cost environment; and (iii) contracting efficiency declines as information acquisition costs rise (i.e., $dr_L/dk > 0$ and $dr_H/dk < 0$).

Four implications of proposition 2 warrant emphasis. First, property i reveals that the truth-telling constraint that binds in the standard incentive problem does not bind when the principal's primary concern is to motivate the agent to acquire valuable planning information.[19] In particular, when he operates in the low-cost environment, the agent is not indifferent between the two reward structures offered by the principal. Instead, the agent receives particularly attractive rewards in the low-cost environment but suffers an expected financial loss in the high-cost environment. Although this reward structure gives rise to payoffs that may appear arbitrary or unfair, it is the most efficient way to motivate information acquisition in the present setting.

Second, the fact that the agent recovers his planning costs only in the low-cost environment implies that the principal's twin problems of motivating the acquisition and accurately reporting and using valuable planning information are not resolved independently. In particular, the agent's compensation is not simply increased uniformly by the amount of his planning costs. Forcing the agent to recover his planning costs fully in the low-cost environment best mitigates his incentive to exaggerate likely production costs.

Third, properties ii and iii of proposition 2 indicate that information acquisition is optimally induced by providing the agent with more extreme financial stakes in the project. Relative to the standard setting, where the agent is perfectly informed about the environment from the outset, the agent's financial payoff is particularly sensitive to his observed cost performance in the low-cost environment and particularly insensitive in the high-cost environment.[20] These extremes in financial sensitivity help to dissuade the agent from remaining uninformed and simply hazarding a guess about his operating environment. The uninformed agent finds it less attractive to claim that he is operating in the low-cost environment because the large rewards that are promised when realized costs are low are offset by substantial financial penalties when realized costs are high.

[19] In the setting in which $C_e(e, \theta_L) = C_e(e, \theta_H)$ for all $e \geq 0$, neither truth-telling constraint in [P] ever binds as long as $k > 0$.

[20] The same qualitative distortions would arise for large k if the agent's effort were more effective at reducing realized production costs in the high-cost environment (i.e., if $|C_e(e, \theta_H)| > |C_e(e, \theta_L)|$ for all $e \geq 0$). However, in this setting, a super-high-powered contract would be implemented in the high-cost environment, and considerable cost sharing would be implemented in the low-cost environment.

Furthermore, the pronounced cost sharing that is implemented under the (R_H, r_H) contract dampens the agent's expected payoff from remaining uninformed and claiming to be operating in the high-cost environment.

Fourth, property iii of proposition 2 points out that optimal contracting inefficiencies increase as the agent's planning costs (k) increase. This fact suggests that the principal will be particularly eager to discover less costly ways to motivate both planning and production as k becomes large. One possible alternative is analyzed briefly in Section IV.

IV. Separate Planning and Production

The analysis to this point has focused on the case in which the same agent who delivers cost-reducing effort is also the agent who is induced to acquire the valuable planning information. This case of unified planning and production is the most relevant one when there are significant economies of scope between the two tasks. In some settings, however, task separation may not be very costly, as when the central findings of a prototype developer are readily conveyed to a firm that can undertake full-scale production of the prototype. In this section, we characterize briefly the principal's optimal strategy under task separation.

Under task separation, the principal designs reward structures for two distinct agents: (1) a planning agent who, at cost k, can discover the actual operating environment ($\theta \in \{\theta_L, \theta_H\}$), and (2) a producing agent who can deliver unobservable effort (e) that serves to reduce expected operating costs. Payments to the producing agent can vary with realized production costs and with the operating environment, as reported by the planning agent. Similarly, payments to the planning agent can vary both with his report and with realized production costs. Both agents have a reservation profit level of zero, and neither agent can be penalized if he chooses to leave the principal's employ before final production costs are realized.

The timing of the interaction between the principal and agents is as follows. First, the principal specifies the reward structures for both agents. Next, the planning agent decides whether to expend k to learn the prevailing environment. The planning agent next announces publicly his (alleged) finding. Having heard the planning agent's report, the producing agent decides whether to operate under the reward structure that the report engenders.[21] If he decides

[21] At this point, the principal also chooses her input supply (I).

to continue with the project, the producing agent next chooses his effort supply. Final production costs are observed next, and then the principal compensates both agents as promised.

The principal designs the reward structures in order to maximize her expected net returns from the project. We denote by [P2] the principal's problem in this setting of task separation. A formal statement of [P2] is presented in the Appendix. Proposition 3 summarizes the key features of the solution to [P2].

PROPOSITION 3. At the solution to [P2], with separate planning and production, the principal achieves the same expected payoff that she would secure if she could discern the prevailing environment herself at cost k and if the agent's effort supply were observable. Neither agent receives any rent, the planning agent discovers and reports truthfully the prevailing environment, and the producing agent delivers the level of effort that maximizes total expected surplus in the prevailing environment.

The principal is able to achieve the ideal outcome reported in proposition 3 because task separation enables her to create two important incentives simultaneously without ceding rent to the agents. First, she is able to dissuade the planning agent from claiming to have learned that the prevailing environment is the high-cost one when, in fact, he has not incurred any planning costs. She can do so, for example, by punishing the planning agent financially when costs turn out to be low after he claims to have discovered that the environment is the high-cost one.[22] Second, the principal can also eliminate rents and still provide (efficient) incentives for the producing agent to deliver effort supply, even in the high-cost environment. She does so by requiring the producing agent to bear all realized production costs in return for a lump-sum payment that provides zero expected profit in the operating environment reported by the planning agent.

