The organization of expertise in the presence of communication

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Abstract

Principal decision-makers are sometimes obliged to rely on multiple sources of information when drawing conclusions about the desirability of given actions in response to decisions they face. They may hire specialized agents to inform their decisions. Principals have authority both to allow communication among agents of information and to prevent information-sharing. I assume that communication facilitates the emergence of some complementarities among agents, but it may also promote collusion. I study the optimal design of contracts focusing on how to sequence communication of expertise. I show that from a principal's point of view, when the advantages of allowing communication dominate, communication is more effective before effort choices are made rather than after.

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1 Introduction

Many decisions are complex and involve multiple aspects. In some cases decision-makers lack time and skill to gather, process, and summarize relevant information on which to base decisions. They may rely on information provided by specialized experts who are hired for the specific goal of offering input on given decisions. In this article, the particular way in which information is produced is determinative of its value. In particular, as Arrow pointed out (1969, p.30), "Knowledge arises from deliberate seeking, but it also arises from observations incidental on other activities".

The goal of this article is to examine an economic framework in which an uninformed principal must elicit information from unbiased experts who must, in turn, decide whether or not to collect costly information (this is what Arrow terms "deliberate seeking"). If agents collect information, each gains access to a noisy signal about the true state of the world. Agents may communicate with each other about the signals that they have obtained, and in doing so, each will get more precise information than initially acquired (this for us is Arrow's remark about "Knowledge...also arises from observations incidental on other activities"). Our simple framework incorporates an opportunistic consideration of communication: I assume that communication opens the possibility of collusion among agents against the main interest of the principal.

Because communication has conflicting consequences, one question addressed in this article is: should principals promote or impede communication among experts? If a principal allows communication among experts, what is the best way to organize agents who are in communication? In particular, *when* is it optimal, from a principal's point of view, to let agents communicate with each other? These issues are studied in a multiagent-principal framework when communication among agents allows not only cooperation in favor of the principal but also collusion against her.

I study and compare the principal's net surplus under different organizational forms. First, I compute the principal's net surplus in the no-communication case. Then I consider a situation in which the principal organizes experts in a common workplace, that is, a group of experts, and facilitates communication among them. In this case, communication has conflicting consequences.

On the one hand, when agents communicate with each other, signals are more precise than in the absence of communication. This fact not only has a positive direct impact on the principal's surplus but it also reduces, since signals are more precise, informational rents to agents. On the other hand, when agents are in communication, they are able to collude; that is, they are able to manipulate in their self interest the private information that they have received. In contrast, when the principal prevents communication among agents, she avoids the collusion problem, but in such a case, she sacrifices signal precision.

We assess trade-offs involved in each work structure. To answer the question of optimal timing for communication among agents, it is important to note the following. Because positive effects of communication arise after agents have collected information, it is intuitive to say that communication should be allowed at this moment. If the principal, however, lets agents communicate with each other from the beginning, i.e., before they collect costly information, they are not only able to manipulate the information that they reveal to the principal, but also they can sign side contracts contingent on their decisions whether or not each actually gathers information. This fact, however, has a positive impact on the principal's well-being since agents will be able to coordinate their effort choices.

In contrast, when agents can only communicate with each other after exerting effort, they are not able to share their effort choices in collecting information. In such cases, each agent makes his decision without information about the other agents' decision. Although the principal can also prevent collusion on the choice of effort in such situations, she imposes more uncertainty on agents than would be imposed if each expert had knowledge about the effort exerted by other experts.

I find that complementarities between experts, that emerge in the communication stage, facilitate principals' provision of incentives to agents who communicate with each other from the outset. In other words, the principal's welfare increases when experts are able to observe their respective effort choices and communicate with each other about their signals.

In the absence of complementarities in the signal communication phase, the principal would be better off if she could avoid communication between experts. If it is not possible to prevent communication, then she should postpone it as long as possible.

The intuition behind this result is that, under complementarity effects of communication, when an agent observes that his partner does not collect information, he has incentives to fail to collect information also. In the absence of complementarities in the communication phase, when an agent observes that his partner does not collect information, he will be better off if, at least, one of them gathers information.

This article is linked to three lines of research: endogenous acquisition of information, transmission of information, and organization of expertise. Literature focusing on information revelation obtains as its main result the notion that if there are no costs of supplying information, perfect information transmission requires that the decision-maker and the expert have identical preferences. In this line of research, Wolinsky (2002) obtains results close to those in this paper. The focus is on how a decision-maker can take advantage of multiple experts. Wolinsky shows that in some circumstances, allowing partial communication among experts may result in the revelation of more information than either full communication or no communication.

In the aforementioned literature, however, the focus is on strategic information revelation rather than on information acquisition. In contrast, in the current article, the decision-maker elicits information from multiple unbiased experts, and agents must decide whether or not to acquire information. Several authors analyze this issue in the literature. For example, Li (2001) and Szalay (2005) examine information acquisition when players have the same preferences but implementation of monetary incentives is not feasible. As in the current article, Gromb and Martimort (2007) consider the design of monetary incentives and study the implications of optimal incentive contracts for the organizational design of expertise. They assume a case with a principal who bases a decision on two signals about a project's value, and agents who can draw independent signals at a fixed cost per signal. After receiving signals, the agents recommend to either to undertake the project or not undertake it. The authors show that it is optimal to reward an agent if his recommendation is confirmed by the state or by another recommendation (conflicting reports are penalized).[1] Subsequently, the authors analyze when it is optimal, from the principal's point of view, to have a single expert gather two signals or two experts collect one signal each.

In the present paper, unlike Gromb and Martimort (2007), I assume that signal precision not only increases with effort (a fixed cost per signal) but also increases with (horizontal) communication among agents. At this point, the organization of expertise becomes crucial. With multiple agents, how should experts be organized to ensure that they refine their knowledge about the true state of the world and fully disclose their signals? Unlike Gromb and Martimort (2007), I analyze the optimal organization of communication among experts. This particular feature is close to the concept of Itoh (1993) in that the principal benefits from contracting a consolidated unit whose utility is the sum of its members' utilities and in which employees can monitor each others' efforts and coordinate their actions.

