Relying on Information Acquired by a Principal

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Abstract

This paper analyzes situations in which a principal is able to privately gather information about a task after contracting with an agent. To benefit from this information, the principal must mitigate her own incentives not only to misreport information to the agent but also to shirk on gathering information. If information gathering costs are large, the principal will design a contract in which output levels are different from the efficient levels in each of the possible states. While the optimal contract appears to provide high-powered incentives to the agent, it is actually designed to mitigate the principal's own incentives to shirk on gathering information and to misreport.

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1 Introduction

Although the existing principal-agent literature emphasizes the implication of asymmetric information where the agent has superior information, in many instances, it is the principal who is better at acquiring information. For example, in outsourcing, the buyer often provides the seller with estimates of the costs and quality of output before production occurs; a franchise firm may be more adept than its franchisee at determining the optimal business strategy, or providing valuable information to coordinate the delivery of supplies;[1] providers of fire insurance have expertise beyond that of building owners in assessing risk as well as identifying optimal precautions against fire. A common issue in many of these scenarios is that the principal privately acquires this information which provides both parties with valuable planning information.

In these settings, the principal may have incentive to misreport information or shirk on the information gathering task without the agent realizing. This poses a problem, because in many cases, the principal provides the agent with information on the costs of performing the task. If the agent cannot rely on the principal's information, the agent will exit the contract unless offered a large enough compensation. Therefore, the principal will design a contract that convinces the agent to rely on the information she[2] provides when carrying out the task. The principal best averts the incentive to shirk by introducing distortions in the output schedule, which result in production levels both above and below the efficient levels for different realized states of nature. In particular, the principal will set production above the efficient level when favorable conditions are realized, and below for unfavorable conditions. These distortions increase the difference in production levels between the states, and the principal is sufficiently penalized for an incorrect report. In effect, these distortions provide the agent with a high-powered reward structure to promote the principal's gathering of information.

In the case of outsourcing, for example, the buyer (principal) may be able to obtain information for the seller (agent) relevant to the cost and quality of output. This is especially likely when the buyer develops some new technology that she assigns to the seller. As other authors have pointed out, a buyer endowed with private information may have incentive to

[1] See Lafontaine & Slade (1997) for a discussion of some of the agency issues in franchising contracts.

[2] For convenience, the feminine pronoun is reserved for the principal, while the masculine is reserved for the agent.

understate the production cost to the seller.[3] However, if the buyer must expend resources to learn the state, the buyer can report a guess and save the information gathering costs. In particular, incentives may arise to understate or *overstate* the costs while remaining uninformed. As I show in the model, depending on the prior distribution of states, the incentive can occur to report either of the two states while remaining uninformed.

This model illustrates a *strategic* cost associated with gathering information, namely, the cost of convincing the agent that the principal has conducted the relevant research for the task. As the cost of information gathering is larger, the distortions that arise will be more severe. Therefore, as the cost of acquiring information rises, so does the cost of designing an incentive-feasible contract that ensures that information gathering occurs. In contrast to other relationships resulting in high-powered incentives (e.g. Moral Hazard), the magnitude of these distortions will vary directly with the cost of information gathering. Thus, in cases where information gathering is not observable by the seller, the buyer will be more likely to remain uninformed relative to cases where information gathering is transparent.

In addition to outsourcing, this model describes a range of other relationships as well. Fire insurers are often more efficient than building owners at ascertaining the precautions against fire a building owner should take.[4] Insurance provides a guarantee to the buyer that the insurer's information is accurate. However, if the costs of these precautions are borne by the building owner, such as unsightly fire escapes or added safety measures for dealing with flammable materials, different incentives may appear. The insurer may have incentive to overstate the optimal level of precaution. Furthermore, if ascertaining the level of efficient care is costly, the insurer may also have incentive to shirk on those duties as well. My model demonstrates why the insurer may prescribe over-precautionary and under-precautionary measures to be taken in different states of risk in order to mitigate her own incentives to shirk on information gathering and misreport. These distortions are included to motivate the insurer to assess risk and will vary directly with the difficulty in obtaining that information.

This paper joins the literature on the informed principal with that of information gathering. When the problem is the agent's gathering of information, as in Crémer, Khalil, & Rochet (1998), the principal must consider the tradeoff from the gain of efficiency of

[3]Shin & Yun (2004) discuss a similar problem when the buyer is endowed private information but can select between the buyer's and seller's own technologies. Demski & Sappington (1993) look at the buyer's incentive to understate privately observed quality when it is unobservable by the seller.