In contrast, the principal cannot create these two incentives simultaneously and preclude rents when the same agent carries out both planning and production. Unless the agent's financial reward increases as realized costs decline, the agent will not deliver any cost-reducing effort. Therefore, if cost-reducing effort is to be induced, the agent cannot be punished effectively should he choose to conserve on planning costs and simply claim to know that he is operating in the high-cost environment. Hence, the principal's preference for

[22] The principal is also able to dissuade the uninformed planning agent from claiming to have discovered that the prevailing environment is the low-cost one. She can do so, e.g., by punishing the planning agent when realized production costs turn out to be high after he reports the environment to be the low-cost one.

task separation here arises from her expanded ability to create multiple desired incentives simultaneously at minimum cost.

As noted in the Introduction, this preference for task separation is not mirrored in the models of Baron and Besanko (1992) and Gilbert and Riordan (1995). Task integration is preferred in those models because suppliers are endowed with two sources of private information, and a double marginalization of information rents is avoided when the same supplier is afforded access to both sources of information. In most other models in the literature (e.g., Riordan and Sappington 1987; Dana 1993; Hirao 1993), the optimal choice between task separation and task integration is ambiguous, varying with critical parameters in the model.

The preference for task separation in our model stems in part from a strong conclusion identified in the contracting literature with correlated signals. Under task separation, realized costs serve as a public signal that is correlated with the private signal that the planning agent is instructed to acquire. The works of Crémer and McLean (1985, 1988), Riordan and Sappington (1988), McAfee, McMillan, and Reny (1989), Hermalin and Katz (1991), and McAfee and Reny (1992), among others, explain how even the slightest correlation between the public and private signals can enable the principal to achieve her most preferred outcome when agents are risk neutral. In contrast, under task integration, the agent has substantial control over the realization of the public signal, thereby limiting its value in securing the principal's preferred outcome.

V. Conclusions

Most investigations of optimal incentive contracts presume that the agent is endowed with complete information about the operating environment from the outset of his relationship with the principal. In contrast, our analysis has examined how incentive contracts are optimally structured in order to motivate the agent to both acquire and employ private information about the environment in which he operates. We found that important differences in incentive contracts arise when the acquisition of valuable planning information must be motivated. For instance, under integrated planning and production, a combination of a super-high-powered contract and one with pronounced cost sharing may be implemented. Furthermore, the agent will tend to fare extremely well financially when, by chance, he happens to be operating in the low-cost environment. In contrast, the agent does not even recover his planning costs when the environment turns out to be the high-cost one. Such extreme reward structures optimally serve to mitigate an agent's incentive to act without detailed knowledge of his operating environment in order to avoid information acquisition costs.[23]

Our analysis was intended to illustrate most simply the changes that arise in optimal procurement contracts when information management concerns arise. Clearly, the simple model that we have analyzed in a procurement setting would benefit from a variety of extensions. For example, richer information structures and corresponding reward structures warrant investigation.[24] It would also be useful to analyze the properties of optimal reward structures in settings in which the agent is privately informed about his planning costs, competition among agents (or principals) is present, and quality or reputation concerns arise. Double moral hazard issues also warrant investigation. Such an investigation could be undertaken in the context of our model by allowing the ultimate value of the project to be observable or by allowing the principal's input to affect project costs rather than project benefits.

Our model of task separation might also be usefully extended to consider alternative contracting arrangements. For example, suppose that the principal's commitment powers were limited, so that she could not credibly promise to refrain from renegotiating her contract with the producing agent after she has finalized her contract with the planning agent. In such a setting, the principal will generally have incentives to renegotiate fixed-fee production contracts. In particular, when the planning agent's reward schedule imposes penalties on him when realized costs turn out to be low (in order to dissuade him from falsely claiming to know that the high-cost environment prevails), the principal will have a financial incentive to increase the likelihood that low costs will be realized. She can do so by providing the producing agent with particularly pro-

[23] The information management concerns that we analyze are unlikely to be the only cause of extreme reward structures in practice. Therefore, these concerns are best viewed as possible (and partial) causes, rather than as the sole cause, of extreme reward structures.

[24] It is important to emphasize that our main qualitative conclusions are not an artifact of the simplifying assumption that θ is a binary random variable. It is tedious, but not difficult, to show, e.g., that if (i) $\theta \in \{\theta_L, \theta_M, \theta_H\}$, where $\theta_L < \theta_M < \theta_H$; (ii) $\theta_M = \phi_L\theta_L + \phi_M\theta_M + \phi_H\theta_H$, so that θ_M, the intermediate value of θ, is also the mean value of θ; and (iii) $C(e, \theta) = \theta - d(e)$, where $d'(e) > 0$ and $d''(e) < 0$ for all $e \geq 0$, then the principal will employ a super-high-powered incentive scheme ($r_L > 1$) to motivate information acquisition whenever $k > \phi_L(\theta_M - \theta_L)$. Therefore, a super-high-powered scheme is a component of the optimal procurement mechanism even when the agent who has not learned the true value of θ can claim to have discovered that his prior beliefs were correct (i.e., that $\theta = \theta_M$), and so the agent is not forced to announce an "extreme" realization of θ.

nounced incentives for effort supply. It can be shown that because of these incentives, when the principal's commitment powers are limited, the equilibrium contract with the producing agent will be super-high-powered ($r_H > 1$) in the high-cost environment and will involve cost sharing ($r_L < 1$) in the low-cost environment.[25] These distortions make the choice between task integration and task separation less clear-cut than it is when the principal's commitment powers are unimpeded, and suggest an interesting avenue for future research.