The paper proceeds as follows. Before introducing the model, I highlight the main issues I wish to elucidate by providing an example. Section 2 presents the general setting, and Section 3 presents the benchmark case: the no-communication situation. Section 4 compares the principal's surplus when communication implies both collusion among experts and synergistic effects. In such a case, I study, from the principal's point of view, the optimality of two alternative organizations of communication: communication among agents *before* they decide to collect information, and *after* they choose whether or not to gather information. Finally, Section 5 offers conclusions. All proofs and details of calculations are in the Appendix.

An example: an intelligence problem

Organization without Communication. Consider the problem faced by the Director of Intelligence of country A. The Director has received an alert of possible sabotage against the tabloid press and must decide whether or not to impose a red alert. She hires two spies who must provide information about the likelihood of sabotage. Let us assume that the two spies work in isolation and the agents' identities remain unknown to each other. Each spy must decide whether or not to collect intelligence data. After collecting data, each processes all available information and obtains a noisy signal about the probability of an attack occurring.

For example, one of the spies might obtain information via interception of communications (telephone calls, e-mails, letters and so on). He processes data and obtains a signal, although some individuals mentioned in telephone calls or in letters cannot be declared "dangerous" because there is no proof to that effect. The other spy concentrates his investigations on information about people who have entered and left the

[1] Köhler (2004) shows that this does not necessarily hold when the state and signal space are continuous.

country in the past year. Similarly, he processes data and gets a signal, but he does not find any conclusive evidence that some particular individuals being investigated are involved in a possible attack on the yellow press.

The Director of Intelligence receives one signal from each agent, after which he will make a decision. If the spies supply conflicting signals, the Director penalizes them, as the state of the world is unitary (that is, sabotage or not).

The Pros and Cons of Communication. Now let us assume that the Director allows agents to communicate with each other. In such a case, they would exchange their initial knowledge and certain items of information that before might have appeared irrelevant but would now become important for the investigation. For example, they would realize that the names of some individuals mentioned in letters or telephone calls (and that, before communication, they were irrelevant for the inquiry) matched people who had entered and left the country in the last few months (and again, before communication, were impertinent for the investigation). This coincidence could provide sufficient evidence that these people were involved in planning an attack. Therefore, communication improves signal precision.

Because the spies are in communication, they may coordinate their reports to show that, for example, the potential sabotage is only a rumor spread by the yellow press itself but without proof of that. The Director's problem shifts to whether or not to allow communication between the spies. If the benefit from sharing information outweighs the potential collusion cost, it seems reasonable that both spies should work together as a single intelligence team.

The Organization of Communication. How should the spies be organized in the communication phase? At what point should the principal allow the agents to communicate with each other?

Before. If the spies' identities are revealed from the outset, they may collude not only on their reports but also on their decision about whether or not to collect information.

After. If each agent knows his partner's identity only after he decides whether or not to gather information, the Director avoids the possibility of collusion on effort choices, and she still takes advantage of exchange of information between the spies. In such a case, however, each spy makes his decision without knowing the other spy's decision.

In summary, the Director must decide not only whether or not she will allow communication but also the optimal time for allowing the spies to communicate with each other.

2 The General Setting

I consider the relationship between one risk-neutral principal (decision-maker) and two risk-neutral agents (experts). The decision-maker has to choose an action: to undertake a policy or not to undertake it. When the policy is undertaken, it will have two possible observable monetary outcomes; that is, $S > 0$ when the policy is a success, or $F < 0$ when it is a failure. The common prior for success is $\Pr(S) = v < 1/2$. If the policy is not undertaken, its outcome will not be observed. Accordingly, the principal's gross payoff depends on the action taken, and on an unknown state of the world. We assume that, without additional information, it is not efficient to implement the policy; that is, $vS + (1-v)F < 0$. Consequently, in such a case, the principal's optimal decision is the status quo.

The decision-maker, however, has neither the time nor skill to gather and process all information related to the policy's success. For that reason, she consults two unbiased experts. Agents are unbiased in the sense that they respond only to monetary incentives. Both experts must simultaneously decide whether or not to exert effort e_i; that is, $e_i \in \{0, 1\}$. I assume that exerting effort is costly, therefore the cost of effort is equal to ce_i, for $c > 0$. When $e_i = 1$, expert i gets a noisy signal $\sigma \in \{\underline{\sigma}, \overline{\sigma}\}$, where $\overline{\sigma}$ means that the policy's outcome is more likely to be a success (good news), and $\underline{\sigma}$ increases the probability that the policy may be failure (bad news). I assume that noisy signals are independent conditional on the policy's outcome. In other words, signals are correlated with the true state of the world but uncorrelated with each other.[2] After this, and before agents send individual reports to the principal, they may communicate with each other. In such a case, there are two forces at play in the communication phase. On the one hand, I assume that communication introduces the possibility of collusion among experts. That is, after agents accept the contract offered by the principal, they can sign a contract contingent on verifiable information and jointly manipulate the information they obtain in their own interest. On the other hand, I assume that communication increases the precision of the signal that each agent receives. We can imagine that after agents exert some effort, they have a "rough" idea about the true state of the world. If they were able to communicate this *preliminary* knowledge with each other, they would obtain a more "refined" idea about the desirability of the principal's actions. We can interpret this as communication among experts allows complementarities or synergy to emerge among them. Therefore, the communication process results the signal having, at least, equal precision as in the no-communication situation. Accordingly, when communication takes place, the signal's precision for agent i will depend not only on e_i but also on e_j. Let us define the signal's precision as $p^i(\cdot) \equiv p(\overline{\sigma}|S) = p(\underline{\sigma}|F)$, $\forall i$, and assume the following:

Assumption $p^i(e_i e_j) = v(1-e_i) + ae_i + (\epsilon - a)e_i e_j$ *where* $\epsilon > a > 1/2$