[4]For a similar discussion on the role of insurance as a guarantee of information, see Barzel (1997), pp60-62.

informed task assignment versus the information rents the agent is able to secure with his resulting private information. Lewis & Sappington (1997) show that to provide incentives for the agent to gather private information after the contract is signed, the principal will not provide a uniform compensation for information gathering costs in different states. Rather, the agent is given a negative rent when the states are determined unfavorable and a positive rent in favorable states as compensation for information gathering costs. These papers do not consider the principal's own incentives to gather information, but rather assume the principal will remain uninformed. On the other hand, the informed principal literature thus far has ignored the incentive to gather information, focusing rather on cases where she is endowed with this information.[5] In Maskin & Tirole (1990) and (1992), the principal is endowed with information, which she considers when designing the contract. Because the principal is informed at the outset, the contract itself acts as a signal to the agent. More closely related to my model is Laffont & Martimort (2002) who consider a principal who becomes informed *after* signing a contract, but they do not account for the incentive to gather this information. [6]

This model is also similar to the models of labor contracts under asymmetric information.[7] Grossman & Hart (1983), look at employment contracts between workers and a firm with superior information on economic conditions. Similar papers include Green & Kahn (1983), Azariadis (1983), and Chari (1983). In these papers, it is assumed that information is freely available to the firm, and they do not account for the hidden action of the firm in the gathering of information. Therefore, as I show, there may be additional costs and distortions resulting from the added incentives needed to induce the firm's action.

The organization of the paper is as follows: In Section 2 the model is formally described in detail and the first best is given for comparison. Section 3 introduces information gathering and goes about showing the characteristics of the optimal contract for zero and then for positive information gathering costs. Section 4 presents extensions of the model by considering more than two states of nature and directly related costs and values. Section 5

[5]The study of an informed principal was pioneered by Myerson (1983).

[6]In related studies, Barzel (1997) argues that it may be optimal for informed parties to also provide insurance, since they can convey useful information via the contracts. Mezzetti & Tsoulouhas (2000) analyze the possibility that an uninformed *agent* may gather information on the costs before undertaking a project offered by an informed principal. Brocas & Carrillo (2003) also consider how and agent can use selective information gathering and transmission to manipulate the beliefs of a decision maker and secure rent.

[7]For a survey, see Hart (1983).

concludes.

2 The Model

2.1 Payoffs and Timing

I present a model of outsourcing that is a modification of a standard principal-agent model with common values.[8] A buyer, who is designated as the principal, contracts with a seller, designated the agent, to produce a quantity of output, q, in exchange for a transfer, t. The agent bears the total cost of production θq, where $\theta > 0$ is the state of nature. The principal, who is risk-neutral, values output by the function $V(q, \theta)$, which is increasing and concave in q. In addition, V decreases with θ and $V_{\theta q} < 0$, and satisfies the Inada conditions in q. [9] Note that the state of nature influences both the cost of production, and the value of output for the principal. Therefore, a lower θ then corresponds to a favorable state for both parties. In Section 4.2, I alter this assumption by assuming that the costs and benefits are directly related.[10]

The state variable can take two possible values, $\theta \in \{\theta_1, \theta_2\}$, $\theta_2 > \theta_1 > 0$. The prior distribution of θ, which is common knowledge, is given by $Pr(\theta = \theta_1) = \pi$. When θ_1 is realized, the marginal cost of production is low, while the quality, and therefore marginal value of output, is high. For example, in the favorable state, the technology enables the agent to produce a higher quality output at a lower cost. The influence of θ on the agent's marginal cost of production captures the principal's incentive to misreport the state. If a lower state is announced, the agent requires a smaller per-unit compensation.

At the time the contract is offered, θ is unknown. After the contract is signed, the principal can expend C and privately learn the state of nature. If the principal does not invest, then she does not observe the state. Alternatively, when information gathering

[8] Laffont & Martimort (2002) and Maskin & Tirole (1992) both use common values when similarly modelling an informed principal.

[9] In keeping with convention, subscripts indicate the first-partial derivative with respect to the subscripted variable (e.g. $V_q \equiv \frac{\partial V}{\partial q}$).

[10] The payoff functions have "common values", meaning the state variable, θ explicitly enters the payoffs of both the principal and the agent. Maskin & Tirole (1990) and (1992) provide motivation for this assumption using examples of insurance, in which the probability of an accident directly affects both parties, as well as franchising. They also note that even in cases of private values, common values may develop if reservation utilities depend on some prior contractual agreement between the same parties. Hence, common values may reflect the renegotiation of subsequent contracts between the same parties.

occurs, the principal observes the true state with certainty. The agent is unable to observe the principal's choice whether to expend C nor the realized state. The payoff functions and distribution of θ are common knowledge throughout the game. To focus on the information gathering contract, I assume that the agent will only accept a contract which provides the principal with incentives to gather information.[11]

The timing of the model is described in four stages. In the first stage, the principal offers a contract to the agent, which the agent accepts or rejects. In the second stage, if the agent accepts the contract, the principal chooses whether or not to privately gather information on the realized θ. In the third stage, the principal announces the information by assigning the agent to produce of a particular level of output. In the fourth stage, the agent produces output and receives compensation from the principal.

2.2 Full-Information Benchmark

As a benchmark, consider a case in which both parties observe the state of nature at no cost in stage 2 (*i.e.*, the *first best*). In stage 1, the principal will offer the agent a contract consisting of two output and transfer pairs, (q_1, t_1) and (q_2, t_2), corresponding to each possible state.