Appendix

A. *Proof of Proposition 1*

It will suffice to show that when k is sufficiently small, the agent prefers to incur cost k to learn the realization of θ rather than remain uninformed when he is presented with the standard incentive contract $\{(\tilde{R}_i, \tilde{r}_i)\}$. This fact follows from

$$\begin{aligned}\tilde{\pi}(k) &\equiv \phi_L\{\tilde{R}_L - \min_e [\tilde{r}_L C(e, \theta_L) + e]\} \\ &\quad + \phi_H\{\tilde{R}_H - \min_e [\tilde{r}_H C(e, \theta_H) + e]\} - k \\ &= \phi_L\{\tilde{R}_H - \min_e [\tilde{r}_H C(e, \theta_L) + e]\} \\ &\quad + \phi_H\{\tilde{R}_H - \min_e [\tilde{r}_H C(e, \theta_H) + e]\} - k \qquad \text{(A1)} \\ &> \phi_L[\tilde{R}_H - \tilde{r}_H C(\tilde{e}_{Ho}, \theta_L) - e_{Ho}] \\ &\quad + \phi_H[\tilde{R}_H - \tilde{r}_H C(\tilde{e}_{Ho}, \theta_H) - e_{Ho}] - k \\ &= \tilde{R}_H - \tilde{r}_H \sum_{i=L}^{H} \phi_i C(\tilde{e}_{Ho}, \theta_i) - e_{Ho} - k \equiv \tilde{\pi}_H(0) - k,\end{aligned}$$

where

$$\tilde{e}_{Ho} \equiv \operatorname*{argmin}_e \left[\tilde{r}_H \sum_{i=L}^{H} \phi_i C(e, \theta_i) + e\right]. \qquad \text{(A2)}$$

The first equality in (A1) holds because, by design, the agent who knows that $\theta = \theta_L$ is indifferent between the $(\tilde{R}_L, \tilde{r}_L)$ and the $(\tilde{R}_H, \tilde{r}_H)$ reward

[25] Notice that these qualitative distortions are in direct contrast to the distortions commonly reported in the incentive literature. In the standard incentive contract, a low-powered contract (i.e., one with cost sharing) is implemented in the high-cost environment, not a super-high-powered contract. Furthermore, a high-powered (fixed-fee) contract is typically implemented in the low-cost environment, not a low-powered contract.

structures. The inequality in (A1) holds because, since $C_e(e, \theta_L) < C_e(e, \theta_H)$ for all $e \geq 0$, $\tilde{e}_{Ho} \neq \text{argmin}_e\, [\tilde{r}_H C(e, \theta_L) + e]$. Expression (A1) reveals that $\tilde{\pi}(k) > \tilde{\pi}_H(0)$ for k sufficiently small. Similar arguments reveal that $\tilde{\pi}(k) > \tilde{\pi}_L(0) - k$, where

$$\tilde{\pi}_L(0) \equiv \tilde{R}_L - \min_e \left[\tilde{r}_L \sum_{i=L}^{H} \phi_i C(e, \theta_i) + e \right].$$

Q.E.D.

B. *Proof of Proposition 2*

The proof proceeds as follows. First, in part 1, the necessary conditions for an interior solution to [P] are derived. Next, these conditions are employed in part 2 to prove properties i and ii of the proposition. Finally, part 3 of the proof employs a reformulation of the principal's problem to derive the comparative static conclusions cited in property iii of the proposition.

1. Deriving the Necessary Conditions for a Solution to [P]

Let λ_i and λ_{ij} denote the Lagrange multipliers associated with constraints (4) and (5), respectively, in [P]. Also let λ_i^I for $i = L, H$ denote the Lagrange multiplier associated with the constraint $\pi(k) \geq \pi_{io}(e_{io})$ that is implicit in (3). Now observe that since $\pi_{Ho}(e_{Ho}) > \pi_H(e_H) \geq 0$, constraint (2) will be satisfied whenever constraints (3) and (4) are satisfied. Therefore, constraint (2) can be ignored. Next, construct the Lagrangean function associated with [P]. Differentiating this function with respect to R_H, R_L, r_H, and r_L provides equations (A3)–(A6), respectively, which constitute the key necessary conditions for an interior solution to [P]:

$$-\phi_H + (\lambda_L^I + \lambda_H^I)\phi_H - \lambda_H^I + \lambda_{HL} - \lambda_{LH} + \lambda_H = 0, \tag{A3}$$

$$-\phi_L + (\lambda_L^I + \lambda_H^I)\phi_L - \lambda_L^I + \lambda_{LH} - \lambda_{HL} = 0, \tag{A4}$$