The Assumption says that if agent i chooses to shirk, i.e., $e_i = 0$, he produces a signal which has a precision equal to the common prior of success, i.e. $\Pr(S) = v$. However, if the expert chooses to work, i.e., $e_i = 1$, he will get a more precise signal but the final level will depend on e_j. In other words, the marginal productivity of i's effort increases as e_j increases. When the two experts have exerted effort, communication

[2] This assumption allows us to express, for an expert i and j, that, $\Pr(\sigma\sigma \mid S) = \Pr(\sigma \mid S)\Pr(\sigma \mid S)$.

between them is useful, and this, in turn, increases the signal precision that agents obtain.[3] In particular, when both agents exert effort, $p^i(1,1) = p^j(1,1) = \epsilon$. In the case where only one expert collects information, $p^i(1,0) = p^j(0,1) = a$, where $\epsilon > a > \frac{1}{2}$. Additionally, let us observe that as ϵ tends to a, the communication effect does disappear.[4]

Next in my sequence, the principal asks the experts to send reports. Based on these messages, the principal updates her belief about the future state of the world and chooses an action. At the end, the state of the world is realized, transfers are paid, and payoffs are realized. Finally, I assume that experts are protected by limited liability and they have the same preferences. Therefore, the expert's payoff function is $U(t,e) = t - ce_i$, where t is the transfer that an agent receives from the principal, which we will discuss further.

It is worth remarking that experts produce soft information that is non-verifiable and fully manipulable. Therefore, the principal must accomplish two goals: design a contract such that experts exert effort and also truthfully reveal their private information.

In the following, I assume that two alternative organizational structures can exist. In the first, agents remain isolated and therefore, no exchange of information can occur. I call this kind of organization an isolated work structure, henceforth IWS. In the second, experts are able to communicate with each other. I call this a communication work structure, CWS henceforth.

Before continuing, it is useful to present some notation and definitions. Let us denote by $p(\sigma)$ the probability of $\sigma \in \{\underline{\sigma}, \overline{\sigma}\}$. That is, for example, when expert i exerts effort, $p(\bar{\sigma}) = av + (1-a)(1-v)$. Likewise, because signals are independent conditional on the policy's outcome, when experts i and j are in communication, $p(\bar{\sigma}\bar{\sigma}) = \epsilon^2 v + (1-\epsilon)^2(1-v)$. Moreover, let $\widehat{v}(\sigma)$ be the probability of success conditional on σ. Therefore, $\widehat{v}(\sigma) = p(S|\sigma)$. That is, $\widehat{v}(\sigma) = \frac{p(\sigma|S)p(S)}{p(\sigma)}$.

3 The benchmark case: the isolated work structure

We consider now the case of the isolated work structure. In such a structure, we assume that agents do not communicate with each other. This implies that the signal each agent obtains, as well as whether an effort is made, is not observable by other parties, that is, this is not observable by the principal or by the another expert.

[3] This means that p^i is a supermodular function in the sense that an increase in expert j's effort choice increases the marginal productivity of the effort for expert i. Following Bulow, Geanakoplos, and Klemperer (1985), efforts are strategic complements, because experts' strategies are complements to each other. I thank an anonymous referee for this observation.

[4] Agents observe only one signal each. That is, each agent can purchase, by means of his effort, a signal of accuracy $a > \frac{1}{2}$. After that, if a communication phase takes place, agents, by means of communication, can improve the precision of the signal that they previously obtained, i.e. $(\epsilon - a) > 0$. Consequently, communication contributes to refine their initial knowledge about the desirability of the principal's actions.

The timing is as follows. The principal offers each expert a contract. Each accepts or rejects it. If he accepts, he decides whether or not to gather information, and then sends a message to the principal. Given these messages, she updates her belief about the future state of the world and chooses an action. Finally, the state is realized, transfers are paid, and payoffs are realized.

Optimal Contracts

Because signals and efforts are not observable by the principal, transfers can only be based on reports and on the policy's outcome. Let us note that the policy is only undertaken by the principal when both reports are positive. This is because after the principal receives either two conflicting or two negative signals and updates her beliefs, the optimal action will be not to undertake the policy, that is $\widehat{v}\left(\underline{\sigma}\ \underline{\sigma}\right) < \widehat{v}\left(\underline{\sigma}\bar{\sigma}\right) = v$.[5,6] In the case in which the principal chooses the status quo, that is not to implement the policy, reports cannot be compared with the true state of the world.[7] However, we will see that the principal can use the correlation between messages to extract informational rents from experts.

Therefore, $\bar{t}$ is the transfer received by the expert if a policy is undertaken and is a success, and $\underline{t}$ is the transfer when the policy is undertaken but it fails. If the policy is not implemented, t_0 is the transfer that each agent receives when both signals are negative. In the event of conflicting reports, the expert reporting $\bar{\sigma}$ receives t_g, and the other expert, whose report is $\underline{\sigma}$, receives t_b. Consequently, expected costs to the principal, which we call henceforth agency costs $T_{(\cdot)}$, will be $p\left(\bar{\sigma}\bar{\sigma}\right)\left[\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\bar{t} + \left(1-\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\right)\underline{t}\right] + p\left(\underline{\sigma}\ \underline{\sigma}\right)t_0 + p\left(\underline{\sigma}\bar{\sigma}\right)\left(t_g + t_b\right)$.

The contract that the principal offers must provide experts with incentives to gather information and report it accurately. A similar problem is solved by Gromb and Martimort (2007), henceforth GM. For brevity, I only report agency costs computed from the optimal transfers for this organizational structure.