The agent's reservation utility is normalized to 0. I assume that the agent can exit the contract at the interim stage, after the principal announces the state but prior to when production occurs. Therefore, the principal must assure that the contract satisfies the following two *interim participation constraints*:

$$t_1 - \theta_1 q_1 \geq 0 \tag{IR1}$$

$$t_2 - \theta_2 q_2 \geq 0 \tag{IR2}$$

Because these participation constraints assure the agent a non-negative payoff ex post, they necessarily imply the ex ante participation constraint (i.e. when signing the contract)

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[11] An equivalent assumption is that the principal's information may provide the agent with additional benefits that are not captured entirely by the knowledge of θ. In general, the information that the principal provides may have many *spill-over* effects for the agent. Franchise firms typically provide a portfolio of information for franchisees, some of which directly identifies the cost of production (e.g. forecasts of demand, input costs, shipping costs), but also provide general cost-reducing information (e.g. shipping times). When accounting for these benefits, information gathering is optimal for a larger range of information gathering costs, C, so long as the additional benefit is sufficiently large as well. Lewis & Sappington (1997) assume a similar spill-over effect, however in their case it is the principal, not the agent, who realizes an additional planning benefit from information.

is satisfied.

The *first-best* outputs, q_1^* and q_2^*, are determined by standard efficiency conditions (MB=MC):

$$V_q(q_i^*, \theta_i) = \theta_i \quad i = 1, 2.$$

Furthermore, the principal compensates the agent for exactly his cost of production:

$$t_i^* = \theta_i q_i^* \quad i = 1, 2.$$

3 Information Gathering

I now assume that the principal privately chooses whether to gather information after signing the contract. Unlike with most other problems of hidden information, the Revelation Principal does not directly apply, for the agent does not observe whether the principal is informed when reporting the state. However, once constraints are imposed to promote information gathering, it is without loss of generality to consider only those contracts for which truthful revelation of the information is incentive compatible for the principal.

The incentive compatibility constraints are given by:[12]

$$V(q_1, \theta_1) - t_1 \geq V(q_2, \theta_1) - t_2 \tag{PIC1}$$

$$V(q_2, \theta_2) - t_2 \geq V(q_1, \theta_2) - t_1 \tag{PIC2}$$

The left-hand side shows the payoff from accurately assigning the agent to the corresponding output/transfer pair, and the right-hand side shows the payoff from assigning the other pair.

For information gathering to occur, the principal must find it optimal to do so *in stage 2*, after signing the contract. Inducing the principal to expend C to acquire information requires the addition of the following *information gathering constraint*:

$$\begin{aligned}\pi\left(V(q_1, \theta_1) - t_1\right) + (1-\pi)\left(V(q_2, \theta_2) - t_2\right) - C \\ \geq \max\{\pi V(q_1, \theta_1) + (1-\pi)V(q_1, \theta_2) - t_1, \\ \pi V(q_2, \theta_1) + (1-\pi)V(q_2, \theta_2) - t_2\}\end{aligned} \tag{IG}$$

This constraint assures the agent that the principal will be informed when announcing the state. The left-hand side shows the principal's expected payoff from gathering information. The right-hand side is the payoff from not gathering information yet claiming the

[12]It is without loss of generality that the information gathering contract contains no contingency for the principal announcing that she is uninformed. Implicitly, this announcement will be followed by a sufficiently low payoff for the principal such that this situation will not occur on the equilibrium path.

agent is of type θ_1 (left-braced term) or θ_2 (right-braced term). When uninformed, the principal will choose the announcement which maximizes her expected payoff.

The information gathering constraint can be written as two distinct constraints:

$$V(q_2,\theta_2) - t_2 \geq V(q_1,\theta_2) - t_1 + C/(1-\pi) \tag{IG1}$$

$$V(q_1,\theta_1) - t_1 \geq V(q_2,\theta_1) - t_2 + C/\pi \tag{IG2}$$

This formulation of the constraints provides us with a more useful interpretation of the information gathering constraints. The principal must prefer the expected payoff from truthfully assigning an accurate level of the task in a realized state to having the agent perform the other output level while saving C by not gathering information. This formulation also shows that any contract satisfying (IG1) and (IG2) will necessarily satisfy (PIC1) and (PIC2).

$$\begin{array}{ccc}(\text{IG1}) & \Rightarrow & (\text{PIC2}) \\ (\text{IG2}) & \Rightarrow & (\text{PIC1})\end{array}$$

In satisfying each information gathering constraint, the *opposite* numbered incentive constraint is necessarily satisfied. Intuitively, the information gathering constraints increase the cost of announcing the true state by C/π for θ_2 and $C/(1-\pi)$ for θ_1. [13]

The information gathering constraints implying the incentive compatibility constraints is indeed not robust, and does not extend to more than two states of nature. With two states, if the principal plans to report a state other than the realized state, she will always be announcing the same state independent of what is learned. Therefore, she will necessarily not be gathering information. Section 4.1 extends this analysis to more than two states and shows that the primary results still hold even without this simplifying feature.

The information gathering principal's optimization problem, denoted $\mathscr{P}$, is:

$$\max_{q_1,t_1,q_2,t_2} \pi\left(V(q_1,\theta_1) - t_1\right) + (1-\pi)\left(V(q_2,\theta_2) - t_2\right) - C$$

subject to (IG1), (IG2), (IR1) and (IR2).