$$\begin{aligned} &[\phi_H(1 - \lambda_L^I - \lambda_H^I) - \lambda_{HL} - \lambda_H] C(e_H, \theta_H) + \lambda_{LH} C(e_{HL}, \theta_L) \\ &+ \lambda_H^I[\phi_L C(e_{Ho}, \theta_L) + \phi_H C(e_{Ho}, \theta_H)] - \phi_H(1 - r_H) C_e(e_H, \theta_H) \frac{de_H}{dr_H} = 0, \end{aligned} \tag{A5}$$

and

$$\begin{aligned} &[\phi_L(1 - \lambda_L^I - \lambda_H^I) - \lambda_{LH}] C(e_L, \theta_L) + \lambda_{HL} C(e_{LH}, \theta_H) \\ &+ \lambda_L^I[\phi_L C(e_{Lo}, \theta_L) + \phi_H C(e_{Lo}, \theta_H)] - \phi_L(1 - r_L) C_e(e_L, \theta_L) \frac{de_L}{dr_L} = 0. \end{aligned} \tag{A6}$$

The envelope theorem is employed in deriving equations (A5) and (A6), recognizing that e_H, e_L, e_{HL}, and e_{LH} are determined by the agent's optimizing behavior. Substituting from (A3) into (A5) and from (A4) into (A6) reveals

$$\phi_H(1 - r_H)C_e(e_H, \theta_H)\frac{de_H}{dr_H} = -\lambda_H^I\left[C(e_H, \theta_H) - \sum_{i=L}^{H}\phi_i C(e_{Ho}, \theta_i)\right] - \lambda_{LH}[C(e_H, \theta_H) - C(e_{HL}, \theta_L)] \tag{A7}$$

and

$$\phi_L(1 - r_L)C_e(e_L, \theta_L)\frac{de_L}{dr_L} = \lambda_L^I\left[\sum_{i=L}^{H}\phi_i C(e_{Lo}, \theta_i) - C(e_L, \theta_L)\right] + \lambda_{HL}[C(e_{LH}, \theta_H) - C(e_L, \theta_L)]. \tag{A8}$$

2. Proving Properties i and ii

We now employ equalities (A3), (A4), (A7), and (A8) along with inequalities (2)–(5) to prove properties i and ii of the proposition.

Proof of property ii:—$r_L > 1$.—Since all Lagrange multipliers are nonnegative and since $de_i/dr_i > 0$ for $i = L, H$, (A7) and (A8) imply that $r_L > 1 > r_H$ if $\lambda_L^I > 0$ and $\lambda_H^I > 0$. Thus the proof of property ii is complete if we can show that there exists a finite $\underline{k}$ such that if $k > \underline{k}$, then $\lambda_H^I > 0$ and $\lambda_L^I > 0$. To do so, first notice from summing (A3) and (A4) that

$$\lambda_H = 1 \quad \text{and so } \pi_H(e_H) \equiv R_H - r_H C(e_H, \theta_H) - e_H = 0. \tag{A9}$$

Now suppose that $\lambda_H^I = 0$. Then (A3) and (A9) imply that $\lambda_{LH} > 0$. Consequently, (A7) and (A8) imply that $r_L \geq 1 > r_H$. These facts, the fact that $C_e(e, \theta_L) < C_e(e, \theta_H)$, and (A9) together imply

$$\begin{aligned}\pi_{Ho}(e_{Ho}) - \pi_{Lo}(e_{Lo}) &= r_L\sum_{i=L}^{H}\phi_i C(e_{Lo}, \theta_i) + e_{Lo} - [r_L C(e_L, \theta_L) + e_L] \\ &\quad - \left\{r_H\sum_{i=L}^{H}\phi_i C(e_{Ho}, \theta_i) + e_{Ho} - [r_H C(e_{HL}, \theta_L) + e_{HL}]\right\} > 0.\end{aligned} \tag{A10}$$

Inequality (A10) implies that if $\lambda_H^I = 0$, then $\lambda_L^I = 0$. With $\lambda_H^I = \lambda_L^I = 0$, (A4) implies that $\lambda_{LH} = \phi_L$, and so $\lambda_{HL} = 0$. Together, $\lambda_{LH} > 0$ and (A9) imply

$$\begin{aligned}\pi(k) &= \phi_L\pi_L(e_L) - k \\ &= \phi_L\{r_H[C(e_H, \theta_H) - C(e_{HL}, \theta_L)] + e_H - e_{HL}\} - k.\end{aligned} \tag{A11}$$

Furthermore, since r_H (and hence e_H and e_{HL}) does not vary with k under these conditions (see [A5]), (A11) provides a contradiction of (2) for k sufficiently large. Hence, $\lambda_H^I > 0$ for k sufficiently large.

If $\lambda_H^I > 0$ and $\lambda_L^I = 0$, then it is readily verified that r_H and r_L do not vary with k. Therefore, it is straightforward to demonstrate that

$$\frac{\partial}{\partial k}[\pi_{Lo}(e_{Lo}) - \pi_{Ho}(e_{Ho})] = \frac{1}{\phi_L}. \quad \text{(A12)}$$

Equation (A12) implies that for k sufficiently large, both λ_H^I and λ_L^I will be strictly positive at the solution to [P].