Lemma 1 (GM, 2007) *Agency costs for the isolated work structure is (T_{IWS})*

$$T_{IWS} = 2c\left[\frac{p\left(\underline{\sigma}\right) + \left(1-v\right)\left(2a-1\right)a}{\left(1-v\right)\left(2a-1\right)a}\right] \tag{1}$$

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[5] That is, $\widehat{v}\left(\underline{\sigma}\ \underline{\sigma}\right) = p\left(S|\underline{\sigma}\ \underline{\sigma}\right)$. By solving this, we get $\widehat{v}\left(\underline{\sigma}\ \underline{\sigma}\right) = \frac{(1-a)^2 v}{(1-a)^2 v + a^2(1-v)}$, which is less than v. Morevover, $\widehat{v}\left(\underline{\sigma}\bar{\sigma}\right) = \frac{(1-a)av}{(1-a)a}$. Additionally, let us recall that, by assumption, $vS + (1-v)F < 0$.

[6] When a principal does not implement a policy based on expert advice, she is destroying the links between agent efforts and outcomes. Therefore, if the principal could commit to implement the policy with a small probability even when an experts' report suggested rejection, agency costs studied in the present article would be lower. Consequently, the results would not change in qualitative terms.

[7] In the model, the alternative to undertake the policy when both signals are $\left(\bar{\sigma}\bar{\sigma}\right)$ is never to undertake the policy. Thus, never to undertake the policy yields zero payoff, and always to implement the policy, by assumption, yields a negative expected payoff. Therefore, this alternative is dominated by never to undertake the policy, and the principal cannot gain from committing to undertake the policy with a probability $\eta\left(\sigma_i, \sigma_j\right) \in [0, 1]$.

To capture the intuition behind the previous expression, it can be rewritten as

$$2c\left[1+\frac{1}{(1-v)(2a-1)\,a/p(\underline{\sigma})}\right]=2c\left[1+\frac{1}{(p(\bar{\sigma}\mid S)-p(\bar{\sigma}))+(p(\underline{\sigma}\mid\underline{\sigma})-p(\underline{\sigma}))}\right]$$

that is, the principal is able to evaluate the performance of an agent not only by the correlation between $\bar{\sigma}$ and S but also by the another agent's signal $((p(\underline{\sigma}\mid\underline{\sigma})-p(\underline{\sigma})))$ by penalizing conflicting reports.

4 The organization of communication work structure

I now analyze the principal's problem when she has to elicit information from unbiased experts, and at the same time, she wants to exploit synergy effects that emerge when they are in communication. In this environment, I study, from the principal's point of view, the best way to exploit complementarities among experts. To be more precise, I will answer *when* it is optimal, from the principal's point of view, to allow agents to communicate with each other.

4.1 Communication between experts after exerting effort

Let us assume that the principal organizes experts in a common workplace. Therefore, they are able to communicate with each other without cost, but communication takes place after they have decided whether to work or shirk, that is, after they have decided to gather information or not. After that, the principal asks agents for a report $\sigma\in\{\underline{\sigma},\bar{\sigma}\}$. If the principal receives two negative or conflicting messages, she will always decide the status quo. This is because $\widehat{v}(\underline{\sigma}\;\underline{\sigma})<\widehat{v}(\underline{\sigma}\bar{\sigma})=v$.[8] It is worth emphasizing the nature of information available to each agent in each phase:

i Whether or not the expert gathers information is not observable either by the principal or by the another expert.

ii Signal σ is not observable by the principal, but it is observable by the another expert in the communication phase.

Consequently, as before, transfers are based only on reports and on the policy's outcome.

[8]Recall that, by assumption, $vS+(1-v)F<0$.

Optimal Contracts

The principal must provide incentives to each expert to acquire information, and also reveal it truthfully. When experts, who are in communication,[9] observe $\bar{\sigma}\bar{\sigma}$, they should prefer to report that rather than $\underline{\sigma}\ \underline{\sigma}$ or $\bar{\sigma}\underline{\sigma}$:

$$2\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\bar{t} \geq \max\left\{2t_0; t_g + t_b\right\} \tag{2}$$

and, when they observe $\underline{\sigma}\ \underline{\sigma}$, they should prefer to report $\underline{\sigma}\ \underline{\sigma}$ rather than $\bar{\sigma}\bar{\sigma}$ or $\underline{\sigma}\bar{\sigma}$[10]

$$2t_0 \geq \max\left\{2\widehat{v}\left(\underline{\sigma}\ \underline{\sigma}\right)\bar{t}; t_g + t_b\right\}. \tag{3}$$

Finally, if experts observe $\underline{\sigma}\bar{\sigma}$, they do not prefer to report $\bar{\sigma}\bar{\sigma}$ or $\underline{\sigma}\ \underline{\sigma}$. That is,

$$t_g + t_b \geq \max\left\{2v\bar{t}; 2t_0\right\}. \tag{4}$$

Moral hazard incentive constraints on gathering information are such that each expert will prefer not to remain uninformed and report $\bar{\sigma}$, under the assumption that the another expert exerts effort:

$$p\left(\bar{\sigma}\bar{\sigma}\right)\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\bar{t} + p\left(\underline{\sigma}\ \underline{\sigma}\right)t_0 + p\left(\underline{\sigma}\bar{\sigma}\right)\left(t_g + t_b\right) - c \geq p\left(\bar{\sigma}\right)\widehat{v}\left(\bar{\sigma}\right)\bar{t} + p\left(\underline{\sigma}\right)t_g \tag{5}$$

or, $\underline{\sigma}$. That is,

$$p\left(\bar{\sigma}\bar{\sigma}\right)\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\bar{t} + p\left(\underline{\sigma}\ \underline{\sigma}\right)t_0 + p\left(\underline{\sigma}\bar{\sigma}\right)\left(t_g + t_b\right) - c \geq p\left(\bar{\sigma}\right)t_b + p\left(\underline{\sigma}\right)t_0. \tag{6}$$

Additional constraints on the principal's problem are: (i) the incentive participation constraint for each expert,

$$p\left(\bar{\sigma}\bar{\sigma}\right)\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\bar{t} + p\left(\underline{\sigma}\ \underline{\sigma}\right)t_0 + p\left(\underline{\sigma}\bar{\sigma}\right)\left(t_g + t_b\right) - c \geq 0, \tag{7}$$

and (ii) limited-liability constraints

$$\bar{t}, t_0, t_b, t_g \geq 0. \tag{8}$$

Consequently, the principal's program is:

$$\min p\left(\bar{\sigma}\bar{\sigma}\right)\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\bar{t} + p\left(\underline{\sigma}\ \underline{\sigma}\right)t_0 + p\left(\underline{\sigma}\bar{\sigma}\right)\left(t_g + t_b\right)$$

[9] Communication between experts is assumed without cost. Additionally, by assumption, communication increases the signal precision of information previously obtained by individual experts. This fact, in turn, increases the expected value of transfers that an expert receives from the principal. Therefore, an agent will not reject communication.