At this point, it is possible to show that (IR1) and (IR2) will bind in the optimum. For this, I invoke the following lemma which I prove in the appendix:

[13] If the principal had incentive to misreport when a particular state was realized, then she would announce the same state regardless of the information obtained. In that case, it is clear that information gathering will not occur. Thus, the contrapositive statement implies that if the principal has incentive to gather information, she will necessarily reveal that information truthfully.

Lemma 1 *In the information gathering principal's problem, $\mathscr{P}$, the agent is not assigned rent in either state.*

When facing the rent-versus-efficiency tradeoff, the principal always favors reducing efficiency in order to induce information gathering. Clearly, if neither of the information gathering constraints bind in the optimum, the principal can profitably lower the transfers until the participation constraints bind. If (IG1) binds, the principal can reduce the rent to the θ_1-type while increasing q_1 to maintain (IG1). From the single-crossing property, increasing q_1 will reduce the principal's surplus from assigning q_1 when θ_2 is realized *by a larger amount* than when θ_1 is realized. Thus, the principal's payoff will increase when moving from providing rent for the θ_1-type to increasing q_1. Furthermore, the transition from rent to distorting q_1 will ease (IG2). The high-cost agent will earn no rent from a similar argument.[14]

3.1 Free Information Gathering

In cases where the cost of acquiring information is zero, the incentive compatibility constraints are identical to the information gathering constraints. Therefore, if $C = 0$ it is without loss of generality to assume the principal always becomes informed. The information gathering constraints are redundant, and therefore are disregarded. Because the problem reduces to an informed principal problem, the results are those found in Laffont & Martimort (2002).

The principal's incentive is to either report truthfully or understate θ. By reporting θ_2 when in fact θ_1 has been observed, the principal will find that she faces a more restrictive participation constraint for the agent, and therefore will need to pay a higher per-unit compensation for output. This implies that (PIC1) will never bind in the optimal contract.

Two possible cases arise, depending on the curvature of V and the variance of θ. In one case, the contract achieves the first best and the principal can credibly reveal information to the agent without altering the contract. This will occur as long as the first-best output levels, q_1^* and q_2^* satisfy (PIC2). This condition is given by:

$$V(q_2^*, \theta_2) - \theta_2 q_2^* \geq V(q_1^*, \theta_2) - \theta_1 q_1^* \tag{1}$$

In the second case, Condition (1) is not satisfied and the optimal contract will exhibit an upward distortion in q_1. In doing so, the contract will satisfy both incentive constraints.

[14] In a more general setting with multiple states of nature, the principal does not assign the agent rent in the highest and lowest states. See Appendix 4.1 for a proof.

Because the distortion does not create an incentive to *overstate* θ, there is no need to alter q_2, and the distortion in q_1 is sufficient.[15]

3.2 Costly Information Gathering

Suppose now that the principal must incur a cost ($C > 0$) in order to learn the state of nature. After the contract is signed, the principal privately chooses whether to invest in information gathering. Because the agent does not observe information gathering, there is a potential for the principal to shirk on this duty. Thus, the principal can remain uninformed and announce one of the two possible states. The principal must now contend with her own incentive to not only misreport information, but to shirk on information gathering as well.

From Lemma 1, the principal's problem simplifies to:

$$\max_{q_1,q_2} \pi\left(V(q_1,\theta_1)-\theta_1 q_1\right)+(1-\pi)\left(V(q_2,\theta_2)-\theta_2 q_2\right)-C$$

subject to

$$V(q_2,\theta_2)-\theta_2 q_2 \geq V(q_1,\theta_2)-\theta_1 q_1+\frac{C}{1-\pi} \tag{IG1*}$$

$$V(q_1,\theta_1)-\theta_1 q_1 \geq V(q_2,\theta_1)-\theta_2 q_2+\frac{C}{\pi} \tag{IG2*}$$

The novel result of this contract is that for large enough information gathering cost, C, both high and low outputs will be distorted as to increase the variance in the output quantities. As a result of $C > 0$, the variability of output increases and the agent is provided with a higher-powered reward structure. These distortions increase the principal's ex post value from gathering information through raising the cost of incorrect task assignments. Thus, the distortions the optimal contract exhibits vary directly with the cost of information. Unlike in the case of free information, the distribution of types will affect the size of these distortions.

When Condition (1) holds, there are four distinct possibilities for the distortions that may arise in the two states. Alternatively, when Condition (1) does not hold, the first best is not attainable even for small information gathering costs, and one of only two combinations of distortions will occur.

Proposition 1 *When Condition (1) holds, the following four cases characterize the optimal information-gathering contract for $\mathscr{P}$:*

[15] For more details about the $C = 0$ case, the reader can refer to Laffont & Martimort (2002), pp 351-360.