Proof of property i: $\pi_L(e_L) > \pi_{HL}(e_{HL})$.—The proof proceeds by contradiction. We shall show that if $\pi_L(e_L) = \pi_{HL}(e_L)$, then $\pi_L(e_L)$, the expected net return of the agent who knows $\theta = \theta_L$, will be smaller than the value that $\pi_L(e_L)$ must assume to ensure that $\pi(k) = \pi_{Ho}(e_{Ho})$. We know that this equality must hold since, from the proof of property ii, $\lambda_H^I > 0$ at the solution to [P] for k sufficiently large.

If $\pi_L(e_L) = \pi_{HL}(e_{HL})$, then it follows from (5) and (A9) that

$$\pi_L(e_L) = r_H[C(e_H, \theta_H) - C(e_{HL}, \theta_L)] + e_H - e_{HL}. \quad \text{(A13)}$$

Since $\lambda_H^I > 0$ for k sufficiently large, it follows from (3) and (A9) that

$$\pi_L(e_L) = \frac{1}{\phi_L}\left\{r_H\left[C(e_H, \theta_H) - \sum_{i=L}^{H}\phi_i C(e_{Ho}, \theta_i)\right] + (e_H - e_{Ho}) + k\right\}. \quad \text{(A14)}$$

Defining $\Delta(r_H)$ to be the difference between $\pi_L(e_L)$ when $\lambda_H^I > 0$ and when $\lambda_{LH} > 0$, it follows from (A13), (A14), and the envelope theorem that

$$\begin{aligned}\frac{d\Delta(r_H)}{dk} = \frac{1}{\phi_L} + \frac{dr_H}{dk}\Bigg\{&\frac{1}{\phi_L}\left[C(e_H, \theta_H) - \sum_{i=L}^{H}\phi_i C(e_{Ho}, \theta_i)\right] \\ &- [C(e_H, \theta_H) - C(e_{HL}, \theta_L)]\Bigg\}.\end{aligned} \quad \text{(A15)}$$

It is readily verified that the expression in braces in (A15) will be nonpositive if $\tilde{C}(e(\phi)\,|\,\phi) \equiv \phi\, C(e(\phi), \theta_H) + (1 - \phi)\, C(e(\phi), \theta_L)$ is concave in ϕ, where $e(\phi) \equiv \text{argmin}_e\, [r_H C(e|\phi) + e]$. It can be shown that $\tilde{C}(\cdot)$ will be concave in ϕ if (1) $C_{eee}(e, \theta_i) \geq 0$ for all $e \geq 0$ for $i = L, H$ or (2) $C_{eee}(\cdot)$ is negative but sufficiently small in absolute value. Equation (A15) implies that, as long as $\tilde{C}(\cdot)$ is concave in ϕ, $dr_H/dk \leq 0$ (which will be proved below), and $\lambda_H^I > 0$ at the solution to [P] (which will be the case for k sufficiently large), then the following conditions hold: (*a*) if $\pi_L(e_L) = \pi_{HL}(e_{HL})$ for a particular k_1, then $\pi_L(e_L) > \pi_{HL}(e_{HL})$ for all $k > k_1$; and (*b*) if $\pi_L(e_L) > \pi_{HL}(e_{HL})$ for a particular k_2, then $\pi_L(e_L) > \pi_{HL}(e_{HL})$ for all $k > k_2$. Consequently, $\pi_L(e_L) > \pi_{LH}(e_{LH})$ at the solution to [P] for k sufficiently large.

3. Proving Property iii: $dr_L/dk > 0$ and $dr_H/dk < 0$

Recall from the proof of property ii that $\lambda_H^I > 0$ and $\lambda_L^I > 0$ at the solution to [P] when k is sufficiently large. Consequently,

$$\pi_{Lo}(e_{Lo}) = \pi_{Ho}(e_{Ho}). \quad \text{(A16)}$$

Differentiating equality (A16) reveals

$$\frac{dr_L}{dr_H} = -\frac{\left[C(e_H, \theta_H) - \sum_{i=L}^{H} \phi_i C(e_{Ho}, \theta_i) + e_H - e_{Ho}\right] \frac{\phi_H}{\phi_L}}{C(e_L, \theta_L) - \sum_{i=L}^{H} \phi_i C(e_{Lo}, \theta_i)} > 0. \quad \text{(A17)}$$

Furthermore, when equality (A16) holds, the expected rent that accrues to the agent is

$$M(r_H) \equiv r_H\left[C(e_H, \theta_H) - \sum_{i=L}^{H} \phi_i C(e_{Ho}, \theta_i)\right] + e_H - e_{Ho}.$$