[10] It is worth noting that $\widehat{v}\left(\sigma\right)$ is the probability of success conditional on observed signal σ. In (3) agents have observed $\underline{\sigma}\ \underline{\sigma}$. Therefore, when we compute the benefit from deviating, if the agents report $\bar{\sigma}\bar{\sigma}$, the transfer that they receive will be $\bar{t}$ each in case of success. However, in this case, the actual probability of success is $\widehat{v}\left(\underline{\sigma}\ \underline{\sigma}\right)$, which is the probability of success after having observed $\underline{\sigma}\ \underline{\sigma}$.

subject to (5)-(8).

Lemma 2 *When communication takes place after agents exert effort, the agency cost, $T_{CWS(F)}$, is*

$$T_{CWS(F)} = 2c\left[\frac{1+(1-v)(2\epsilon-1)}{(1-v)\left[(2\epsilon-1)-p(\bar{\sigma})(2a-1)\right]}\right]. \quad (9)$$

In this case, there are two issues to be considered with respect to the costs of the previous organization structure (IWS). One of these is the related problem to the potential collusion between agents. The another is an issue related to the positive impact on the cost of the synergy between experts. To clarify these aspects, we can isolate each of them. Let us observe that when no synergy effects exist, i.e. $\epsilon = a$, the agency cost will be

$$T_{CWS(F)} = 2c\left[\frac{1+(1-v)(2a-1)}{(2a-1)(1-v)-p(\bar{\sigma})(2a-1)(1-v)}\right] \quad (10)$$

$$= 2c\left[\frac{1+(1-v)(2a-1)}{(p(\bar{\sigma}\bar{\sigma}\mid S)-p(\bar{\sigma}\bar{\sigma}))-p(\bar{\sigma})(p(\underline{\sigma})-p(\underline{\sigma}\mid S))}\right],$$

which is bigger than T_{IWS} since when experts are in communication with each other, a collusion problem emerges. In particular, in the current case, the principal is not completely able to penalize conflicting reports because she is not able to distinguish between $\underline{\sigma}\ \underline{\sigma}$ or $\bar{\sigma}\underline{\sigma}$.[11] The principal rewards a positive reports when it is followed by a successful outcome (the correlation between $\overline{\sigma}\overline{\sigma}$ and S). However, the cost rises when conflicting reports might appear $(p(\bar{\sigma})(p(\underline{\sigma})-p(\underline{\sigma}\mid S)))$. Moreover, in expressions (9) and (10) underlies the same collusion problem, whereby the only difference between them is the precision of the signal gotten by experts when the synergy effect exists.

4.2 Communication between experts before exerting effort

I now introduce some changes to the organization described in the preceding section. I assume that the principal organizes agents in a common workplace, and in this common workplace, they are able to observe one another from the outset. That is, each expert knows not only the signal received by the other agent but also whether or not the other agent exerts effort. Consequently, the information available to each agent in each phase is the following:

i Whether or not the expert gathers information is not observable by the principal, but is observable by the other expert.

ii The signal σ is not observable by the principal, but it is observable by the other expert in the communication phase.

[11] Both of them lead the principal to the statu quo.

As before, given the information available to the principal, transfers are based on reports and on the policy's outcome.

Optimal Contracts

The principal must provide incentives to both experts to acquire information and also to reveal it truthfully. In this case, the adverse selection constraints are the followings. If experts observe $\bar{\sigma}\bar{\sigma}$, they should prefer to report $\bar{\sigma}\bar{\sigma}$ rather than $\underline{\sigma}\ \underline{\sigma}$ or $\bar{\sigma}\underline{\sigma}$. That is,

$$2\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\bar{t} \geq \max\left\{2t_0; t_g + t_b\right\} \tag{11}$$

If each expert observes $\underline{\sigma}$, they should prefer to report $\underline{\sigma}\ \underline{\sigma}$ rather than $\bar{\sigma}\bar{\sigma}$ or $\bar{\sigma}\underline{\sigma}$. That is:

$$2t_0 \geq \max\left\{2\widehat{v}\left(\underline{\sigma}\ \underline{\sigma}\right)\bar{t}; t_g + t_b\right\} \tag{12}$$

Moreover, if experts observe $\underline{\sigma}\bar{\sigma}$, they do prefer not to report $\bar{\sigma}\bar{\sigma}$ or $\underline{\sigma}\ \underline{\sigma}$. Then

$$t_g + t_b \geq \max\left\{2v\bar{t}; 2t_0\right\} \tag{13}$$

Likewise, moral hazard incentive constraints on gathering information are such that the two agents jointly will not prefer to remain uninformed and report either $\bar{\sigma}\bar{\sigma}$, $\underline{\sigma}\ \underline{\sigma}$ or $\bar{\sigma}\underline{\sigma}$. Therefore:

$$2\left[p\left(\bar{\sigma}\bar{\sigma}\right)\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\bar{t} + p\left(\underline{\sigma}\ \underline{\sigma}\right)t_0 + p\left(\underline{\sigma}\bar{\sigma}\right)\left(t_g + t_b\right) - c\right] \geq \max\left\{2v\bar{t}; 2t_0, t_g + t_b\right\}. \tag{14}$$