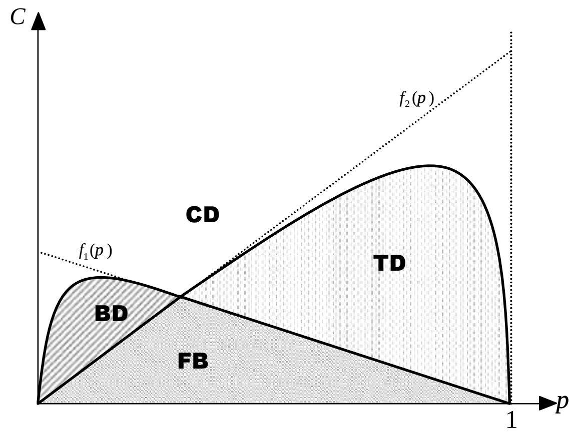

Figure 1: A graph of regions using the value function $V(q,\theta) = 2\sqrt{q}/\theta$, with $\theta_1 = 1$ and $\theta_2 = 2$. Note that these parameters satisfy Condition (1).

1. *There exists a region where the principal offers the first-best contract; i.e.* $q_1 = q_1^*$ *and* $q_2 = q_2^*$.
2. *There exists a region where the optimal contract exhibits a downward distortion of output in the unfavorable state only; i.e* $q_1 = q_1^*$ *and* $q_2 < q_2^*$.
3. *When information gathering costs are sufficiently large the optimal contract exhibits an upward distortion of output in the favorable state* (θ_1) and *a downward distortion of output in the unfavorable state* (θ_2)*; i.e.* $q_1 > q_1^*$ *and* $q_2 < q_2^*$.
4. *There exists a region where the optimal contract exhibits an upward distortion of output in the favorable state only; i.e* $q_1 > q_1^*$ *and* $q_2 = q_2^*$.

Figure 1 illustrates the cases that arise when Condition (1) holds. The exact distortions will depend on the values of π and C. Thus, to characterize the resulting distortions, the parameter space is partitioned into four distinct regions.

If C is small, the problem closely resembles the free-information problem of Section 3.1, the information gathering constraints only differ from the incentive constraints in the addition of C/π and $C/(1-\pi)$. Recall that when $C = 0$, the first-best is attainable given that Condition (1) is satisfied. It follows that for both $C/(1-\pi)$ *and* C/π small enough, the first-best contract is still optimal. When π is close to 1 and $C > 0$, (IG1*) will bind. As a result, the principal will increase q_1 above q_1^* in order to reduce the right-hand side of this constraint. It may be the case that this distortion is sufficient to satisfy the constraints, and the region in which this distortion appears alone is denoted as **TD** (*top distortion*).

When π is close to 0, the probability of realizing θ_1 is small, and therefore reporting θ_2 is unlikely to produce an incorrect assignment. The first-best output levels will not satisfy (IG2*) because C/π is large. In order to satisfy this constraint, the principal must decrease the attractiveness of announcing θ_2 which can only occur by distorting q_2 below q_2^*. This distortion will successfully reduce the right-hand side of (IG2*). In this region, denoted as **BD** (*bottom distortion*), this distortion is sufficient to induce information gathering.

It will also be the case that if C is large, both distortions appear *simultaneously*. This will correspond to cases in which both constraints are binding. As C increases, or similarly π approaches an extreme, the binding information gathering constraint requires a greater distortion of the corresponding output. When the distortion is large and/or C is large, the opposite information gathering constraint will bind as well. For example, to satisfy (IG1*) when $C/(1-\pi)$ is large, q_1 increases, which also decreases the left-hand side of (IG2*) which requires a lower q_2. That is, the large cost of information coupled with the distortion in q_1 leads to (IG2*) binding. In Figure 1, this region is given by **CD** (*c*omplete distortion). Because both constraints bind, the principal is actually indifferent between gathering information and announcing *either* of the two possible states.

Proposition 2 *When Condition (1) does not hold, the following two cases characterize the optimal information-gathering contract for $\mathscr{P}$:*

1. *When the cost of information is small and π not too close to 0 or 1, an upward distortion appears in the favorable state alone; i.e $q_1 > q_1^*$ and $q_2 = q_2^*$.*

2. *When information gathering costs are sufficiently large, distortions occur in both the favorable and unfavorable states; i.e. $q_1 > q_1^*$ and $q_2 < q_2^*$.*

When Condition (1) does not hold, the regions **BD** and **FB** will disappear as the boundary ($f_1(\pi)$) reduces to zero,[16] leaving the (π, C)-space with simply the two regions, **TD** and **CD** . When C is small, the principal's problem is similar to the benchmark free-information case, resulting in a single distortion in the favorable state. However, when the cost of information is large, simultaneous distortions appear in the unfavorable and favorable states.

[16]See Appendix B for precise derivations of $f_1(\pi)$ and $f_2(\pi)$.

The distortions described in both of these propositions imply that in cases where the principal privately acquires information, the cost of information gathering will include an additional cost from the inefficiencies in production levels. Larger information gathering costs will require greater distortions, increasing the difference in output levels between the two states. This creates a reward structure which appears to be more high-powered. Interestingly, these high powered incentives are to ensure the principal's, not the agent's, performance.