Therefore, the principal's problem is effectively to choose r_H to maximize the difference between total expected surplus and expected rent to the agent, subject to the restriction given by (A17). Formally, the principal's problem can be restated as

$$\underset{r_H}{\text{maximize}}\ G(r_H) \equiv \sum_{i=L}^{H} \phi_i[V(I_i, \theta_i) - C(e_i, \theta_i) - I_i - e_i] - k - M(r_H) \quad \text{(A18)}$$

subject to (A17). It follows from (A17) and the envelope theorem that the optimal value of r_H is given by

$$\begin{aligned} Z \equiv G'(r_H) = &-\phi_H[C_e(e_H, \theta_H) + 1]\frac{de_H}{dr_H} \\ &- \phi_L[C_e(e_L, \theta_L) + 1]\left(\frac{de_L}{dr_L}\right)\left(\frac{dr_L}{dr_H}\right) \\ &- \left[C(e_H, \theta_H) - \sum_{i=L}^{H} \phi_i C(e_{Ho}, \theta_i)\right] = 0. \end{aligned} \quad \text{(A19)}$$

Since the principal's problem is strictly concave in r_H, (A19) implies that

$$\begin{aligned} \frac{dr_H}{dk} \overset{s}{=} \left(\frac{\partial Z}{\partial r_L}\right)\left(\frac{\partial r_L}{\partial k}\right) = \frac{\partial r_L}{\partial k}\Bigg(\frac{\partial}{\partial r_L}&\left\{-\phi_L[C_e(e_L, \theta_L) + 1]\frac{de_L}{dr_L}\right\}\frac{dr_L}{dr_H} \\ &- \phi_L[C_e(e_L, \theta_L) + 1]\frac{de_L}{dr_L}\left[\frac{d}{dr_L}\left(\frac{dr_L}{dr_H}\right)\right]\Bigg). \end{aligned} \quad \text{(A20)}$$

When $\lambda_L^I > 0$, it follows from (A8) that $C_e(e_L, \theta_L) + 1 > 0$. It follows from (A17) that $(d/dr_L)(dr_L/dr_H) \geq 0$ if $C_{e}(e, \theta_H) \leq C_{e}(e, \theta_L)$ for all $e \geq 0$ and if $C_{eee}(\cdot)$ is either negative or positive but sufficiently small in absolute value. It can also be shown that

$$\frac{\partial}{\partial r_L}\left\{-\phi_L[C_e(e_L, \theta_L) + 1]\frac{de_L}{dr_L}\right\}$$

is negative if $C_{eee}(\cdot) \geq 0$ or $C_{eee}(\cdot)$ is negative but sufficiently small in absolute value. Therefore, since $de_L/dr_L > 0$ and $dr_L/dr_H > 0$ from (A17), (A20) implies

$$\frac{dr_H}{dk} \overset{s}{=} -\frac{\partial r_L}{\partial k} < 0 \tag{A21}$$

when $C_{ee}(e, \theta_H) \leq C_{ee}(e, \theta_L)$ for all $e \geq 0$ and when $C_{eee}(\cdot)$ is sufficiently small in absolute value. The inequality in (A21) follows from differentiating the equality

$$\pi(k) = \pi_{Lo}(e_{Lo}) \tag{A22}$$

and from the envelope theorem. Equality (A22) holds because $\lambda_L^I > 0$.

Finally, to determine the sign of dr_L/dk, it follows from (A19) that

$$\frac{\partial^2 G}{\partial r_H^2}\left(\frac{dr_H}{dk}\right) + \left\{\frac{\partial^2 G}{\partial r_L^2}\left(\frac{dr_L}{dr_H}\right) + \frac{\partial G}{\partial r_L}\left[\frac{d}{dr_L}\left(\frac{dr_L}{dr_H}\right)\right]\right\}\frac{dr_L}{dk} = 0. \tag{A23}$$

Expressions (A21) and (A23) imply that $dr_L/dk > 0$ under the maintained assumptions. Q.E.D.

The following notation is useful in stating [P2] and in proving proposition 3. The notation here parallels that in the text, except that we employ the superscript 1 to denote the planning agent and the superscript 2 to denote the producing agent.

We shall denote by R_j^n the fixed fee paid to agent n (for $n = 1, 2$) when the planning agent reports that $\theta = \theta_j$ (for $j = L, H$). We shall use r_j^n to denote the corresponding fraction of realized costs borne by agent n. The principal bears the fraction $1 - r_j^1 - r_j^2$ of realized costs when the planning agent announces that $\theta = \theta_j$.

The expression $\pi_{ji}^1 \equiv R_j^1 - r_j^1 C(e_j, \theta_i)$ will denote the expected (ongoing) profit of the planning agent who discovers that $\theta = \theta_i$ and reports that $\theta = \theta_j$. Furthermore, $\pi_{jo}^1 \equiv R_j^1 - r_j^1[\phi_L C(e_j, \theta_L) + \phi_H C(e_j, \theta_H)]$ will denote the expected profit of the planning agent who has not discovered the realization of θ but claims to know $\theta = \theta_j$.

The expression $\pi_i^2(e) \equiv R_i^2 - r_i^2 C(e, \theta_i) - e$ will denote the expected profit of the producing agent who exerts effort e following a truthful report of θ_i by the planning agent. The expression $e_i \equiv \text{argmax}_e\, \pi_i^2(e)$ will denote the corresponding effort supply that maximizes the expected net return of the producing agent.