Moreover, the two experts should prefer not to base their report on only one signal. Therefore,

$$2\left[p\left(\bar{\sigma}\bar{\sigma}\right)\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\bar{t} + p\left(\underline{\sigma}\ \underline{\sigma}\right)t_0 + p\left(\underline{\sigma}\bar{\sigma}\right)\left(t_g + t_b\right) - c\right] \geq 2\left[p\left(\bar{\sigma}\right)\widehat{v}\left(\bar{\sigma}\right)\bar{t} + \left(1 - p\left(\bar{\sigma}\right)\right)t_0\right] - c. \tag{15}$$

The incentive participation constraint for each agent is

$$p\left(\bar{\sigma}\bar{\sigma}\right)\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\bar{t} + p\left(\underline{\sigma}\ \underline{\sigma}\right)t_0 + p\left(\underline{\sigma}\bar{\sigma}\right)\left(t_g + t_b\right) - c \geq 0, \tag{16}$$

and the limited-liability constraints are

$$\bar{t}, t_0, t_g, t_b \geq 0. \tag{17}$$

Therefore, the principal's program is:

$$\min p\left(\bar{\sigma}\bar{\sigma}\right)\widehat{v}\left(\bar{\sigma}\bar{\sigma}\right)\bar{t} + p\left(\underline{\sigma}\ \underline{\sigma}\right)t_0 + p\left(\underline{\sigma}\bar{\sigma}\right)\left(t_g + t_b\right),$$

subject to (14)-(17).

Lemma 3 *When $\epsilon - a > a - \frac{1}{2}$, and the communication between experts takes place* *before they exert effort, the agency's cost ($T_{CWS(B)}$) is*

$$T_{CWS(B)} = 2c\left[1 + \frac{1}{(1-v)(2\epsilon - 1)}\right] = 2c\left[1 + \frac{1}{p(\bar{\sigma}\bar{\sigma}|S) - p(\bar{\sigma}\bar{\sigma})}\right].$$

When synergy effects are sufficiently high, i.e., $\epsilon - a > a - \frac{1}{2}$, experts are always better off collecting two signals rather than one. This means that (14) is binding. In this case, the principal give incentives to gather two signals and uses as instrument the correlation between positive signals and the final state of the world ($p(\bar{\sigma}\bar{\sigma}|S)$). That is, when experts report good signals ($\bar{\sigma}\bar{\sigma}$), they will be rewarded if the final outcome is a success. As signals are more accurate, positive reports will be linked with the experts's effort and the moral hazard cost -and consequently the agency cost, will be lower.

Lemma 4 *When $\epsilon - a < a - \frac{1}{2}$, and communication between experts takes place before they exert effort, the agency's cost ($T_{CWS(B)}$) is*

$$T_{CWS(B)} = c\left[2 + \frac{(2a - \epsilon^2)}{(1-v)\left(\epsilon^2(1-a) - a(1-\epsilon)^2\right)}\right] = c\left[2 + \frac{(2a - \epsilon^2)}{p(\bar{\sigma})\, p(\bar{\sigma}\bar{\sigma}|S) - ap(\bar{\sigma}\bar{\sigma})}\right].$$

When $\epsilon - a < a - \frac{1}{2}$, the agents are always better off collecting information, but in this case, (15) is binding. When the signal precision is not sufficiently high, the agents might be tempted to gather just one signal. This is because an additional signal imposes an additional cost c, and it will be valuable only in the event that both signals are the good ones. Therefore, the principal must distort transfers to induce an extra effort to get two signals.

It is worth noting the main difference between this structure and the IWS. In the IWS, the principal must induce each agent to get a signal each, and she has the ability to penalize conflicting reports. In present case, however, the principal not only loses her capacity to distinguish two negative reports and two conflicting reports, but also the principal has to give incentive to collect two signals in order to avoid they base their report in just only one.

4.3 Communication: before or after?

In the present context, the principal, who exploits synergy effects between experts, allows communication between them. However, when agents are in communication, they may collude against the principal. That is, experts may share their information in a credible way, make a report that is jointly optimal for them and after that, exchange side-transfers.[12]

We may interpret this as follows. Exploiting synergy between agents bears some cost in terms of collusion. Is there any way to reduce this cost? When the principal

[12] I assume enforceable side-contracts between experts.

allows agents to communicate with each other before exerting effort, the principal is also allowing them to write a side-contract contingent not only on the signal and the policy outcome but also on effort choices. Therefore, the principal offers experts a contract such that agents jointly choose an effort pair that is optimal from the principal's point of view.

On the other hand, when communication is only possible after agents have exerted effort, each agent selects his own effort without knowing the other's choice. That is, in this case, agents are not able to coordinate their selection of effort despite the fact that joint choice would have improved the principal's welfare. This observation leads us to the following:

Proposition 1 *In the presence of communication and synergy effects between experts, the principal is better off allowing experts to communicate before they collect information rather than after they exert effort.*

Proof. By simple manipulation, it is easy to check that $T_{CWS(F)} - T_{CWS(B)} > 0$, on both cases, i.e. when $\epsilon - a > a - 1/2$ and when $\epsilon - a < a - 1/2$.[13] ■

In other words, the principal is better off allowing agents to communicate with each other on their effort choices rather than permitting communication only after they collect information. Let us observe that, in both cases, that is, before and after exerting effort, two experts can manipulate the report sent to the principal. Consequently, in both cases, experts must be given incentives to reveal the truth. However, when agents are able to communicate from the beginning, they are able to select an effort pair on which they optimally agree.

The principal imposes more uncertainty on agents when she allows them to communicate only after collecting information rather than before gathering information. In this circumstance, the principal must let some rents to agents since this organization introduces strategic uncertainty to risk-neutral agents protected by limited liability constraints.