Corollary 1 *In satisfying the information gathering constraints, a high-powered reward structure is used to compensate the agent. This feature becomes more pronounced as C increases.*

Indeed the purpose of using high-powered incentives is to increase the principal's cost from providing incorrect information, and, thus, induce information gathering. Intuitively, the higher variable payment the principal is forced to pay for the output, the lower the return from overstating the true θ. The variability of the transfer with output assures the principal a bigger cost from remaining uninformed, increasing the sensitivity of her payment to the realized state.

4 Extensions

4.1 Information Gathering with More than Two States

To show that these distortions may also appear with multiple states, consider the case of three states of nature: $0 < \theta_1 < \theta_2 < \theta_3$. In this setting the information gathering constraints no longer imply the incentive constraints. However, as with two states of nature, upward distortions of the output in the most favorable state and downward distortions in least favorable state will occur when information gathering costs are large.

First, consider the principal's incentive to report the state after gathering information. To produce truthful revelation when θ_i is realized, the following constraints are given (for $i = 1, 2, 3$):

$$V(q_i, \theta_i) - t_i \geq \max_{j=1,2,3} \{V(q_j, \theta_i) - t_j\} \tag{2}$$

This constraint is analogous to the incentive constraints of the previous sections, (PIC1) and (PIC2). As before, only the downward constraints are required to induce truthful revelation by the principal of θ.

Denoting the probability of θ_i by π_i for $i = 1, 2, 3$, the constraint to induce information gathering is given by:

$$\sum_{i=1}^{3} \pi_i \left[V(q_i, \theta_i) - t_i\right] - C \geq \max_{j=1,2,3} \left\{ \sum_{i=1}^{3} \pi_i \left[V(q_j, \theta_i) - t_j\right] \right\} \tag{3}$$

Analogous to Lemma 1, the following (weaker) result holds: the principal does not provide the agent with rent in the highest (θ_3) or lowest (θ_1) cost states. A similar intuition and proof as the binary setting confirm this (see Appendix 4.1). When the cost of information gathering is large, the uninformed report may fall on any of the three states, depending on the distribution of states. For example, to combat the incentive to not gather information and announce θ_1, the principal will make this announcement less attractive. Because the principal does not provide the agent with rent for producing q_1, she must resort to distorting output (i.e. $q_1 > q_1^*$) in order to induce information gathering. For large C, the distortion of q_1 will be more severe, which will add to the incentive to provide an uninformed announcement of one of the other two states. For sufficiently large C, q_3 must be distorted as well.

4.2 Directly Related Costs and Values

The previous analysis assumed that the ranking of states of nature was common to both the principal and the agent; a low realized θ "favorably" influenced both parties' payoff functions. Alternatively, the principal and agent may not share the same ranking of states. For example, the buyer may find the quality of the output high (low) when the costs of production are high (low). The incentive to shirk on gathering information and misreport information, as arose in the prior sections, will also arise in this setting. To mitigate these incentives, the optimal contract will exhibit *increases* in the high-cost output and *decreases* in the low-cost output. Precisely, it is the influence of θ on the principal's value function which determines the direction the distortion in each state takes.

For a simple example, consider a two-state model in which a higher θ implies a higher value of output for the principal, and as before a larger marginal cost for the agent.[17] The intuition for the distortions is the same as the previous sections: To combat the incentive to remain uninformed and announce costs are low, the principal reduces the surplus from

[17] For example, consider the value function $V(q, \theta) = \theta \tilde{V}(q)$, and cost to the agent θq. This results in a first best $q_1^* = q_2^*$, whereas incentive compatibility and information gathering require that q_1 be sufficiently less than q_2.

producing q_1. Distorting q_1 below q_1^* will reduce her payoff from q_1 when θ_2 is realized. Because θ_2 indicates a higher marginal value, the principal will sufficiently gain by paying a higher per-unit compensation to the agent for the larger output resulting from a truthful announcement. Similarly, the principal will bypass the incentive to not gather information and potentially over-state costs by increasing q_2 from q_2^*.[18]

5 Conclusion

This paper extends the problem of an informed principal by considering the effects of costly of information gathering. If the principal is to gather information, she must mitigate the incentive to provide uninformed reports. This is achieved through upward distortions of output in favorable states and/or downward distortions in unfavorable states. In doing so, the burden of misreporting the state is increased to the principal, creating incentive to gather information and provide an honest report. As these distortions apparently increase the difference in output levels between states, the contract utilizes high-power incentives to induce the principal's compliance with the task.

A Proof of Lemma 1

The Lagrangian for the principal's optimization problem is:

$$\begin{aligned}\mathscr{L} =& \pi\left[V(q_1,\theta_1)-t_1\right]+(1-\pi)\left[V(q_2,\theta_2)-t_2\right]\\ &+\mu_1\left[t_1-\theta_1 q_1\right]+\mu_2\left[t_2-\theta_2 q_2\right]\\ &+\lambda_1\left[V(q_2,\theta_2)-t_2-V(q_1,\theta_2)+t_1-C/(1-\pi)\right]\\ &+\lambda_2\left[V(q_1,\theta_1)-t_1-V(q_2,\theta_1)+t_2-C/\pi\right],\end{aligned}$$

where μ_1, μ_2, λ_1, and λ_2 are the non-negative Lagrange multipliers associated with (IR1), (IR2), (IG1), and (IG2), respectively.