With this notation, [P2] is readily stated as

$$\max_{R_i^n, r_i^n, I_i} \sum_{i=L}^{H} \phi_i[V(I_i, \theta_i) - (1 - r_i^1 - r_i^2)C(e_i, \theta_i) - R_i^1 - R_i^2 - I_i]$$

subject to, for all $i, j = L, H$,

$$\pi^1(k) \equiv \phi_L\pi_L^1 + \phi_H\pi_H^1 - k \geq 0, \tag{A24}$$

$$\pi^1(k) \geq \pi^1(0) \equiv \text{maximum}\{\pi_{Lo}^1, \pi_{Ho}^1\}, \tag{A25}$$

$$\pi_i^1 \geq 0, \tag{A26}$$

$$\pi_i^1 \equiv \pi_{ii}^1 \geq \pi_{ji}^1 \quad \text{for } j \neq i, \tag{A27}$$

and

$$\pi_i^2(e_i) \geq 0. \tag{A28}$$

The planning agent's individual rationality constraint (A24) ensures that he expects nonnegative profit from his interaction with the principal. The information acquisition constraint (A25) ensures that the planning agent prefers to incur cost k to discover the realization of θ rather than remain uninformed. The voluntary participation constraints for the planning agent (A26) ensure that he anticipates earning at least his reservation profit level, regardless of his initial finding about the operating environment. The truth-telling constraints for the planning agent (A27) ensure that he will report truthfully the realization of θ that he observes. The voluntary participation constraints for the producing agent guarantee that he anticipates earning at least his reservation profit level in both the high-cost and the low-cost environments.

C. *Proof of Proposition 3*

The proof proceeds by construction. We shall show that the reward structures specified in (A29)–(A32) ensure the ideal outcome for the principal that is summarized in the statement of the proposition:

$$R_L^1 = r_L^1 = 0, \tag{A29}$$

$$R_H^1 = r_H^1 C(e_H^*, \theta_H) + \frac{k}{\phi_H}, \tag{A30}$$

$$R_L^2 = C(e_L^*, \theta_L) + e_L^*; \quad r_L^2 = 1, \tag{A31}$$

and

$$R_H^2 = C(e_H^*, \theta_H) + e_H^*; \quad r_H^2 = 1, \tag{A32}$$

where

$$e_i^* \equiv \underset{e}{\operatorname{argmin}} \, [C(e, \theta_i) + e]. \tag{A33}$$

Equations (A31) and (A32) guarantee that $e_i = e_i^*$ and $\pi_i^2(e_i) = 0$ for $i = 1, 2$. Furthermore, it follows from (A29) and (A30) that

$$\pi^1(k) = \phi_H\left(\frac{k}{\phi_H}\right) + \phi_L(0) - k = 0. \tag{A34}$$

Equation (A34) implies that (A24) is satisfied.

Equations (A29) and (A30) also imply that

$$\pi_L^1 = 0, \quad \pi_H^1 = \frac{k}{\phi_H} > 0. \tag{A35}$$

Expression (A35) ensures that (A26) is satisfied.

It follows from (A29) and (A30) that if the following inequality holds, then $\pi_L^1 \geq \pi_{HL}^1$:

$$0 \geq R_H^1 - \left[\frac{R_H^1 - (k/\phi_H)}{C(e_H^*, \theta_H)}\right]. \tag{A36}$$

It follows from (A36) that $\pi_L^1 \geq \pi_{HL}^1$ if

$$R_H^1 \leq -\frac{k}{\phi_H}\left[\frac{C(e_H^*, \theta_L)}{C(e_H^*, \theta_H) - C(e_H^*, \theta_L)}\right]. \tag{A37}$$

Also notice from (A29) and (A30) that $\pi_H^1 = R_H^1 - r_H^1 C(e_H^*, \theta_H) = k/\phi_H > 0 = \pi_{LH}^1$. Therefore, the truth-telling constraints (A27) will be satisfied as long as R_H^1 satisfies inequality (A37).

It only remains to show that (A25) is satisfied under the prescribed reward structures. Notice that

$$\begin{aligned}\pi^1(0) &= \max\{0, R_H^1 - r_H^1[\phi_L C(e_H^*, \theta_L) + \phi_H C(e_H^*, \theta_H)]\} \\ &= \max\left\{0, z\left(\frac{k}{\phi_h}\right) + (1 - z)R_H^1\right\},\end{aligned} \tag{A38}$$

where

$$z = \frac{\phi_L C(e_H^*, \theta_L) + \phi_H C(e_H^*, \theta_H)}{C(e_H^*, \theta_H)}. \tag{A39}$$

The second equality in (A38) follows from (A30) and some straightforward rearranging of terms. It then follows from (A34) and (A37)–(A39) that the proof is complete if

$$R_H^1 \leq \min\left\{-\frac{k}{\phi_H}\left[\frac{C(e_H^*, \theta_L)}{C(e_H^*, \theta_H) - C(e_H^*, \theta_L)}\right], -\frac{k}{\phi_H}\frac{z}{1 - z}\right\}. \tag{A40}$$

It is straightforward to verify that inequality (A40), and thus inequalities (A24)–(A28), will be satisfied under the reward structures identified in (A29)–(A33) provided that $R_H^1 \leq -(k/\phi_H)[z/(1 - z)]$. Q.E.D.

References

Baron, David P., and Besanko, David. "Information, Control, and Organizational Structure." *J. Econ. and Management Strategy* 1 (Summer 1992): 237–75.