Ex-post efficient rule From the principal's perspective, the alternative to eliciting two signal is eliciting only one. That is, the ex-post efficient rule is to gather two signals if

$$\epsilon^2 vS + (1-\epsilon)^2 (1-v) F - T_{CWS(B)} > avS + (1-a)(1-v) F - \frac{T_{IWS}}{2}$$

We can prove that $T_{CWS(B)} > \frac{T_{IWS}}{2}$ both either for $\epsilon - a > a - \frac{1}{2}$ and for $\epsilon - a < a - \frac{1}{2}$. However, in the first case, i.e. $\epsilon - a > a - \frac{1}{2}$,

$$\left[\epsilon^2 vS + (1-\epsilon)^2 (1-v) F\right] - \left[avS + (1-a)(1-v) F\right] > T_{CWS(B)} - \frac{T_{IWS}}{2}$$

[13]Let us note that the result of Proposition 1 requires that $\epsilon \neq a$. That is, the result holds when the effect of communication does exist.

Consequently, the principal will base her decision on two signals rather than on only one when she is deciding to implement a policy.

Without synergy effects It is important to note that the above result does not hold when complementarity of effort between agents in the communication phase is absent, i.e. $\epsilon - a = 0$. When the synergy effect exists, if agent i decides that $e_i = 0$, then this implies that e_j must also be equal to zero since communication is not useful when only one agent exerts effort. Therefore, if the principal gives one agent sufficient incentives to exert effort, agents will find that it is optimal that both of them exert effort because the marginal productivity of effort j will be greater when the other agent also exerts effort.

Moreover, when no synergy effect exists, the principal is better off if she can avoid communication between experts. If communication, however, cannot be controlled by the principal, then she will be better off if communication can be postponed as long as possible. This is because, if agents are able to observe each other from the outset, when agent i observes that $e_j = 0$, due to complementarities not emerging in the communication phase, the productivity of effort i does not improve at that stage. Consequently, the two agents will coordinate to base their reports on only one signal. In terms of the problem, equation (15) is binding.

Proposition 2 *When no synergy effects between experts exists and if the principal is not able to control communication between them, then she is better off if communication takes place after agents exert effort rather than before.*

Proof. See Appendix. ■

4.4 IWS versus CWS with synergy effects

At this point, the question is: Is the principal better off allowing agents to communicate with each other or not? When agents communicate with each other, signals are more precise than when no communication exists. This fact not only has a positive direct impact on the principal's surplus but also makes the information problem less severe. Additionally, when communication between agents exists and experts are organized into a group of experts from the outset, they are able to communicate their effort choices. That is, when synergy effects exist in the communication phase, agents' efforts can be interpreted as complementary efforts. Therefore, the principal might improve her welfare by allowing agents to coordinate their effort choices in collecting information rather than avoiding such coordination. Moreover, when no communication exists, the principal sacrifices precision but avoids the collusion problem.

Proposition 3 *When signal precision increases sufficiently with communication, i.e.* $\epsilon - a > a - 1/2$, *the principal is better off allowing agents to communicate with each other from the outset rather than not allowing communication.*

Proof. In the Appendix. ■

When $\epsilon - a > a - 1/2$, we can easily show that $T_{IWS} > T_{CWS(B)}$. In other words, when synergy effects are sufficiently high, the principal need only induce agents to get two signals and base her control over agents' efforts by using the correlation between positive signals and the final state of the world. Accordingly, the principal always prefers to allow communication between experts and to organize them as a group of experts from the beginning rather than to prevent communication.

Proposition 4 *When signal precision does not increase sufficiently with communication i.e. $\epsilon - a < a - 1/2$, the principal should compare whether the gross benefit from communication outweighs the increase of the cost of the communication work structure.*

Proof. In the Appendix. ■

When $\epsilon - a < a - 1/2$, the relationship between agency costs is reversed, $T_{IWS} < T_{CWS(B)}$ because in the CWS the principal is not only not able to penalize conflicting signals, but she must also give incentives to agents to base their reports on two signals. Therefore, the principal will be better off with communication if it sufficiently increases the principal's gross payoff.[14]

5 Conclusion

The aim of this article is to elucidate how the organization of expertise affects production and transmission of accurate information by taking into account incentive problems. This issue is studied in a multiagent-principal framework when communication among agents has conflicting consequences. On the one hand, I assume that communication allows some complementarities between agents. On the other hand, communication also allows agents to collude. I concentrate on an uninformed principal who has to elicit information from unbiased experts. I study the optimal design of contracts in different communication settings, and I focus on the organization of expertise, specially in the communication phase.

If the principal organizes experts such that communication is not possible, she avoids the collusion problem but she cannot take advantage of complementarities between agents. If communication takes place, it is better for the principal to form a group of experts from the outset. This kind of organization enables the principal not only to exploit synergy effects among experts but also to take advantage of communication of their effort choices. Therefore, when the advantages of synergy effects outweigh the disadvantages of collusion, horizontal communication from the outset improves the principal's welfare.

This article suggests some interesting avenues for further research. One of them arises when we ask the following question: what happens if the complementarities vary

[14] That is, if $\left[\epsilon^2 vS + \left(1-\epsilon^2\right)(1-v)F\right] - \left[a^2 vS + \left(1-a^2\right)(1-v)F\right]$ sufficiently compensates the difference $T_{IWS} - T_{CWS(B)}$.

between agents? When complementarities between agent A and agent B differ from the complementarities between agent A and agent C, what is the optimal organization of expertise from the principal's point of view?

Another interesting, and even more realistic, avenue to study emerges when we relax assumption on the cost of communication. In this paper, we assume horizontal communication is costless. When we assume that communication among agents is costly (for example, communication is time-consuming; sometimes it is not easy to "translate" certain specific knowledge for an expert who has different skills, and so on), experts must be given incentives not only to gather costly initial information but also to communicate among themselves. What is the optimal organization of expertise from the principal's point of view in these circumstances?