The *first-order conditions* are:

$$\pi V_q(q_1,\theta_1)-\mu_1\theta_1-\lambda_1 V_q(q_1,\theta_2)+\lambda_2 V_q(q_1,\theta_1)=0 \tag{4}$$

$$(1-\pi)V_q(q_2,\theta_2)-\mu_2\theta_2+\lambda_1 V_q(q_2,\theta_2)-\lambda_2 V_q(q_2,\theta_1)=0 \tag{5}$$

$$-\pi+\mu_1+\lambda_1-\lambda_2=0 \tag{6}$$

$$-(1-\pi)+\mu_2-\lambda_1+\lambda_2=0 \tag{7}$$

[18] A formal proof of these results can be found in Appendix D.

Combining (4) and (6):

$$\mu_1 \left(V_q(q_1, \theta_1) - \theta_1\right) = \lambda_1 \left(V_q(q_1, \theta_2) - V_q(q_1, \theta_1)\right) \tag{8}$$

If $\mu_1 = 0$, from the assumption that $V_{q\theta} < 0$, it must be that $\lambda_1 = 0$. However, from (6), $\pi = -\lambda_2$, which is a contradiction. Hence, it must be that in the optimum $\mu_1 > 0$. A similar argument using (5) and (7) implies that:

$$\mu_2 \left(V_q(q_2, \theta_2) - \theta_2\right) = \lambda_2 \left(V_q(q_2, \theta_1) - V_q(q_2, \theta_1)\right) \tag{9}$$

and $\mu_2 > 0$. Hence, (IR1) and (IR2) must bind in the optimum.

B Proof of Propositions

Define the following:

$$\begin{aligned} f_1(\pi) &\equiv (1-\pi)\left[(V(q_2^*, \theta_2) - \theta_2 q_2^*) - (V(q_1^*, \theta_2) - \theta_1 q_1^*)\right] \\ f_2(\pi) &\equiv \pi\left[(V(q_1^*, \theta_1) - \theta_1 q_1^*) - (V(q_2^*, \theta_1) - \theta_2 q_2^*)\right] \\ C_1(\pi) &\equiv \min\left\{f_1(\pi), f_2(\pi)\right\}. \end{aligned}$$

There are four possibilities to consider: (a) $\lambda_1 = 0, \lambda_2 = 0$; (b) $\lambda_1 > 0, \lambda_2 = 0$; (c) $\lambda_1 = 0, \lambda_2 > 0$; and (d) $\lambda_1 > 0, \lambda_2 > 0$.

Possibility (a) implies that $q_1 = q_1^*$ and $q_2 = q_2^*$. This is possible as long as $C_1(\pi) \geq 0$ and $C \leq C_1(\pi)$. This region corresponds to **FB**. The existence is shown using the $V(q) = 2\sqrt{q}$, $\theta_1 = 1$ and $\theta_2 = 2$. Thus, the first assertion of the proposition has been shown. Possibility (b), from (8), implies that $q_1 > q_1^*$ and $q_2 = q_2^*$ which corresponds to region **TD**. Possibility (c), from (9), implies that $q_1 = q_1^*$ and $q_2 < q_2^*$ which corresponds to region **BD**. Possibility (d), from both (8) and (9), implies that $q_1 > q_1^*$ and $q_2 < q_2^*$ which corresponds to region **CD**.

To shown that (c) is possible, consider when $V(q) = 2\sqrt{q}$, $\theta_1 = 1$ and $\theta_2 = 2$. There exists a range of $\pi < 1/6$ where for $C > C_1(\pi)$ this will occur. On the other hand, a range of C and π will exist in which (b) occurs. This is because for $C = 0$, (IG2) will not bind whereas (IG1) may or may not. This will depend on the curvature of the value function and values of θ_1 and θ_2. By considering π close to 1 and $C > C_1(\pi)$, **TD** will be possible. Finally, the existence of **CD** is shown by simply setting $C > \max\left\{f_1(\pi), f_2(\pi)\right\}$.

In region **TD**, q_1 is determined by q_2^* and (IG1). Thus, it is clear that q_1 is increasing as C increases. Similarly, in region **BD**, q_2 is determined by q_1^* and (IG2). It follows that

q_2 is decreasing in C. Finally, when both constraints bind (region **CD**), the constraints simultaneously determine the outputs. It follows that both q_1 increases and q_2 decreases in C.

C Three States of Nature: Proof of Results

In this section, I prove that a range of C, π_1, and π_2 can exist in which q_1 is distorted above the first-best level, and, in a range, q_3 may be distorted below.