Baron, David P., and Myerson, Roger B. "Regulating a Monopolist with Unknown Costs." *Econometrica* 50 (July 1982): 911–30.

Chung, Tai-Yeong. "On the Social Optimality of Liquidated Damage

Clauses: An Economic Analysis." *J. Law, Econ., and Organization* 8 (April 1992): 280–305.

Craswell, Richard. "Precontractual Investigation as an Optimal Precaution Problem." *J. Legal Studies* 17 (June 1988): 401–36.

Crémer, Jacques, and Khalil, Fahad. "Gathering Information before Signing a Contract." *A.E.R.* 82 (June 1992): 566–78.

Crémer, Jacques; Khalil, Fahad; and Rochet, Jean-Charles. "Strategic Information Gathering before a Contract Is Offered." Manuscript. Toulouse: Inst. d'Economie Industrielle, June 1996.

Crémer, Jacques, and McLean, Richard D. "Optimal Selling Strategies under Uncertainty for a Discriminating Monopolist When Demands Are Interdependent." *Econometrica* 53 (March 1985): 345–61.

———. "Full Extraction of the Surplus in Bayesian and Dominant Strategy Auctions." *Econometrica* 56 (November 1988): 1247–57.

Dana, James D., Jr. "The Organization and Scope of Agents: Regulating Multiproduct Industries." *J. Econ. Theory* 59 (April 1993): 288–310.

Demski, Joel S., and Sappington, David E. M. "Delegated Expertise." *J. Accounting Res.* 25 (Spring 1987): 68–89.

Gilbert, Richard J., and Riordan, Michael H. "Regulating Complementary Products: A Comparative Institutional Analysis." *Rand J. Econ.* 26 (Summer 1995): 243–56.

Hermalin, Benjamin E., and Katz, Michael L. "Moral Hazard and Verifiability: The Effects of Renegotiation in Agency." *Econometrica* 59 (November 1991): 1735–53.

Hirao, Yukiko. "Task Assignment and Agency Structures." *J. Econ. and Management Strategy* 2 (Summer 1993): 299–323.

Hirshleifer, Jack. "The Private and Social Value of Information and the Reward to Inventive Activity." *A.E.R.* 61 (September 1971): 561–74.

Laffont, Jean-Jacques, and Tirole, Jean. "Using Cost Observation to Regulate Firms." *J.P.E.* 94, no. 3, pt. 1 (June 1986): 614–41.

Lambert, Richard A. "Executive Effort and Selection of Risky Projects." *Rand J. Econ.* 17 (Spring 1986): 77–88.

Lewis, Tracy R., and Sappington, David E. M. "Ignorance in Agency Problems." *J. Econ. Theory* 61 (October 1993): 169–83.

———. "Supplying Information to Facilitate Price Discrimination." *Internat. Econ. Rev.* 35 (May 1994): 309–27.

———. "Cream-Skimming, Cost-Sharing, and Subjective Risk Adjusting in the Health Care Industry." Manuscript. Gainesville: Univ. Florida, Dept. Econ., June 1996.

Liu, Wei-Lin. "Motivating and Compensating Investment Advisors." Manuscript. Gainesville: Univ. Florida, Dept. Econ., October 1995.

McAfee, R. Preston; McMillan, John; and Reny, Philip J. "Extracting the Surplus in the Common-Value Auction." *Econometrica* 57 (November 1989): 1451–59.

McAfee, R. Preston, and Reny, Philip J. "Correlated Information and Mechanism Design." *Econometrica* 60 (March 1992): 395–421.

Matthews, Steven A. "Information Acquisition in Discriminatory Auctions." In *Bayesian Models in Economic Theory,* edited by Marcel Boyer and Richard E. Kihlstrom. Amsterdam: North-Holland, 1984.

Milgrom, Paul, and Weber, Robert J. "The Value of Information in a Sealed-Bid Auction." *J. Math. Econ.* 10 (June 1982): 105–14.

Myerson, Roger B. "Incentive Compatibility and the Bargaining Problem." *Econometrica* 47 (January 1979): 61–73.

Piccione, Michele, and Tan, Guofu. "A Simple Model of Expert and Nonexpert Bidding in First-Price Auctions." *J. Econ. Theory* 70 (August 1996): 501–15.

Prendergast, Canice. "A Theory of 'Yes Men.'" *A.E.R.* 83 (September 1993): 757–70.

Riordan, Michael H., and Sappington, David E. M. "Information, Incentives, and Organizational Mode." *Q.J.E.* 102 (May 1987): 243–63.

———. "Optimal Contracts with Public Ex Post Information." *J. Econ. Theory* 45 (June 1988): 189–99.

Sappington, David E. M. "Limited Liability Contracts between Principal and Agent." *J. Econ. Theory* 29 (February 1983): 1–21.

Sobel, Joel. "Information Control in the Principal-Agent Problem." *Internat. Econ. Rev.* 34 (May 1993): 259–69.

Stole, Lars A. "The Economics of Liquidated Damage Clauses in Contractual Environments with Private Information." *J. Law, Econ., and Organization* 8 (October 1992): 582–606.

Taylor, Curtis R. "The Economics of Breakdowns, Checkups, and Cures." *J.P.E.* 103 (February 1995): 53–74.