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Appendix

Proof Lemma 2

From (3) and (4) we know that $2t_0 = t_g + t_b$. Given this and from (4),

$$t_0 \geq v\bar{t} \tag{3'}$$

From (2), $\widehat{v}(\bar{\sigma}\bar{\sigma})\,\bar{t} > t_0$. Inequality (5)and (6) can be rewritten as:

$$p(\bar{\sigma}\bar{\sigma})\,\widehat{v}(\bar{\sigma}\bar{\sigma})\,\bar{t} + (1 - p(\bar{\sigma}\bar{\sigma}))\,t_0 - c \geq p(\bar{\sigma})\,\widehat{v}(\bar{\sigma})\,\bar{t} + p(\underline{\sigma})\,t_g \tag{5'}$$

$$p(\bar{\sigma}\bar{\sigma})\,\widehat{v}(\bar{\sigma}\bar{\sigma})\,\bar{t} + (1 - p(\bar{\sigma}\bar{\sigma}))\,t_0 - c \geq p(\bar{\sigma})\,[2t_0 - t_g] + p(\underline{\sigma})\,t_0 \tag{6'}$$

Assume that (3'), (5'), and (6') hold with equality. Then, after simple manipulation, we get the transfers:

$$\bar{t} = \frac{c}{v(1-v)\,[(2\epsilon - 1) - p(\bar{\sigma})\,(2a-1)]} \qquad t_0 = \frac{c}{(1-v)\,[(2\epsilon - 1) - p(\bar{\sigma})\,(2a-1)]}.$$

$$t_g = \frac{c\,(1-(1-v)\,(2a-1))}{(1-v)\,[(2\epsilon - 1) - p(\bar{\sigma})\,(2a-1)]} \qquad \text{and } t_b = \frac{c\,(1+(1-v)\,(2a-1))}{(1-v)\,[(2\epsilon - 1) - p(\bar{\sigma})\,(2a-1)]}$$

and the agency cost is which is in the text. At this level of transfer, we can check that other inequalities hold. ■

Proof Lemma 3

Assume that $t_0 = v\bar{t}$; then (11) is slack. Likewise, assume that (14) holds with equality and (15) is slack. By simple manipulation, when $\epsilon - a > a - 1/2$, we find that the optimal transfers are

$$\bar{t} = \frac{c}{v(1-v)\,(2\epsilon - 1)} \qquad \text{and} \quad t_0 = \frac{c}{(1-v)\,(2\epsilon - 1)},$$

and that agency cost is which is in the text. At this level of transfer, we can check that other inequalities hold.■

Proof Lemma 4

Assume that $t_0 > v\bar{t}$; then (11) is slack. Likewise, assume that (14) and (15) hold with equality.

By simple manipulation, when $\epsilon - a < a - 1/2$, we find that the optimal transfers are

$$\bar{t} = \frac{c\,(2p(\bar{\sigma}) - p(\bar{\sigma}\bar{\sigma}))}{2v(1-v)\left(\epsilon^2(1-a) - a(1-\epsilon)^2\right)} \qquad \text{and} \quad t_0 = \frac{c\,(2a - \epsilon^2)}{2(1-v)\left(\epsilon^2(1-a) - a(1-\epsilon)^2\right)}.$$

and that agency costs is which is in the text. At this level of transfer, we can check that other inequalities hold. ■

Proof Proposition 1

Assume $\epsilon - a < a - 1/2$. In such a case, it is easy to show that $T_{CWS(F)} > T_{CWS(B)}$.

That is,

$$2c\left[\frac{1+(1-v)(2\epsilon-1)}{(1-v)((2\epsilon-1)-p(\bar{\sigma})(2a-1))}\right]>c\left[2+\frac{(2a-\epsilon^2)}{(1-v)\left(\epsilon^2(1-a)-a(1-\epsilon)^2\right)}\right]$$

When $\epsilon-a>a-1/2$, we can also show that $T_{CWS(F)}>T_{CWS(B)}$. That is,

$$2c\left[\frac{1+(1-v)(2\epsilon-1)}{(1-v)((2\epsilon-1)-p(\bar{\sigma})(2a-1))}\right]>2c\left[1+\frac{1}{(1-v)(2\epsilon-1)}\right].$$

Since in these cases the gross payoff for the principal is the same $(\epsilon^2 vS+(1-\epsilon)^2(1-v)F)$, the principal will always be better off allowing agents to communicate with each other before they exert effort.■

Proof Proposition 2

Consider equations (11) to (17), and assume that no synergy effects exist, i.e., $\epsilon=a$. In this case, equations (14) and (15) hold with equality. After simple manipulation, the agency's cost is $c\left[2+\frac{(2-a)}{(1-v)(2a-1)(1-a)}\right]$,which is bigger than the agency's cost for CWS after agents collect information in the absence of synergy effects. That is,

$$c\left[2+\frac{(2-a)}{(1-v)(2a-1)(1-a)}\right]>2c\left[\frac{1+(1-v)(2a-1)}{(1-v)(2a-1)p(\underline{\sigma})}\right]\blacksquare$$

Proof Proposition 3

When $\epsilon-a>a-1/2$, we find that $T_{IWS}>T_{CWS(B)}$. That is,

$$2c\left[1+\frac{p(\underline{\sigma})}{(1-v)(2a-1)a}\right]>2c\left[1+\frac{1}{(1-v)(2\epsilon-1)}\right].$$

Since the gross payoff for the principal when experts work in communication is greater than the gross payoff for the principal when they work in isolation that is $\epsilon^2 vS+(1-\epsilon)^2(1-v)F>a^2vS+(1-a)^2(1-v)F$, the principal always prefers to allow agents to communicate with each other and from the outset.■

Proof Proposition 4

When $\epsilon-a<a-1/2$, we can show that $T_{IWS}<T_{CWS(B)}$. That is,

$$2c\left[1+\frac{p(\underline{\sigma})}{(1-v)(2a-1)a}\right]<c\left[2+\frac{(2a-\epsilon^2)}{(1-v)\left(\epsilon^2(1-a)-a(1-\epsilon)^2\right)}\right].$$

Therefore, if $\left[\epsilon^2vS+(1-\epsilon)^2(1-v)F\right]-\left[a^2vS+(1-a)^2(1-v)F\right]$ sufficiently compensates the difference in agency costs, the principal will be better off allowing agents to communicate with each other from the outset.■