The information gathering constraints can be rewritten so:

$$\pi_2\left[V(q_2,\theta_2)-t_2\right]+\pi_3\left[V(q_3,\theta_3)-t_3\right]-C\geq\pi_2\left[V(q_1,\theta_2)-t_1\right]+\pi_3\left[V(q_1,\theta_3)-t_1\right]\quad\text{(I1)}$$

$$\pi_3\left[V(q_3,\theta_3)-t_3\right]+\pi_1\left[V(q_1,\theta_1)-t_1\right]-C\geq\pi_3\left[V(q_2,\theta_3)-t_2\right]+\pi_1\left[V(q_2,\theta_1)-t_2\right]\quad\text{(I2)}$$

$$\pi_1\left[V(q_1,\theta_1)-t_1\right]+\pi_2\left[V(q_2,\theta_2)-t_2\right]-C\geq\pi_1\left[V(q_3,\theta_1)-t_3\right]+\pi_2\left[V(q_3,\theta_2)-t_3\right]\quad\text{(I3)}$$

Similarly, the principal's six incentive constraints are:

$$V(q_i,\theta_i)-t_i\geq V(q_j,\theta_i)-t_j\quad\text{(PIC}ij\text{)}$$

where $i,j=1,2,3$ and $i\neq j$.

The agent's participation constraints are:

$$t_i-\theta_i q_i\geq 0\quad\text{(IR}i\text{)}$$

where $i=1,2,3$.

The Lagrangian for the principal's optimization problem is:

$$\begin{aligned}\mathscr{L}&=\pi_1\left(V(q_1,\theta_1)-t_1\right)+\pi_2\left(V(q_2,\theta_2)-t_2\right)+\pi_3\left(V(q_3,\theta_3)-t_3\right)-C\\&+\sum_{i=1}^{3}\mu_i\left(t_i-\theta_i q_i\right)+\sum_{k=1}^{3}\sum_{j\neq k}\alpha_{kj}\left(V(q_k,\theta_k)-t_k-V(q_j,\theta_k)+t_j\right)\\&+\lambda_1\left(\pi_2\left[V(q_2,\theta_2)-t_2\right]+\pi_3\left[V(q_3,\theta_3)-t_3\right]-\pi_2\left[V(q_1,\theta_2)-t_1\right]-\pi_3\left[V(q_1,\theta_3)-t_1\right]-C\right)\\&+\lambda_2\left(\pi_3\left[V(q_3,\theta_3)-t_3\right]+\pi_1\left[V(q_1,\theta_1)-t_1\right]-\pi_3\left[V(q_2,\theta_3)-t_2\right]-\pi_1\left[V(q_2,\theta_1)-t_2\right]-C\right)\\&+\lambda_3\left(\pi_1\left[V(q_1,\theta_1)-t_1\right]+\pi_2\left[V(q_2,\theta_2)-t_2\right]-\pi_1\left[V(q_3,\theta_1)-t_3\right]-\pi_2\left[V(q_3,\theta_2)-t_3\right]-C\right)\end{aligned}$$

with multipliers μ_i for (IRi), λ_i for (Ii), and $\alpha_i j$ for (PICij).

The first-order conditions for t_1 and q_1 (respectively) are:

$$-\pi_1+\mu_1-\alpha_{12}-\alpha_{13}+\alpha_{21}+\alpha_{31}+\lambda_1\pi_2+\lambda_2\pi_3-\lambda_2\pi_1-\lambda_3\pi_1=0\quad(10)$$

$$\begin{aligned}(\pi_1+\alpha_{12}+\alpha_{13}+\lambda_2\pi_1+\lambda_3\pi_1)V'(q_1,\theta_1)-\mu_1\theta_1-&\\(\alpha_{21}+\lambda_1\pi_2)V'(q_1,\theta_2)-(\alpha_{31}+\lambda_1\pi_3)V'(q_1,\theta_3)=0&\quad(11)\end{aligned}$$

Combining (10) and (11) yields: $[V'(q_1,\theta_1)-\theta_1]\,\mu_1 = [V'(q_1,\theta_2)-V'(q_1,\theta_2]\,(\alpha_{21}+\lambda_1\pi_2)+[V'(q_1,\theta_3)-V'(q_1,\theta_1)]\,(\alpha_{31}+\lambda_1\pi_3)$. This implies two results. First, because the right-hand side is non-positive, $q_1 \geq q_1^*$. Secondly, $\mu_1 = 0$ only if $\alpha_{21}=\alpha_{31}=\lambda_1=0$. But if none of these constraints bind, the principal can profitably increase t_1 without violating any of the remaining constraints. Hence, the contradiction implies $\mu_1 > 0$ and hence (IR1) binds. A similar argument also shows that in the optimum, (IR3) will bind and $q_3 \leq q_3^*$.

To show that it is possible for both (I1) and (I3) to bind, simply choose C sufficiently large. Starting from the first best, increasing the cost of information gathering will eventually lead to each of the information gathering constraints binding.

D Directly Related Costs and Values: Proof of Results

Consider the problem where the principal's value function is given by $V(q,\theta)$. In contrast to before, $V_\theta > 0$, $V_{qq} < 0$, and $V_{q\theta} > 0$. This reflects that now the principal's preferences with respect to θ are reversed.

The Lagrangian and first-order conditions are identical to the previous case (Appendix A). As before, equations (8) and (9) imply that (IR1) and (IR2) bind. These two equations also imply that if $\lambda_1 > 0$ then $q_1 < q_1^*$, and if $\lambda_2 > 0$ then $q_2 > q_2^*$. Both information gathering constraints will clearly bind for C sufficiently large.

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